PETIOLE LEVELS - WHAT DO THEY MEAN?

by
R. Kunkel, R.E. Thornton, & N.M. Holstad
Washington State University

It is often worthwhile to look back to see what has happened, take a note of where we are today and then predict what lies ahead. Only a few years ago Washington potatoes were discriminated against in many market places. They were not considered to be shippable, storable, or processable. They were called, "Moses Lake Water Bags." At about that time the Washington State Potato Commission was organized requesting a research program with the assistance of the State Department of Agriculture and Washington State University. As a result Washington State has become a major potato producing area, contrary to the assessment by some that the climatic conditions of the Columbia Basin were too hot, and the days too long for a short day, cool season crop like potatoes.

In 1960 the average yield of late potatoes in Washington was about 320 cwt/A. Ten years later it was about 420 cwt/A, and in 1980 it was almost 500 cwt/A. According to the Bureau of Reclamation data there was essentially a linear increase in mean yield of potatoes between 1960 and 1980. On the basis of these data by 1990 the average yield per acre should approach 600 cwt/A with the Russet Burbank variety and could go even higher if a new variety of high yielding potential were available. In past years high yielding varieties that averages over 750 cwt/A over a 5-year period have been tested. In some individual years the yields were near 900 cwt/A. This indicates that yield potential as provided by the Washington climate is actually very high.

Many of the costs of production are relatively fixed regardless of yield. It costs little more to produce a large yield than a small yield. Therefore the production of high yields of high quality potatoes per acre is still of primary importance. As the yield goes up the relationship between the cost of production and value of the crop is what determines if a grower stays in business. The increases in yield these past years have almost paid for the increases in cost of production that have occurred.

If the average Columbia Basin yield is 500 cwt it only represents the mid-point with some yields being both lower and higher. The same kind of logic can be applied to the average yield of a circle of potatoes. For example, if the average yield of a circle was 600 cwt/A it is almost certain that the range of production varied from about 400 to 800 cwt.

Many factors contribute to achieving yields approaching the climatic potential. Two of the most difficult factors to manage are water and fertilizer. It is impractical to speak of these two factors independently because they are so closely interdependent. All life depends on water. Most of the water and nutrients are absorbed from the top foot of soil. How to irrigate and fertilize to keep the plant producing tubers during the heat of the day when photosynthesis should be proceeding most rapidly, without leaching essential nutrients beyond the shallow root system of the potato plant is a challenge. Even moderate water deficiencies can result in uneven development, and reduced tuber yields.

Potatoes are sensitive to water stress from the time the seed piece is planted until the potatoes are utilized. A deficit of water affects rate of growth, size of yield, quality of tubers, susceptibility to injury when handled, shrink in storage, and the rate and level of sugar accumulation. Were it not for irrigation there would be no commercial potato production in the Columbia Basin. Because of the interdependence of water and fertilizer it is often difficult to attribute poor crop results directly to water deficit or improper fertilizer practices. Ideally,

---

This Presentation is part of the Proceedings of the 1983 Washington Potato Conference & Trade Fair.

to achieve maximum yields of high quality potatoes, the water potential of the cell, tissue, or organ should not drop below zero potential. At zero potential, the individual cells are fully turgid. When plant leaves wilt, it is because the cells have lost their turgidity, the stomata are closed and the plant is not producing carbohydrates that are needed for plant and tuber growth. If there is no growth, nutrients will accumulate and a tissue analysis at that point in time will show a high level when in actuality the nutrient(s) could be too low for rapid growth under favorable conditions.

All parts of a potato plant are interdependent. A malfunction of leaves, the conductive system, the roots or the tubers can make the difference between profit and loss.

The yields of early planted and early harvested crops is limited because the number of days available for rapid growth are limited. Usually yields reach between 350 and 400 cwt/acres. In contrast, yields of 800 cwt/acre are possible in 160 to 180 days of favorable growth. There is a close relationship between final yield, the number of days that plants are actively growing and the quantity of nutrients needed. Since the length of the growing season varies and the yield of potato varies, the amount of fertilizer needed also varies.

Hence, there must be many fertilizer recommendations for areas like the Columbia Basin and each recommendation must take into consideration the anticipated yield of potatoes, in other words, how long the plants are to live. For any given yield the amount of nutrients removed from the land in the tubers can be determined. The level seems to apply directly to yield regardless of variety or location where grown. (Table 1) These values do not include the amount of nutrients needed to grow the entire plant, nor is the sources from which the nutrients are derived identified. Most likely these nutrients will come from a combination of sources including fertilizer, residues from previous crops, and the water.

Table 1. Mineral elements removed from the land in potato crops of different sizes.

	TONS PER ACRE				
ELEMENT	10	20	30	40	50
	ELEMENTS IN POUNDS				
N	60	120	180	240	300
P	14	28	42	56	70
K	88	176	264	352	440
Ca	1.6	3.2	4.8	6.4	8.0
Mg	5.0	10.0	14.0	20.0	25.0
S	4.8	9.6	14.4	19.2	24.0

If potatoes are planted May 15 and the tubers are harvested July 15, it is possible that 100# N is too much. Research plots have shown a linear decrease in yield as the amount of fertilizer increased from 100 to 500# N/A with these plantings and harvest dates. It is possible for some soils to have a fertilizer pool that is so high that they should not be used to grow early potatoes.

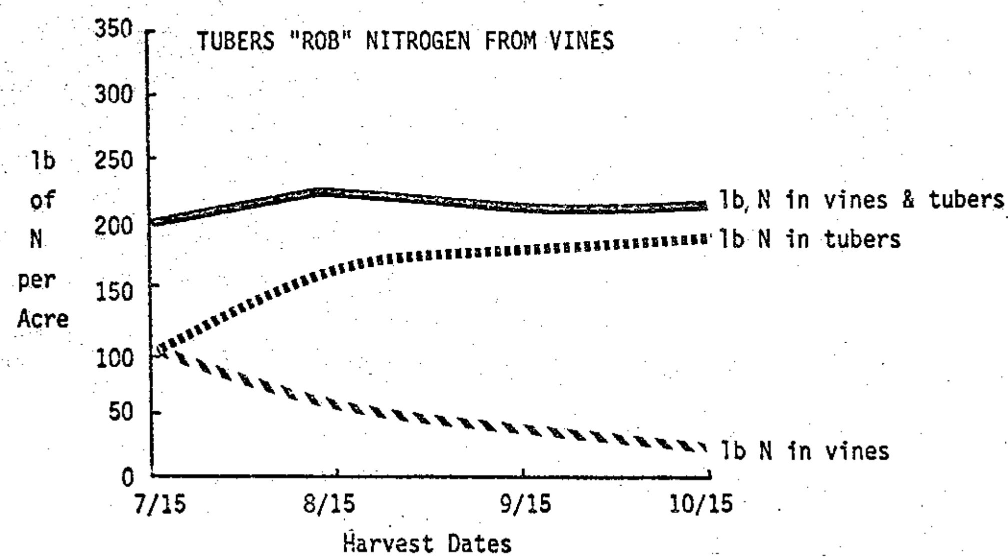
When harvest is delayed until October 15 the 500#/A of N may not have produced a yield equal to the climatic potential.

A tuber represents carbohydrate and minerals not used for growth. After tuber growth (bulking) becomes rapid there is a rapid transfer of the materials in the vines into the tubers. When potato seed was planted April 1 and harvest was July 15 only 200 #/A of N was present in the tops and tubers (Table 2-Figure 1).

Table 2. Nitrogen distribution when seed planted April 1 with 200 lbs/A of Nitrogen. (Total yield = cwt/A 617)

DATE SAMPLED	TUBER	VINES	TOTAL	PERCENT
July 15	102	100	202	101
August 15	162	58	220	111
September 15	177	32	209	105
October 15	186	25	211	104

Figure 1. Applying nitrogen at a rate of 200 lb/acre at planting did not maintain a high level of nitrogen in the vines throughout the growing season. Crop planted and fertilized on April 1.



Two hundred pounds N/A produced 617 cwt/A. Note the rapid movement from the vines into the tubers after August 15. It is probably too late to add Nitrogen to increase yield following this change. If, however, the level of N in the petiole had been monitored it may have been possible to anticipate the deficit, and if it were decided to keep the plants growing longer, supplemental N could have been applied.

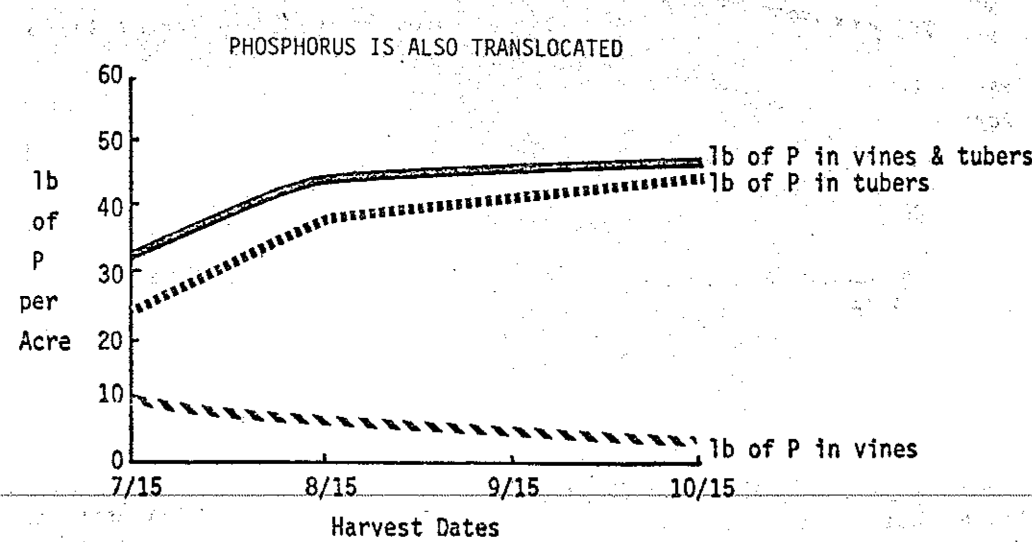
With the 200 pound N/A application the N in the vines and tubers exceeded that which was applied and some of the nitrogen came from the soil bank. How about the amount in the roots?

When 500 pounds per acre of N was used the amount of N in the tubers was relatively small early in the growth season. (Table 3 - Figure 2) Note that the point at which there was an equal amount of N in the tubers and vines occurred a month later than when only 200 #/A of N was applied. Thereafter the amount in the vines decreased rapidly and the amount in the tubers increased rapidly. The yield on October 15 was now 732 cwt/A. The 500 pound application of N may have been excessive but after rapid tuber enlargement began the N taken up by the roots did not maintain the N level in the vines.

Table 3. Nitrogen distribution when seed was planted April 15 with 500 lbs. /A of nitrogen. (Total yield = 732 cwt)

	NITROGEN IN POUNDS			
DATE SAMPLED	TUBER	VINES	TOTAL	PERCENT
July 15	81	164	245	49
August 15	177	175	355	71
September 15	207	94	301	60
October 15	219	49	268	54

Figure 2. Pounds of phosphorus translocated from vines to tubers throughout the growing season, exclusive of roots. Planted and fertilized with 87 lb P/acre on April 1.



A balance sheet accounting of the 500 #/A application of N is not possible because the amount in the roots is not known nor is the amount of fixed N, or leached N known. Nevertheless, 268 lbs. (54%) was accounted for in the 732 cwt/A crop of potatoes. On August 15, 71% of the nitrogen applied was accounted for in the tubers and vines. How much of the unaccounted for N was in the roots is not known.

The 500 #/A application of N produced 732 cwt of potatoes/A. The 200 #/A application of N produced 617 cwt of potatoes/A. The extra N increased the yield 115 cwt/A. At $60/ton the value of the increased yield would be $345. The cost of the extra 300 lbs. of N @ .30/lb. would be $90. The extra investment in N produced $255 added income. Furthermore, some of the "extra" N would remain in the soil for succeeding crops. The apparent movement of nutrients from the plant to the tubers shown for N was also shown to occur for both P and K. The data for potassium are given in Table 4.

Table 4. Potassium distribution when seed was planted April 1 with 416 lbs./A of Potassium. (Total Yield = 732 cwt.)

	POTASSIUM IN POUNDS			
DATE SAMPLED	TUBER	VINES	TOTAL	PERCENT
July 15	119	260	379	91
August 15	260	314	574	138
September 15	304	158	462	111
October 15	321	28	349	84

At one stage of growth (August 15) 574 pounds of K were present in the vines and tubers while only 416 #/A had been applied. The amount present in the roots is unknown but it could be sizeable. Perhaps the "loan" from the soil bank is too slowly available to maintain a level in the plant necessary to produce 1000 cwt/acre.

Large quantities of P are seemingly needed to produce large yields of potatoes but the quantities removed from the soil are relatively small. This would result in a rapid accumulation of available P in the soil and may allow for reduced P applications as land is used for potato production over time.

The soil is a bank for water, mineral nutrients, and CO_2. As with any bank in which you have an account your soil bank account should not be overdrawn.

This introduces a subject not fully appreciated -- namely that all acres of land are not equally productive, i.e. the soil nutrient deposits are not at the same level. The rental or sales value of the land among other things, should consider the nutrients in the soil.

Fertilizers are commonly applied onthe basis of pounds or tons per acre. This practice can result in one of the following: 1) uneconomical production; 2) maximum yield; 3) reduced yield; 4) reduced dry matter content of the tubers; 5) many oversized tubers; 6) many undersized tubers; 7) optimum yield for maximum profit. The correct amount of chemical fertilizer to use depends upon, among other things, the amount of nutrient(s) available from the soil, the plant population (which should not be interpreted to mean "the number of seed pieces planted," and the anticipated yield.

Each seed piece must have at least one "bud eye cluster." A number of plants can grow from a single eye or bud eye cluster. Each plant that emerges from the seed piece is an independent unit with its own root system, tuber set, and leaf development. If the seed pieces are spaced 9-inches apart and three plants develop from a bud, it is equivalent to putting a plant every three inches. The number of plants that grow from a bud is difficult to control, not only from the standpoint of seed dormancy, but also from the standpoint of sprout damage during the cutting and planting operation and seed age.

There is essentially a linear relationship between seed piece size and yield. Part of the increase in yield due to seed piece size may result from more nutrients in the larger seed pieces but it can also be from an increase in the number of plants per acre. In other words, more plants per acre developed from the large seed pieces.

The number and size of the seed pieces planted is not always a reliable indicator of the number of plants that need to be fertilized. When 24, 074 seed pieces were planted on different dates, the plant population was greatly different. This probably was the result of the degree of dormancy of the seed, which was different at each planting. It is not uncommon to find that more plants grow from an eye as the seed gets older. Since it is difficult to predict the number of plants that will grow, petiole analysis as a tool used for monitoring nutrients in the plant may help preventing nutrient deficiencies before they actually limit the growth of the plant by providing a guide for making nutritional adjustments before the plant stops growing. If plants once stop growing, the effect or restarting growth on tuber quality can be disastrous.

The amount of plant nutrients that should be readily available for plant growth depends on the number of plants to be fed and these can only be determined by counting them after they emerge. In a study where different plant populations were obtained by different numbers of seed pieces yield was still increasing at the highest level (600 #/A) of N, $P_2 0_5$, $K_2 0$ at the higher plant populations. At the lower plant population yield had reached a maximum between two intermediate fertilizer rates.

The quantity of N P K fertilizer that may be needed for yields of potatoes near the climatic potential could be so large that it would be desirable for only part of it to be applied at planting. In which case only portion should be preplant applied. Neither P or K move appreciably in most soils and they remain available to plants for long periods of time. Therefore the major amount of P and K could be applied preplant. The quantity of nitrogen applied at planting time should be sufficient to get the plants well started but not enough to delay plant emergence or reduce the number of plants that develop from a seed piece. In two studies the same kind and amount of fertilizer was used for two years. In one year applying 500 pounds/A of N, $P_2 0_5$ and $K_2 0$ in bands two inches out from the side of the seed piece gave different results. One year the high rate of fertilizer did not reduce the number of plants per acre at the May 15 planting, but it did on the April 30 planting. The previous year the high rate of fertilizer reduced the number of plants on both planting dates. The different effects on the number of plants that developed is believed to have been caused by differences in available soil moisture at the time of planting. These results emphasize a need for knowing the levels of soil moisture present at planting time and making certain that it is near the field capacity to a depth of two feet.

When considering total nutrients needed for the crop whether they come from the soil, a recently applied fertilizer or foliar sprays doesn't make much difference as long as adequate amounts of nutrients are readily available when needed by the plant.

PETIOLE ANALYSIS vs YIELD vs PLANT ANALYSIS

Since the first half of the 1800's researchers have been trying to devise a method by which the requirements for optimum plant growth could be predicted. It was soon discovered that it was impossible to talk of a single factor or condition as being the cause of an observed effect on plant growth. All parts of the plants are interrelated and the growth of all parts depends on the health of each of the other parts.

During the past 25 years we have collected petioles for nutrient analysis from plants in about 22 experiments. Most of the petioles were collected 100 days after planting. The results show that if more fertilizer was applied, higher levels of the nutrients would appear in the petioles. Unfortunately, the correlations between the concentrations found in the petioles 100 days after planting and the yield of potatoes at harvest were often very poor. (Table 5)

Table 5. Yield and percent nitrogen in Russet Burbank petioles 100 days after planting (All fertilizer banded at planting.)

cwt/A	Percent N	Comparison		
1051	3.0	cwt/A	% N	
942	3.4	1051	3.0	
914	3.6	882	2.9	
902	4.5	169	0.1	Difference
882	2.9			

Yield from the lowest to the highest differed by 169 cwt but the difference in percentage of N in the petioles of .10% was well within the differences between samples. The petiole N levels would be considered high -- about 30,000 PPM, but so would the yields. An explanation for this poor correlation is not known but some speculations are possible. The sampling date may have been wrong for later potatoes.

Over a 6-year period petiole analysis were determined from plots used to study the effect of sources of K on the total N and/or K content of the petiole. Results showed that no differences in petiole levels resulted from the treatments.

Petiole analyses were used in plots designed to study the effect on the concentrations of the major ions in the petiole. Increasing the rate of ammonia increased the total N, the nitrate N and P in the petiole but had very little effect on the percentages of Ca, Mg, or K.

Petiole analysis were used in studies designed to determine if the anion associated with K caused differential effects on other ions in the petiole. It was found that the different sources of K did not effect the ion level in the petiole except that the percentage of NO_3 was higher when sulfate of potash and potassium nitrate were the source of K (but the total N included in the petiole was about the same.)

The results of a petiole analysis are usually given as percentages or in PPM. These numbers are indecies but to be useful they must be related to something which has a meaning such as production per acre, or pounds of an element. Because the relationship between petiole indecies and yield were disappointing, it was decided to analyze the total plant except the roots for content to see if a relationship between nutrient content and yield could be found. By these analyses it was found that the percentage mineral composition of the tubers was relatively constant regardless of yield of potatoes or variety and correlations between percent mineral content and yield were very low. However, the correlations with the amount of an element in the tubers were very high (Table 6).

Table 6. Linear correlation coefficients relating tuber mineral composition to yield (Sample size 256).

	PERCENT			POUNDS PER ACRE		
Factor	N	P	K	N	P	K
cwt	-0.16	-0.12	-0.23	0.93	0.90	0.93
N	-	0.39	0.49	-	0.89	0.91
P	-	-	0.56	-	-	0.94

The nearer the correlation coefficient is to 1.000 the better is the agreement.

1. The concentration of mineral nutrients in the petiole indicate only the quantities not being used by the plant in the growth of the vegetation or the tubers.

2. Many growth factors both above and below the soil surface directly and indirectly determine how rapidly a plant can utilize the available nutrients. If conditions are adverse to growth, mineral elements tend to accumulate. For example: in a N-P-K factorial experiment where each nutrient was used at four levels and in all possible combinations, the nitrate nitrogen level in the petioles was high when the lowest rate of nitrogen was applied because a deficiency of either phosphorus or potassium or both was controlling the amount of new growth.

3. Insufficient soil moisture and/or cold temperature can cause slow growth which results in nutrient accumulation in the petioles.

4. The nutrients found in the petioles usually come from the soil if the roots are healthy and the nutrients are in the soil solution. However, they may come from the lower, older parts of the plant if soil nutrients are not available in adequate amounts.

5. One nutrient may interfere with the uptake or movement of other nutrients thereby causing different petiole levels which are the result of soil nutrient levels.

In studies on the effect of planting date on concentration of N-P-K in the petiole it was found that planting two weeks later greatly reduced the concentration of Nitrogen (or NO_3) in the petiole. This was also the case for P and K. The soil temperature could have been warmer at the later date and resulted in a more rapid growth. Also more plants likely developed from each seed piece because of decreased seed dormancy therefore the levels of the elements in the petiole would have been lower due to dilution of the available nutrients by the increased number of plants when the petioles were taken the same number of days after planting. In all cases, the percentage of N in the Petiole was higher 80 days after planting than 100 days after planting.

Petiole analysis was useful in comparing slow release forms of nitrogen with several sources of nitrogen to see if they were taken up equally by the plant. As the amount of slow release N in the fertilizer was increased, the percent N in the petiole decreased as did the yield.

The question is often asked, is it economical? Data relating production and price to profit have been summarized by extension agricultural economists. There are three ways to make an enterprise profitable: 1) more production; 2) higher prices; 3) lower cost inputs.

A fact to remember is that "the cost of production, except for fertilizer, is about the same regardless of yield."

The average yield of potatoes in the Columbia Basin in 1982 was just under 25 T/Acre (500 cwt). At 25 T/A it would require about $60 per ton to cover the cost of production. The use of averages has its limitations because some growers produce higher yields than the average and at a cost per acre which could be higher or lower than average.

Potatoes are expensive to grow. We studied the effect of high production and fertilizer needs for two years. The results of the two years were almost identical. It was found that the major cost of increasing production was the cost of fertilizer. The data illustrates two well known principles. Namely, that the cost of fertilizer increased linearily, but the response in yield followed the law of diminishing returns. The highest increment of fertilizer used in the experiment cost more than the value of the additional potatoes produced, but the fertilizer was not lost. It could be considered as money in the bank, a reserve that could be used when needed because of financial problems or exceptionally favorable growing seasons -- the highest yield in the study was 710 cwt/A. The climatic potential yield for a full season of growth approaches 1,000 cwt/A. Experimentally we have produced very high yields of potatoes without loss of grade or loss of tuber quality. Some growers have produced potato yields approaching the average highest experimental yields on relatively large areas.

In summary please remember:

1. Profits are closely related to production.

2. Increasing production require increasing amounts of nutrients.

3. Profit is the difference between value of the crop and the cost of production.

4. Many of the costs of production are about the same regardless of yield.