GROWTH OF THE POTATO

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Introduction

Growth of an organism is an increase in the amount of material within it. This usually means not only an increase in cell number, but also an increase in cell size.

An increase in cell number is accomplished by cell division in areas called meristematic regions such as in the shoot, root apices and cambium tissue. Just what triggers the cell to divide is uncertain, but such things as light, temperature, water and chemical substances from the environment have their effect. There also are internal factors such as genetics which seem to control cell size. It is in the actively dividing areas where a certain cell size seems to activate the cell to divide.

"A knowledge of the structure and growth processes and the effect that various inherent varietal or environmental factors have upon the potato plant is useful in determining proper cultural procedures and their practical adaptation," (Werner). "Because of the closely interconnected mechanisms which make up the whole plant, it is rarely possible to deduce the response of an organism to a given factor, or complex of factors, from a knowledge of the separate responses of single biological reactions, or groups of reactions, to these factors" (Milthorpe). Both of these statements are fundamental truths when it comes to explaining why something happened. For a number of years I have listed some 17 factors which are essential for the production of maximum yields of quality potatoes (Table 1). Only when all factors are present in optimum amounts will yield of 700-800 and even 1,000 cwt/acre be achieved. The light intensity, temperature, length of growing season and water supply available in the Columbia Basin should make it possible to grow yields almost double the top yields reported so far. That the Columbia Basin environment is ideal for top yields even in years like this past season when an unprecedented period of high temperature occurred the latter part of June and early July is proven by the fact that yields as high as 774 cwt/acre did occur in some of our plots. To obtain answers to the conplex problem of what influences potato growth and development requires concurrent investigation of all the influencing factors if an understanding of the entire behavior is to be achieved. To understand an automobile requires a knowledge of all its parts and their function. So it is with a potato.

<u>The Cell:</u> The fundamental unit of all living organisms is the cell. Plant cells differ from animal cells in that their functional units are separated by walls which in turn are cemented together. All of life's functions are carried on within cells. Young cells are very similar but as they mature, they develop into specialized organs such as roots, stems, leaves, tubers, etc., where they are endlessly at work generating energy and building new materials for growth and reproduction. The marvelous thing about these mechanisms is that they can be depended upon to perform a certain way under a given set of conditions. It is this dependability that makes it possible to predict what will happen in a given situation.

At one time it was believed that a potato tuber had all its cells by the time it was 1/2 inch in diameter, and that any increase in size from there on was due to cell enlargement. This may be true for some varieties, but currently it is believed that potato enlargement is a combination of an increase in both number and size of cells. The energy to make the process go comes from the sun. One of the sun's contributions is to increase temperature which controls the rate of the "living" processed (Figure 1). The higher the temperature, within limits, the faster the processes go, and as the temperature gets higher, the rate of acceleration becomes greater. The converse is also true. Light from the sun supplies the energy required for growth through photosynthesis, a process which makes sugar from carbon dioxide in the air and water.

Anything that works, works best when it is under control. Of the 17 important factors listed only 10 can be more or less grower-controlled. Fortunately the uncontrollable factors usually are such that in the Columbia Basin they approach the optimum conditions for producing high yields as long as the grower-controlled factors are adequately supplied. As the yields go up and the investment in time and materials increases, greater attention to details of operation are necessary. In some cases experimental guidelines are available and in others the grower must rely upon experience.

Factors which have been proven to affect both cell multiplication and increase in cell size are:

1. Water

   a. Unless cells are full of water there is no growth.

   b. In sufficient water in Russet Burbank potatoes causes dumbbell shaped tubers, pointed ends and jelly end rot.

   c. Extremes of water shortage cause starches to be converted to reducing sugars cause dark colored chips and fries.

   d. High water content in cells causes tubers to be mechanically resistant to blackspot. The optimum water content depends upon the temperature if both blackspot and shatter bruise are to be minimized.

2. Temperature

   a. At cold temperatures cells enlarge and multiply slowly. For this reason, low temperature storage is usually desirable for holding seed potatoes. Potatoes have been stored at 38°F. for two years without sprout growth.

   b. Temperatures below 45°F. result in an accumulation of reducing sugars which cause a sweet taste and brown colored chips and fries. The level of reducing sugars which accumulate during low temperature storage can be reduced by holding at a warmer temperature for a period of time. However, once the reducing sugars are allowed to accumulate, the level will remain above the original level even after warm storage.

   c. Wound healing of cut or injured surfaces is slow at temperatures below 50° F. even if humidity is high.

   d. When tuber flesh temperature is below 50° F. the tubers crack easily when bruised.

3. Mineral nutrients

   a. Abundance of water and nitrogen favor cell enlargement. Abundance of carbohydrates resulting from warm bright days with limited water and nitrogen favors cell division. Nitrogen promotes vegetative growth both above and below ground. The course of cell differentiation is dependent not onlyupon genetic, but also upon many environmental factors.

   b. Phosphorus promotes cell division in roots, but has little effect on cell elongation, whereas nitrogen promotes cell elongation but not cell division. For this reason, phosphorus tend to favor root growth over top growth.

   c. Potassium controls the opening and closing of stomata, the breathing pores in the leaves, and is vital in the process of cell division, because without it, the nucleus, the control center, does not divide.

Though some 12 additional elements are essential for normal growth N, P, K and zinc are the only ones which must be currently applied to the soil for potatoes in the Columbia Basin.

Tuber Development: Two terms are often used when referring to tuber development, tuberization and tuber set. Tuberization refers to the time of tuber initiation at the end of the rhizomes. There is no definate time at which this phenomenon begins. Early flower bud stage, about 6 weeks after planting and when the vines are about half grown, are terms used to indicate the approximate time of tuberization. Potato tubers are food and water storages, the content of which can be utilized by a growing plant. Experience has shown,however, that tuberization can begin whenever there are carbohydrates and nitrogen in excess of those required for vine growth. Tubers the size of hen eggs were found on Russet Burbank plants only 4 to 6 inches tall.

The explanation lies in the fact that the seed was planted early during a very warm, moist spring when conditions were favorable for quick plant emergence and rapid vegetative growth. Thereafter, cold weather occurred, greatly decreasing vine growth. A surplus of carbohydrates occurred and they were diverted into tuber growth. Still later environmental conditions again became favorable for rapid vine growth and the carbohydrates in the newly developed tubers were utilized in the vine growth. Some of the tuber which had formed were partially or even completely absorbed to meet the water and nutrient demands of the new vegetative growth. The uneven growth of plants and tubers could result in numerous tuber abnormalities. Unfavorable temperatures followed by favorable temperature, inadequate soil moisture, especially early in the tuber's developmental stages, and fluctuating nitrogen supplies have all produced tuber malformations. In short, any factor which stops and later starts tuber development can result in malformed tubers. The degree of malformation depends upon the severity of the tuber adjustment. Severe and profound unfavorable carbohydrate balance resulting from growing conditions can result in loss of tubers already set, thereby reducing the total number of tubers one finds early in the spring compared to the number present at harvest time, on any plant. These effects are especially critical during the early stages of cell differentiation which is much earlier in the growing season than generally realized.

Tuber set refers to the number of tubers which develop on a plant, rather than in a "hill". It is commonly believed that the number of tubers which will set is determined in a relatively short time - about two weeks. Early in the season as many as 15 - 20 small tubers occur in a "hill". This number often decreases to at most 6 or 8 by harvest time because many of the smaller tubers disappear. It is believed that they areabsorbed into the larger tubers and that this process continues until close to harvest, but this is not confirmed after two years' of study with the Russet Burbank variety. From our studies, it would appear that the number of tubers which develop varies from year to year and that the time of final tuber initiation also varies from year to year. Nevertheless, few tubers develop after 60 - 90 days after planting (Table 2).

The Seed Tuber: Potato tubers have numerous eyes, or rather clusters of buds. The eyes are spirally arranged and get closer together toward the bud end of the tuber. The most apical bud is dominant over all other buds and it sprouts first. As the tuber gets older, apical dominance diminishes and the lateral buds begin to sprout. If a tuber is cut for seed before the apical bud sprouts all buds will begin to sprout at about the same time. If, however, the apical bud has sprouted prior to cutting, the development of lateral sprouts will be delayed. The extent of the delay depends upon the degree of dormancy existing at each bud. Age of tuber, variety and environmental conditions all influence the number of eyes which sprout as well as the number of sprouts which develop from each eye. De-sprouting results in more eyes forming sprouts and also in more sprouts per eye. Warm temperature storage produces the same effect but to a lesser degree. As a general rule, the older the seed the greater the number of plants which will develop from the seed pieces and the greater the number of tubers. There is a direct relationship between the number of plants and the number of tubers which develop.

Single eyes can produce from one to five sprouts. Each sprout which develops at the seed piece is an independent plant having its own roots, stem, leaves and tubers. It should now be obvious that planting a given number of seed pieces may or may not be a reliable indicator of the number of plants and tubers which will result.

The number of plants and the number of tubers which develop is also influenced by the amount of fertilizer used. High fertilizer rates tend to decrease the number of plants and thereby the number of tubers which form is also decreased.

Depth of Tuber Formation: The rhizomes from which tubers develop emerge from the nodes which occur beneath the soil surface. From this point of origin they grow horizontally and follow the path of least resistance. If the nodes are far apart the rhizomes are far apart, therefore so are the tubers. The location of the rhizomes on the stem greatly influences tuber greening. Hilling per se is not necessary for the prevention of greening of potatoes if the seed is planted 3 1/2 to 4 inches below land level. Moderate hilling is, nevertheless, a good cultural practice. It aids in weed control, makes harvesting easier and provides adequate furrows for rill irrigation.

Nutritional Effects on Growth: Stunting of growth and early death of plants due to inadequate nutrition is common throughout the Columbia Basin. Limiting nutrition, particularly nitrogen, can be used to produce maximum potato yields for a given market period. The amount of nutrients removed from the soil by a potato crop is closely related to the yield and the yield is related to the number of growing days. When the analytical results for mineral nutrients are expressed as a percentage of the yield on a dry weight basis there is an almost linear decrease in the concentration of the nutrient with an increase in the number of growing days. The response to nitrogen is used as an illustration in Figure 2. This is, however, primarily a dilution effect because the total amount of a nutrient removed is proportional to the yield which gets larger as the season gets longer. On the basis of a number of analytical studies over a period of years and with several varieties it was possible to compute the amount of nutrients in a potato crop of most any size. The relationship between yield and nutrients removed was linear for yields ranging form 30 to nearly 1400 cwt/acre. The data in Table 3 show the amount of nutrients in the tubers and indicate the minimum amount of nutrients needed. They do not take into account those in the tops or roots or the quantity which must be present in the soil to make the minimum amount available to the plant.

Growth Curves: One researcher divided the growth of the potato into three phases: 1) Rapid plant growth during which every seed and cultural practice should be designed to promote vigorous development of the plant, 2) Plant maintenance and rapid tuber development during which time maintaining a vigorous photosynthesic area is important, and 3) Plant decline during which time the vine is dying and tuber enlargement is slowing down. Another researcher divided potato growth into four phases: 1) stolon (rhizome) formation, 2) tuber setting and rapid plant growth, 3) rapid tuber growth and slow top growth and 4) slow tuber growth and dying tops. The plant - tuber relationship is shown in Figure 3. The results obtained in areas with a short planting and harvesting period, such as depicted above, should not be applied directly to the Columbia Basin wherein the planting season extends from early March until June and the harvesting season from early July until November. In the Columbia Basin the life span of a potato plant, from planting to death, may range from 80 to 200 days. The division of the developmental stages of a plant given above are, nevertheless, true within a given planting and harvest period. Therefore, to obtain the highest yields possible, the longest growth period available should be utilized and the shape of the growth curve will be modified by the time of planting, time of harves and amount of fertilizer used (Figure 4).

Environmental factors influence the time of tuber initiation. Any factor or combination of factors which retard vegetative growth, such as temperature, moisture and nitrogen will induce early tuberization. For this reason, time of planting, amount of fertilization and time of harvest greatly influence the type of growth curve obtained.

Several effects are obvious from Fig. 4: 1) Yield increased as harvest was delayed from July until September for the three lower fertilizer rates; but 2) Yield continued to increase until mid-October with the highest fertilizer rate and the slope of the line indicates that yield would have continued to increase until the plants were killed, 3) The loses in yield resulting from leaving tubers in the ground after the vines are dead were almost 57 cwt/acre, depending upon the length of time involved. The revenue from an extra 57 cwt/acre of potatoes could pay quite a few bills. How to utilize these differences depends upon what use the grower wishes to make of the potatoes. For example, those which were close to maximum yield early in October might best have been harvested while flesh temperatures were still high, and put into storage. Those which were heavily fertilized and still growing could have been moved directly from the field to processing. The grower would benefit from the increased tonnage and the processor would benefit from having to handle the potatoes only once and without storage shrink.

Another way of presenting the same story is illustrated in Figure 5. When too much fertilizer is used for the length of the growing season, a loss in yield results. The amount of loss depends upon the amount of the excess. By increasing the length of the growing period more and more fertilizer can be used efficiently.

SUMMARY

1. All potatoes, plants and tubers, are composed of cells which increase in size and number according to the genetic make-up and the environmental conditions under which they are grown. Some effects are temporary, but others are permanent. Factors which cause permanent effects are moisture stress, extreme temperatures and nutrient deficiencies.

2. The number of plants and the size of each plant which develops is influenced by the age of the seed, the time of seed cutting, size of the seed piece, temperature of storage and nutrients available for growth.

3. The amount of nutrients removed from the soil in a potato crop is determined by the size of the crop which is determined by the plant population and number of growing days which is influenced by the amount of fertilizer used.

4. Yields change as depicted in growth curves, according to the date of planting, amount of fertilizer used and the length of the growing season.

Table 1. Factors affecting Yield and Quality.

1. Frost Free Period
2. Air Temperature
3. Soil Temperature
4. Light Intensity
5. Length of Day
6. Humidity
7. Wind
8. Moisture
9. Insects
10. Diseases
11. Days Grown
12. Fertilizers
13. Seed Quality
14. Seed Piece Size
15. No. of Plants
16. Timely Operations
17. Variety

Items 8–17: More or Less Grower Controlled

Table 2. The effect of Planting Date, Harvest Date & Fertilizer Rate on the number of plants and tubers produced.

Planting Date	Year	Number of Plants per 10 Hills: July 15	Aug. 15	Sept. 15	Oct. 15	Mean	2-yr. Mean	Number of Tubers per 10 Hills: July 15	Aug. 15	Sept. 15	Oct. 15	Mean	2-yr. Mean
April 1	1967	15	16	15	--	15		48	57	58	51	54	
	1968	15	17	16	18	17	16	72	82	74	74	76	65
April 15	1967	17	16	17	--	17		53	52	71	58	59	
	1968	18	16	16	18	17	17	75	81	79	84	80	69
April 30	1967	21	21	20	--	21		58	52	67	59	59	
	1968	22	24	22	25	23	22	79	86	87	90	86	72
May 15	1967	24	22	22	--	23		68	59	70	60	64	
	1968	25	28	26	25	26	25	76	91	96	94	89	77
Mean	1967	19	19	19	--	19		57	55	67	57	59	
	1968	20	21	20	22	21	20	75	85	84	86	83	71

Table 3. Mineral nutrients removed from the soil in a 100 Cwt/acre Russet Burbank potato crop.[1]

Element	Yield (Cwt/acre)	lbs/Cwt	lbs/acre
Nitrogen	100	0.30	30.0
Phosphorus	100	0.07	7.0
Potassium	100	0.44	44.0
Calcium	100	0.008	0.8
Magnesium	100	0.025	2.5
Sulfur	100	0.024	2.4
Zinc	100	0.0002	0.02
Copper	100	0.00016	0.016
Manganese	100	0.00015	0.015
Iron	100	0.00047	0.047
Boron	100	0.00007	0.007

[1]To estimate the nutrients removed in a tuber crop multiply the pounds of the element per Cwt by the size of the crop in Cwt. Example: the nitrogen in a 1000 Cwt crop of potatoes is about 1000 x 0.30 = 300 lbs.

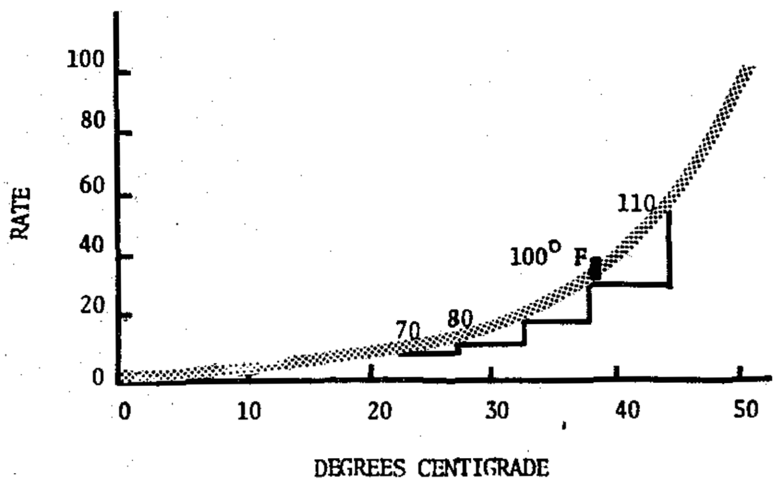

Figure 1. As the temperature increases the rate of enzyme activity increases at an accelerating rate.

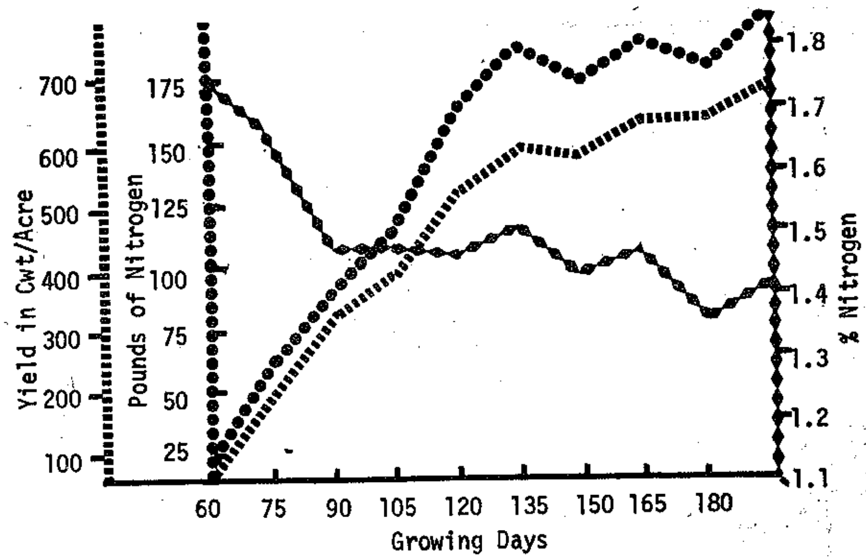

Figure 2. As the number of growing days increases the yield and the amount of nitrogen in the tubers increases, but the percentage of nitrogen in the plant decreases.

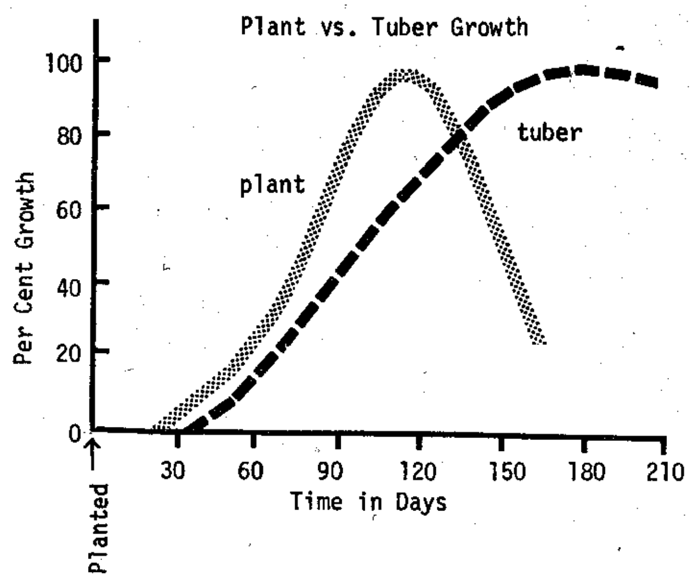

Figure 3. The relative rate of plant and tuber growth.

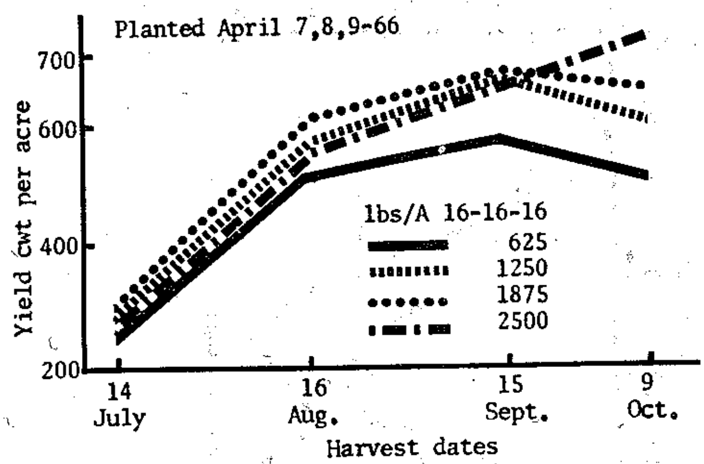

Figure 4. Yield curves for Russet Burbank potatoes as influenced by time of harvest and amount of fertilizer used.

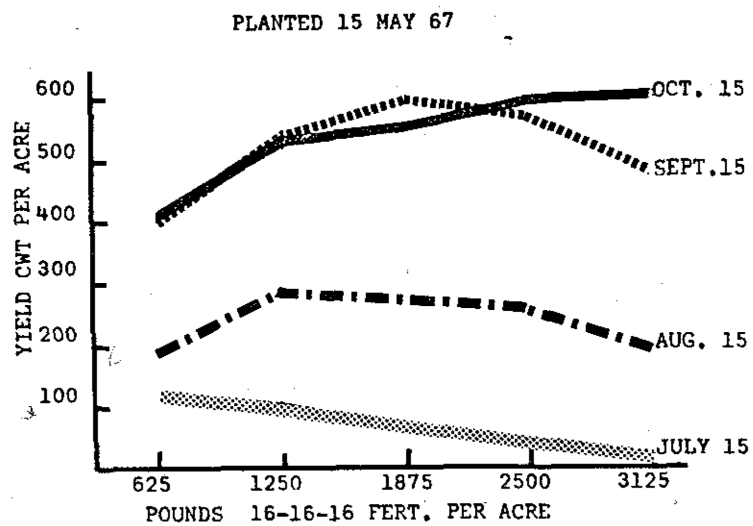

Figure 5. Yield curves for Russet Burbank potatoes as influenced by time of harvest and amount of fertilizer used.