PRINCIPLES FOR PRODUCING MAXIMUM YIELD OF HIGH QUALITY POTATOES[1]

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INTRODUCTION

High yield and high quality potatoes are the result of the integration of a combination of factors and not the result of any one factor alone. The principle of limiting factors is operative, and if any one factor is short supply or out of balance both yield and quality could be affected. Some seventeen factors are known to affect potato yields and quality.

Of the seventeen factors listed (Fig. 1), ten can be more or less grower controlled. Though some additional factors could be grower controlled, the cost is currently uneconomical. With so many factors influencing potato yield and quality, it is not surprising that very high yields are produced only occasionally. It is only when all factors are present in optimum amounts that 700 CWT per acre potato yields are achieved. But as will be pointed out later, even higher yields can be expected.

The Columbia Basin is different. The potato has been described as a cool season, short day crop. If this were true, potatoes would not be produced commercially in the Columbia Basin where the temperature exceeds 90°F. and it is light enough to see from 4:00 A.M. until 9:00 P.M. during the long days of summer. The fact that potatoes are grown commercially in the Columbia Basin, and the fact that the average yields per acre are the highest in the nation should cause us to take a new look at the conditions required for maximum yields.

Many of the costs of production are fixed. It costs little more to produce and harvest a large yield per acre than it does a small yield. The average yield per acre for the state of Washington is about the same as that for the state of California, but since most Washington potatoes are produced in the Columbia Basin, it is more meaningful to consider the yields produced in the Basin.

The average yield per acre in the Columbia Basin is top in the nation (Fig. 2). This makes it possible to compete with production areas closer to the markets. In 1962, the results of a series of experiments with high fertilizer rates were discussed in a number of meetings. In addition, a series of experiments was started to determine maximum production if the best known practices were used.

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[1]Funds for these studies were provided by the Washington State Potato Commission.

This was the first time our yields exceeded 560 CWT per acre and this yield was produced with 400 lbs, of N, 230 lbs. of P_2O_5, and 320 lbs, of K_2O per acre. The biggest surprise, however, was the fact that no important loss in grade, specific gravity, or chipping quality resulted from such a large application of fertilizer. As a result of these studies, the use of larger quantities of fertilizer was suggested, especially if the potato crop was to be planted early and harvested late for storage. The increased yield per acre of late potatoes since 1962 is probably the result of the use of higher levels of fertilization with nitrogen phosphorus, and potash. Ample fertilizer keeps the plants growing until late in the fall and makes it possible to utilize the long season. Because of the long growing season in the Columbia Basin, plants require more plant food than is needed in short, cool season areas.

The rate of an enzymatic action is slightly more than doubled for every 10 degrees centigrade increase in temperature. All living is controlled by enzymatic actions.

A glance at the dotted line on Figure 3 shows that the rate of an enzymatic action goes faster as the temperature increases, and that the rate is faster for a 10 degree temperature increase in the high range than in the low range. The data also show the rate of increase for every 10°F increase in temperature. The vertical part of the black line between 70° and 80°F shows how much faster life processes are going on at 80° than at 70°F. Now compare the length of the vertical black line for an increase in temperature from 100° to 110°F. If all essential factors, particularly water, are adequately provided, the available energy from the sun makes the high yields of many crops possible in the Columbia Basin.

During the long hot, bright days, a maximum of synthesis occurs. During the cooler nights, the rate of respiration decreases and in addition, the nights are short, thus most of the dry matter produced during the day is retained. This is important because it not only results in the production of high yields, but also in a high dry matter content of the potatoes which is essential for nearly all forms of potato processing.

Simply stated, yield is a function of the amount of dry matter produced per hour, X the number of hours per day the plant is operating, X the number of days the plant can produce, X the number of plants in operation.

Yield can also be called the difference between the "amount produced" and the "amount lived up." This is why high daily temperatures and low night temperatures are important (Fig. 4).

The American Potash Institute has published data showing how many pounds of N, P_2O_5, and K_2O are present in the total plant of a 400 CWT potato crop. I have taken the liberty to extrapolate this data to the size of a 200 CWT potato crop and also to an 800 Cwt potato crop (Fig. 5). It can be seen that there is a relationship between the amount of plant nutrients needed and the size of the crop produced. If a maximum yield of early potatoes is desired it will require less fertilizer because the yields are lower. On the other hand, it can be seen that large yields require large quantities of fertilizer, especially potassium. For the plants to take these amounts of nutrients from the soil, requires that the level of readily available nutrients present in the soil be even higher.

These data (Fig. 6) were obtained in 1966 and illustrate that high yields require lots of fertilizer and a long growing season. The highest rate of fertilizer application produced the largest yield and, had the vines not been killed by frost on October 9, the yield would have continued to increase at a linear rate for some time. If on the other hand, the potatoes were to have been harvested July 14, the lowest rate of fertilization would certainly have been all that could be justified. Intermediate harvest dates required intermediate amounts of fertilizer. Note the rapid rate of increase in yield between July 14, and August 16. The rate of increase was 8 CWT /day/acre. The maximum rate of increase occurred during the hottest days and was associated with the amount of fertilizer used. Between September 15 and October 9, some of the yields actually decreased; the plants were living off the tubers. Tubers from the lowest rate of fertilization would not have been marketable October 9 because of black spot. Thosetubers receiving the highest rate of fertilization would easily have made grade. The specific gravity curves, during this same period of study, resembled the yield curves, but the relative positions have changed (Fig. 7). The greenest plants received the most fertilizer and had tubers with the lowest specific gravity.

The nutrients used by plants come from recently applied fertilizers and from plant and fertilizer residues of previous crops. The amount supplied as commercial fertilizer is easy to determine, but the amount of nutrients a plant can get from the soil is difficult to ascertain because of the extreme variability of furrow irrigated land.

Potato plants feed to a depth of 2 feet and more, and little is known of the soil nutrient content below the top foot of soil, but indications are that the second foot is as variable as the top foot. Even the surface appearance can be misleading. Some filled areas resemble cut areas because they were filled with subsoil. A laboratory analysis is accurate but the soil sample must be accurate also.

It is most difficult to obtain a soil sample for either phosphorus or potash which represents the average nutritional status of the 0.73 acres studied in this test (Fig. 8). The area was divided into plots 11.3 feet x 50 feet, and each plot was sampled separately. This made it possible to determine what percentage of the entire areas was in each category.

It is not even easy to determine the best fertilizer treatment with relatively comprehensive fertilizer experiments, because of the complicating effect of soil heterogeneity, unequal water infiltration into the soil in different parts of the same experiment, and differences among growing seasons. An experimenter can, however, use a great many replications, as was done in these experiments, and come to some rather definite conclusions by observing the trends and by using statistical procedures. The data in figure 9 were selected from 3-N-P-K factorial experiments. Each nutrient was used at 4 levels and in all possible combinations.

Figure 9 shows the different yields that can be produced from the same fertilizers but in different seasons and on land with a different cropping history and with different plant populations.

The 1963 results (black bars) are the means of eleven replications. The top yield exceeded 600 CWT per acre and was obtained with the highest rate of fertilizer applied. When potash was reduced yield was reduced. When potash was restored and phosphate was reduced, the yield was nearly the same. When both phosphorus and potash were reduced, the yield was nearly equal to the highest rate of fertilization. When nitrogen was reduced from 400 to 300 pounds, the yield was generally reduced at all phosphorus and potash levels.

The 1964 experiment (checked bars) was on different land. Each point is the mean of 8 replications. Note that the highest rate of fertilizer application produced over 700 CWT/acre. Note that reducing the potash levels increased the yield to over 750 CWT/acre. Maintaining the nitrogen level at 400 pounds per acre, and reducing the phosphorus and restoring the potash produced the same amount of yield as when the potash was low and the phosphorus was high. When nitrogen was high and both phosphorus and potash were reduced, the yield remained at a maximum. Reducing the nitrogen reduced the yield similarly to the reduction in 1963.

The 1965 experiment was conducted on land which was in alfalfa for two years prior to the experiment (dotted bars). Each point is the mean of 6 replications. When nitrogen, phosphorus, and potash were each at the highest level per acre, the yield was over 700 CWT per acre for this treatment as it was in 1964 (checked bar). However, in 1965 a definite reduction in yield occurred when phosphorus and potash were reduced, and nitrogen was kept at 400 pounds per acre. The 300 pound per acre application of nitrogen was about equal to the 400 pound application of nitrogen, but the experiment was on land the first season out of alfalfa. The 1965 season was shorter than normal. The vines were killed by frost on September 17; on September 9, the vines in the plots receiving the 400 pounds rate of nitrogen were still green and had they grown for another two weeks, the yields would undoubtedly have been higher.

The large difference in yield between the 1963 (black bars) and the 1964 (checked bars) and the 1965 (dotted bars) may have been due in part to a difference in growing seasons, but a better explanation is that the plants were spaced 11 inches apart 1963 and 9.2 inches apart in 1964 and 1965 (fig. 10).

The relationships among yield, plant population, and fertilizer rates are shown in figure 10. There was little difference in yield due to differences in plant population when 938 pounds per acre of triple 16 fertilizer was applied. The greater yield may actually have occurred with the fewest number of plants. The highest rate of fertilization with the largest plant population produced the greatest total yield. Therefore the title, plants to feed and not acres to fertilize.

Some growers have tried to space plants 6.6 inches apart and ended up with many small potatoes, but they used only 400 pounds per acre of each of the three major nutrients. This year we found the same thing.

A study of this data, however, suggest that on a very deficient soil the fewest plants with the most fertilizer might give the best yields. The fertility status of the soil on which a test is conducted has a lot to do with whether or not the correct spacing is used. The results may apply only to the particular area used. In this experiment, when the plant population was increased to about 32,000 plants per acre, by decreasing the distance between the rows to 30 inches, the plants died from nitrogen starvation even though 3750 pounds per acre of triple 16 fertilizer was used. Each stem in a hill is an individual like a steer in a feeding lot. It has its own root system and set of tubers. The total amount of food available for each individual is important in determining how many plants should be used. Food per unit is a basic principle to consider when it comes to feeding people or animals. Why not also for plants?

The data in Figure 11 were selected to illustrate the law of limiting factors. This law states that the extent of a reaction is limited by the essential factor present in least amount. In this example there are two limiting factors - nitrogen and potash. Phosphorus was applied at 175 pounds of phosphorus per acre.

Note the yield which resulted from applying different rates of nitrogen without potassium (Fig. 11). There is essentially no increase in yield from applications of nitrogen even though phosphorus at 175 pounds per acre and nitrogen at 400 pounds per acre were applied. Potash is the limiting factor as shown by the dashed line. Had the experiment included only high levels of phosphorus and nitrogen, the logical conclusion would be that 100 pounds of nitrogen adequately supplies all that is necessary. Not long ago a yield of 355 CWT per acre of potatoes was considered a good yield. When 110 pounds per acre of potassium (dashed line) was added to the 100 pounds per acre rate of nitrogen, only a slight yield increase accurred because not enough nitrogen was applied. Nitrogen is now the limiting factor. This is evident from the fact that yield increased at a linear rate from 100 to 400 pounds per acre of nitrogen. When still more potash was added (dotted line) there was an additional increase in yield for the higher rates of nitrogen. When still more potash was added, the highest yield was obtained with the highest rate of nitrogen and potash (black line) and the slope of the line indicates the yield might go even higher than 600 CWT per acre. This response in yield due to applications of nitrogen with a high level of phosphorus and potash is quite in contrast to the response obtained from nitrogen and phopshorus alone. In addition to the effect on yield, potassium decreased the severity of blackspot almost proportional to the amount of potassium applied.

The effect of high fertilization on grade has always worried growers. Nearly every grower has experienced a low percentage grade of potatoes and attributed the effect to high levels of fertility and particularly to too much nitrogen. The conclusion is only partially correct. It was too much nitrogen for the amount of water available to the plant. This may have been the result of under irrigation, but it was more likely the result of poor water penetration into the soil or the lack of some other essential element. We have had 83% number 1 grade potatoes in one plot hwer moisture was adequate and only 45% in another plot receiving the same fertilizer but in which water was limiting. The answer to this problem is complex and cannot be satisfactorily corrected by simply running water.

Experimentally we have produced dumbell shaped tubers and pointed end tubers by manipulating the water supply. We have also produced tubers of many different kinds of growth defects by side dressing with nitrogen after growth had ceased due to a nitrogen deficiency. In contrast, side dressing with nitrogen derived from all the common sources has not caused malformation of the tubers if it was done before nitrogen became deficient in the plant. It seems to be the starting of tubers again after they had stopped growth for, perhaps, any of a number of reasons that cuased many typed of tuber malformation.

Artificially heating the soil in the ridges with electrical heating cables resulted in tubers that were crooked, small in diameter and extremely long and sometimes no tubers at all. I have seen tubers of this type in fields in which irrigation was disrupted for several weeks.

Studies have suggested that 1-1-1 ratio fertilizer at about 400 pounds per acre of each nutrient might lead to the production of maximum yields. A triple 16 fertilizer was applied at rates to supply increasing amounts of N, P_2O_5, and K_2O (Fig. 12). Each point on the yield curve and grade curve is the mean of 16 replications. The highest rate of fertilizer applied was 3,150 pounds per acre of triple

16 fertilizer and the yield was still increasing at this rate of fertilizer application. The yield of number 1 grade potatoes increased as the fertilizer increased and then leveled off with further increases of fertilizer. The specific gravity, a measurement of processing quality and culinary properties, was about the same regardless of fertilizer application and chip color was actually improved by the large amounts of N-P-K. The lower the value the better the chip color.

Fertilizers per se do not appear to be important factors in determining chip color. In this study 4 levels of N, P_2O_5, and K_2O were used alone and in all possible combinations without affecting chip color. What applies to chips also applies to French fries, but to a lesser degree.

For several years we have studied the effect of fertilizer treatments on potato chip color. High and low rates of nitrogen with and without phosphorus and potash; high and low rates of phosphorus with and without nitrogen and potassium; high and low rates of potassium with and without phosphorus have failed to demonstrate a detrimental effect of fertilization on color of potato chips on the Columbia Basin.

This year in a harvest date experiment, wherein 400 lbs. of N, P_2O_5, and K_2O per acre were used and potatoes were harvested on July 14, August 16, September 15, and October 12, there was no effect on potato chip color due to the fertilizer used. High fertilization, however, does generally result in some reduction in specific gravity of the tubers. From the grower standpoint, there appears to be no reason why growing potatoes for maximum yield should not be practiced in the Columbia Basin.

Much has been said and written concerning the value of different sources of potassium for potatoes. We've made comparisons between muriate and sulfate of potash for almost as long as I've been in Washington. Recently potassium nitrate became available for use in fertilizers. This enabled us to study levels of potassium without the confounding effect of chloride or sulfate ion. To date we have not been able to demonstrate that source of potassium is an important factor in yield, grade, specific gravity, blackspot, or chip color of Russet Burbank potatoes in the Columbia Basin, but sulfate of potash has consistently produced tubers with a better net than either the muriate or the nitrate source of potassium. Why this should be I don't know because potatoes on the same plant, and even different parts of the same tuber, can differ so greatly in degree of netting when nourished by the same fertilizer.

There are some areas in the Columbia Basin where good plant nutrition and good cultural practices alone are not sufficient to produce high acre yields because some other factor is controlling the response. This is illustrated in Figure 13. Destroying soil pathogens by soil fumigation in these experiments resulted in substantial increases in yield in both early and late crop potatoes.

What are our yield potentials?

Thirty-four hills of potatoes were hand dug and weighed separately. Each hill had a plant on each side of it. The yields ranged from 1.27 pounds per plant to as high as 8.27 pounds per plant. If the smallest yield found is

YIELD PER HILL AND CWT/A - 20,055 PLANTS/A

	LBS/PLANT	CWT/A
MIN.	1.27	255
MEAN.	4.31	865
MAX.	8.27	1658

BASED ON 34 INDIVIDUALLY HARVESTED HILLS

Table 1

multiplied to an acre, the yield would be 255 CWT per acre. If the largest yield found on a plant is multiplied to an acre basis, the yield would be 1658 CWT per acre. If the yield of the 34 plants is averaged and the average yield per plant is multiplied to an acre basis, the yield would be 865 CWT per acre.

Size of seed piece is believed to be partially responsible for some of the differences in yield among potato hills (fig. 14). As the size of the seed piece increased from 10 to 60 grams, there was over a 100 CWT per acre increase in yield in 1965. In 1964, there was a late spring frost, some seed piece decay occurred, and there wasn't enough food left in the small pieces to put out a second plant. These responses to seed piece size do not occur, however, if fertilizer is limiting growth.

Diseases which destroy, or partially destroy a plant may also be part of the cause for the low yields produced by some hills. Sometimes the stems are killed by the Verticillium Wilt organism, others by Rhizoctonia, and still others by Sclerotinia. While some stems are dead in a hill, others are green. So far climatic conditions of the Columbia Basin, the necessity for high levels of all the necessary plant nutrients, soil pathological problems, plant populations and size of seed piece have been stressed as factors important in the production of high quality potato yields. With the increasing amount of potatoes being processed, a variey other than the Russet Burbank should be considered. Though some selections seemed promising, the Russet Burbank inspite of its many shortcomings, still has much to offer.

Figure 15 shows named varieties and selections of potatoes currently being tried in our tests. We planted enough 369.55-3 in 1966 to run a commercial processing trial, providing it does well in the 1966 variety trial. The varieties shown in this figure were planted April 28 and the plants were dead by September 30. They were dug October 2. They were fertilized with 350 pounds N, 393 pounds P_2O_5, and 312 pounds K_2O per acre. July 2, the experiment was put on a 5 day irrigation rotation. On August 5, it was changed to a seven day r otation and September 10, the water was shut off for the season. June 25, July 7, and July 22 the test was dusted with Thiodan and Sulfur. On August 23, it was sprayed with Thiodan and Zineb.

The preceding is a list of the cultural practices used to produce the high yields in Figure 15.

Again let me emphasize that high results and high quality are not the result of one factor alone but rather the integration of all essential factors.

FIG. 1.--SOME 17 FACTORS AFFECT POTATO YIELD AND QUALITY, SOME UNCONTROLLED, OTHERS MORE OR LESS GROWER CONTROLLED.

1. FROST FREE PERIOD
2. AIR TEMPERATURE
3. SOIL TEMPERATURE
4. LIGHT INTENSITY
5. DAYLENGTH
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

(8–17:) MORE OR LESS GROWER CONTROLLED

Fig. 2.--Relative yields per acre of some potato producing states.

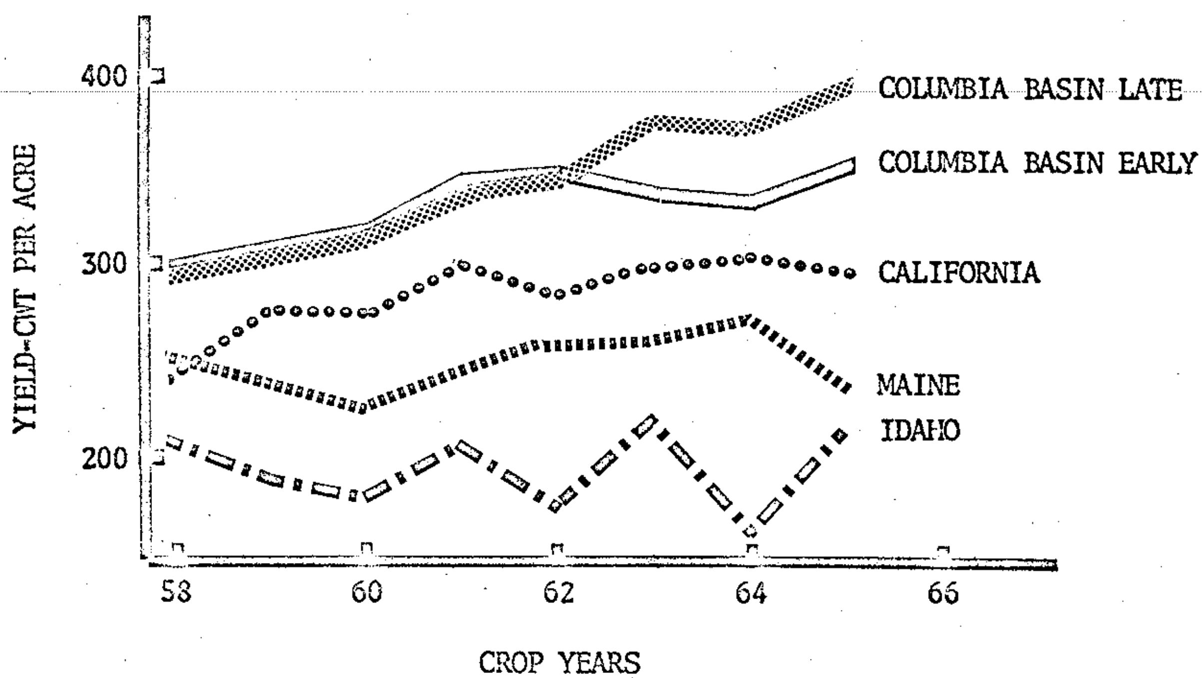

Fig. 3.--The rate of an enzymatic action goes faster as the temperature increases.

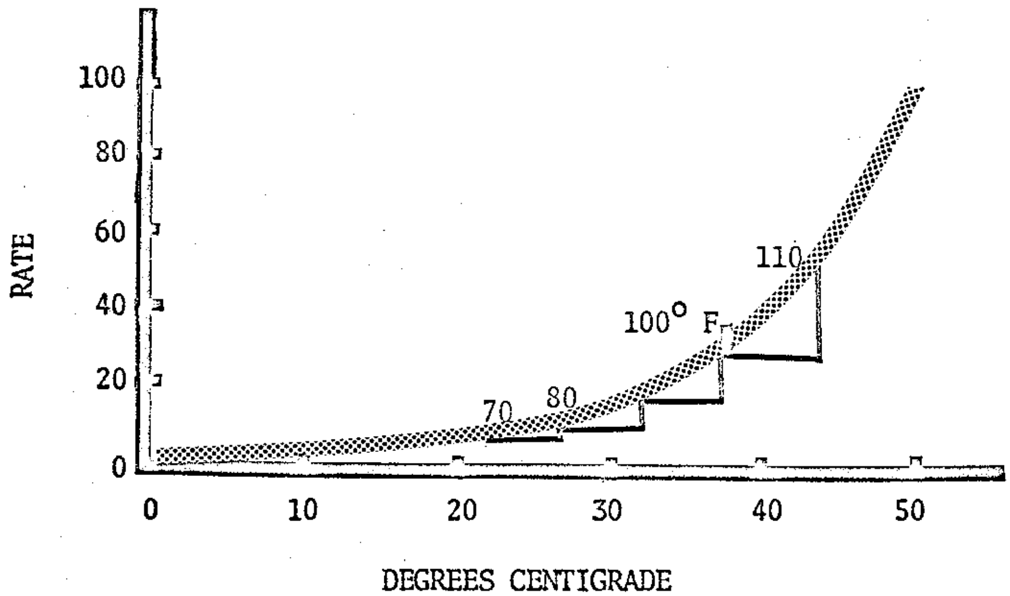

Fig. 4.--A simplified expression of what it takes to produce large yields of high dry matter content potatoes.

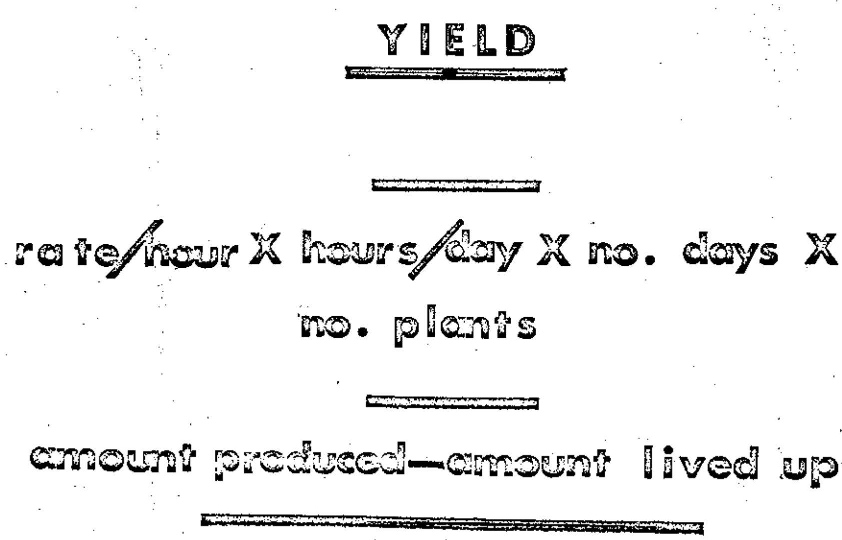

Fig. 5.--An approximation of the amount of nitrogen, phosphorus and potassium contained in the total potato plant for different yields.

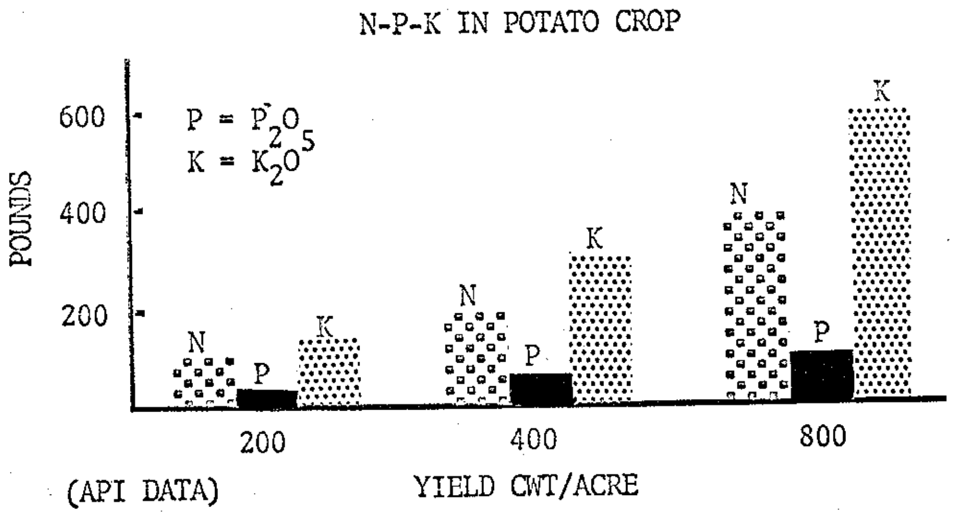

Fig. 6.--The amount of plant food required depends upon when the crop is to be harvested.

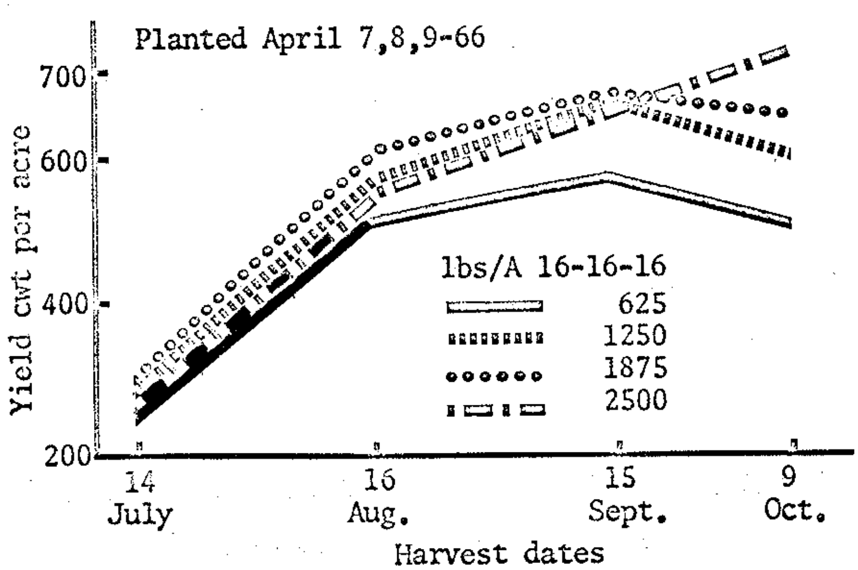

Fig. 7.--Specific gravities of potatoes at different periods of harvest and with varying amounts of fertilizer.

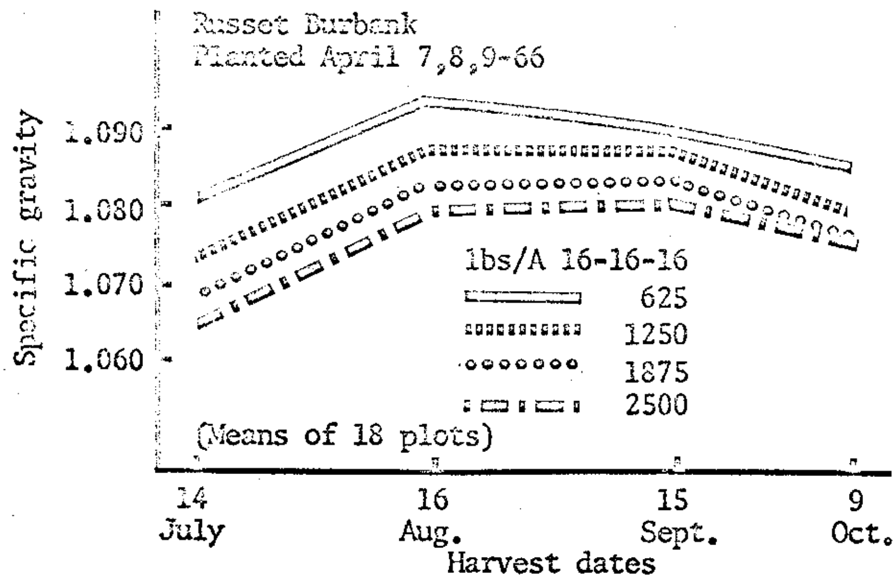

Fig. 8.--Soil variability is a major problem in obtaining a soil sample on which to base a fertilizer recommendation.

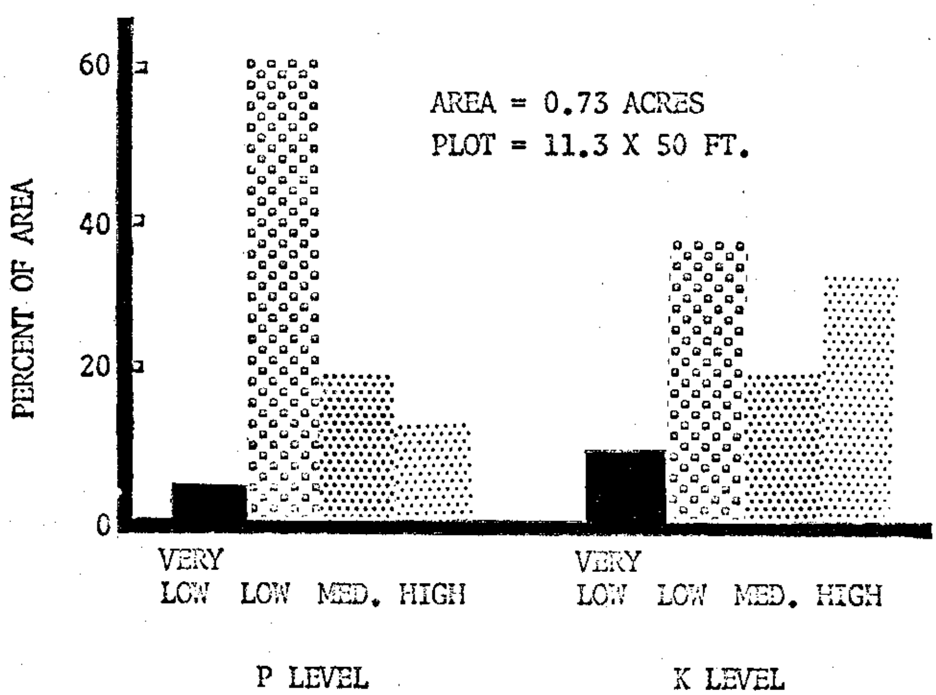

Fig. 9.--The same fertilizer does NOT ALWAYS produce the same results.

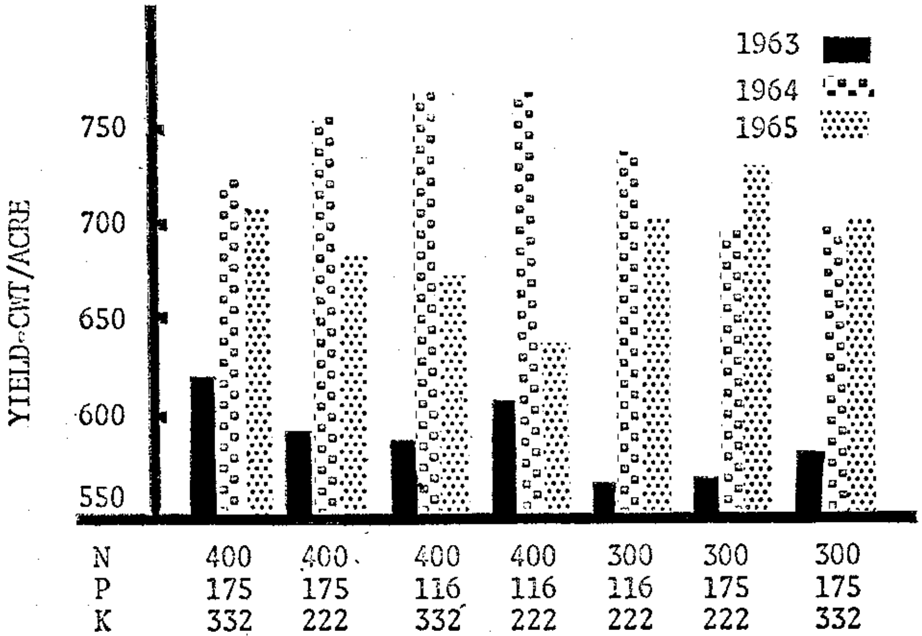

Fig. 10.--Plants to feed and not acres to fertilize is a guiding principle in determining how much fertilizer to use.

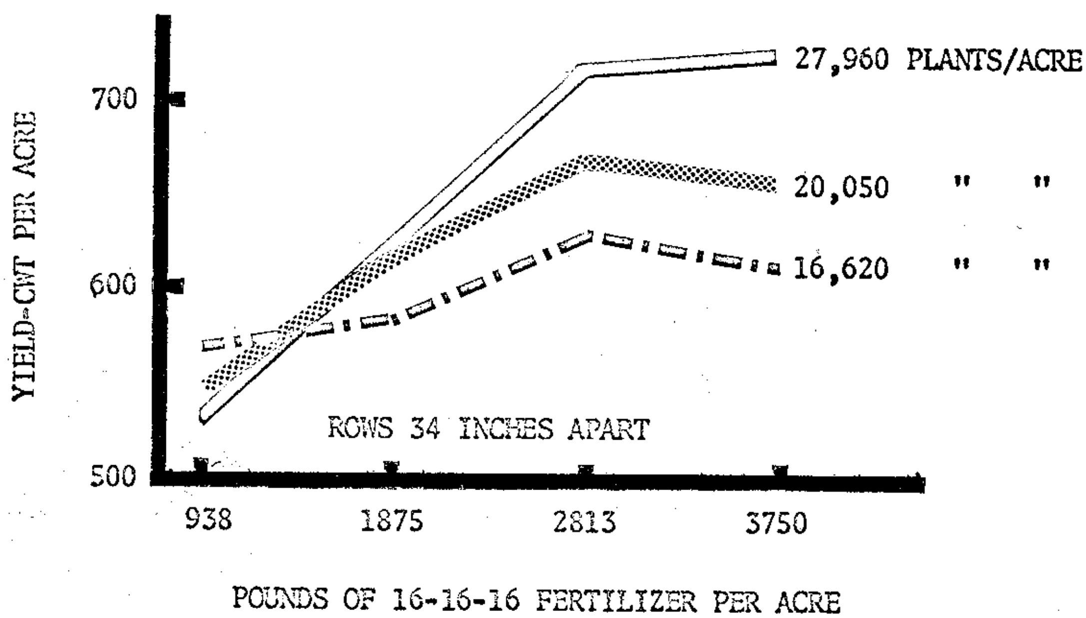

Fig. 11.--There was no response in yield to increased amounts of nitrogen when phosphorus was adequate and potassium was limiting.

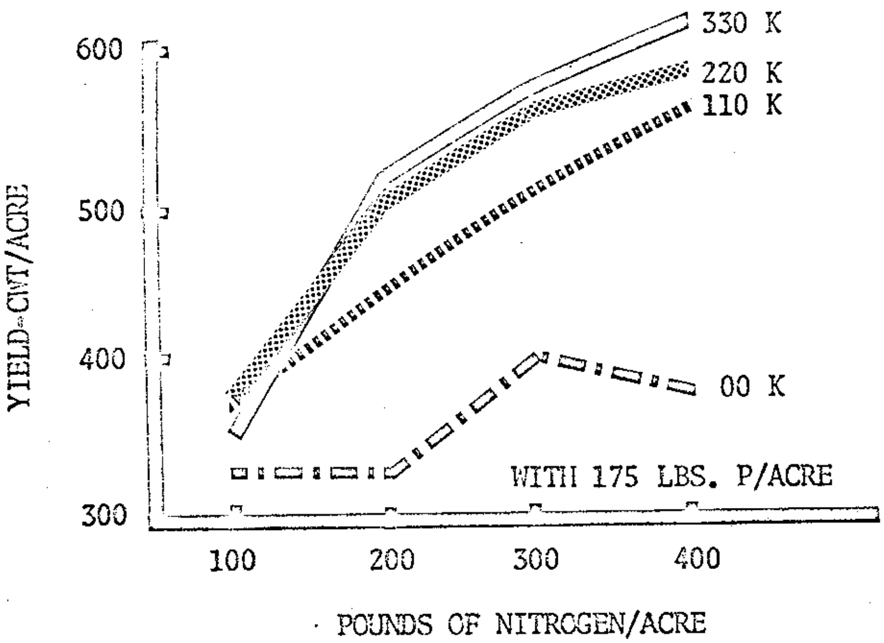

Fig. 12.--The effect of large quantities of a triple 16 fertilizer on the yield and quality of Russet Burbank potatoes.

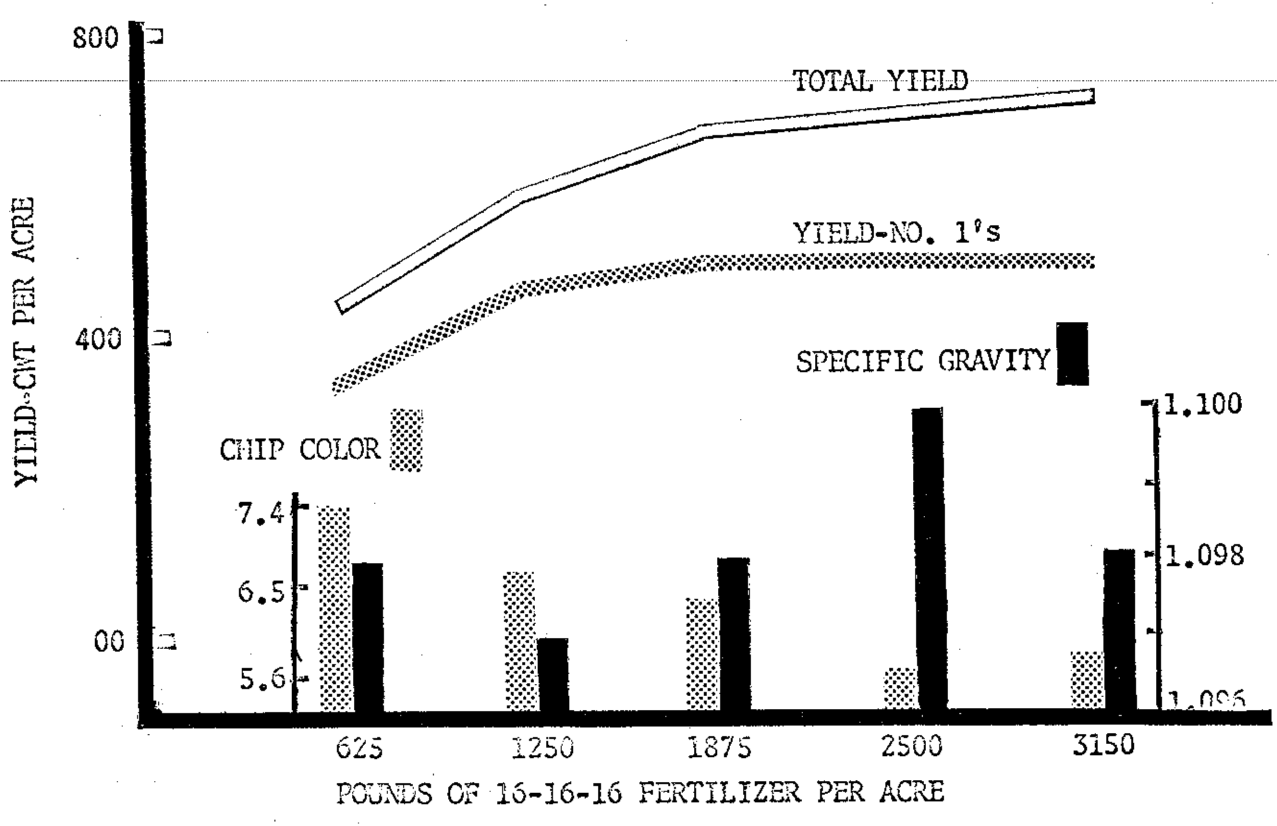

Fig. 13.--Good fertilizer and cultural practices may not increase the yield of potatoes because some unknown factor is controlling the response.

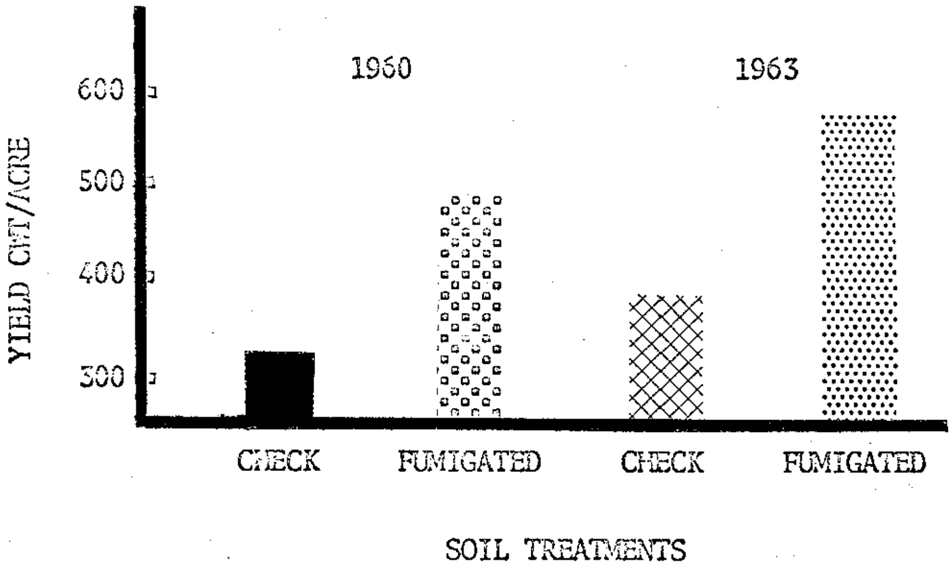

Fig. 14.--Increases in yield of potatoes resulted from increasing the size of the seed piece.

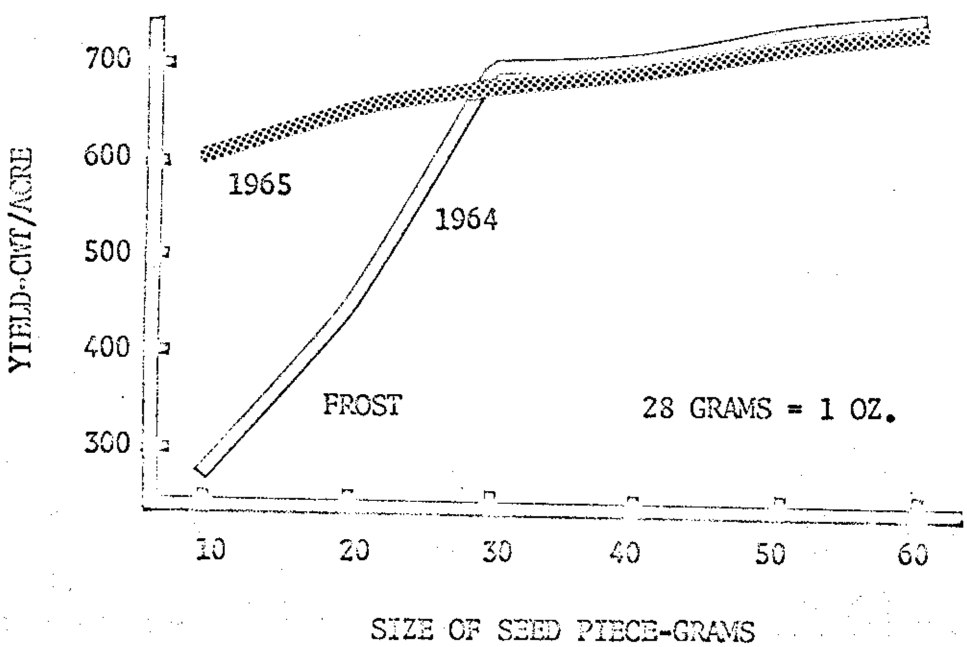

Fig. 15.--The testing of new potato varieties may eventually result in higher production of commercial varieties.