SUNSHINE, SUPERSTITION, AND SPECIFIC GRAVITY

by
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The measurement of specific gravity as an estimate of potato tuber quality has been performed in this country since at least the early 1920's. It has been used primarily because of its generally good correlation to dry matter or, more particularly, starch content of the tuber. The specific gravity measurement is relatively easy compared to the laboratory oriented procedures used for starch or dry matter determinations and thus makes a rapid method to estimate the quality of the raw product. The use of specific gravity clauses in processor contracts in the past six years has resulted in renewed interest in this subject. The following information has been compiled in order to summarize the evidence developed during the 20th century by scientists throughout the world concerning factors which influence specific gravity or, more precisely, dry matter content of potato tubers.

Perhaps the single most obvious factor affecting dry matter content of the raw product are those which are genetically controlled. The selection of a variety with the proper genetic makeup is essential if a high dry matter product is desired. The following table illustrates how varieties may differ in both yield potential and dry matter potential although the two may not be related (22).

Variety	Cwt/Acre	Specific Gravity
396.55-3	1003	1.082
A503-42	976	1.093
Red Skin	964	1.079
Kennebec	895	1.087
Golden Cup	889	1.090
Russet Burbank	790	1.096

It is important to note at this time that the dry matter content may not always remain at the highest point reached during the season until harvest. The date of sampling for dry matter potential may be more important than some people realize. Further comments on this subject will follow in this discussion.

Although data is not plentiful on the influence of soil type on dry matter content of tubers, it has been suggested that medium or light textured soils may give higher dry matter content at times (33). This apparent effect of soil texture may be due more to different cultural practices used on these soil types rather than to the soil type itself.

The results of the survey by Ohms (33) indicate that increased plowing depth increased both yield and specific gravity of tubers. Although the results seem relatively clear cut, the reason that deeper plowing increases yield or dry matter was not provided by the author.

The use of different varieties and changes in the use of fertilizers are two of the most important factors leading to high yields and quality of potatoes in the United States (other factors including pesticide useage are also important). Researchers have studied the influence of fertilizers in almost every conceivable combination to determine their effects on yield and dry matter. The following is a summary of some of the major findings accompanied by specific examples. There are those who will argue that unless the experimental information resulted from research performed in Washington's Columbia Basin with Russet Burbank under center pivot irrigation, it has little or no application to our situation. Analysis of research conducted in Washington during the past 20 years and comparing this with results from other areas, I conclude that the primary difference between this area and others is the increased quantity and quality of the product produced.

Research indicates that a 25-ton crop of potatoes will remove 225-300 lbs. (21) of nitrogen from the soil in the tubers alone. The amount of nitrogen fertilizer that needs to be applied to produce this size of crop will depend on how much leaching is expected and other factors which reduce nitrogen utilization by the plant. Excessive amounts of nitrogen maintain plants in a vegetative state which will delay tuber set and cause the plant to use its carbohydrates produced in photosynthesis for production of new leaves instead of filling tubers. It is extremely important to maintain plants in a healthy state, but it is also important to realize that over fertilization can result in reduced yield and reduced dry matter. Two other elements used as fertilizer in large quantities are phosphorous and potassium. Phosphorous seems to have little effect on the dry matter content of potatoes and, therefore, needs little discussion here. Potassium, on the other hand, can affect quite drastically the dry matter of tubers. It has been known for many years that high rates of potassium generally result in tubers of lower (1, 4, 24, 17) dry matter content. Except in a very few cases, increasing amounts of potassium fertilizer caused reduced dry matter content of the tubers. The effect of potassium fertilizer is further complicated by the fact that the source of potassium fertilizer may also have an influence on the final level of dry matter produced (9, 11, 12). The chlorine form of potassium seems to reduce dry matter in the tubers to a greater degree than does the sulfate form. The chlorine form of potassium fertilizer seems to have its effect by reducing transport of carbohydrates from the leaves to the tubers (6). Although correlations between increased or reduced ratios of various mineral elements when potassium fertilizer is increased have been found, the reason for decreased transport of carbohydrate is still uncertain (6).

The effect of minor elements have been studied to a lesser extent and perhaps should be evaluated more thoroughly before any definite conclusions are drawn. Sawyer and Dallyn (35) have shown that boron (3 lbs/acre), when used in conjuntion with 140 lbs. per acre of potassium resulted in somewhat lower dry matter. Smith and Nash (39) found that a low level of manganese or magnesium in the nutrient solutions of their experiments resulted in lower starch content of the tubers. These experiments are somewhat inconclusive, however, because other research has shown no effect of added magnesium in the field (7, 31).

The number of plants per acre may have some influence on the dry matter of the tubers. One study indicates that tuber number and yield were not affected, but dry matter content decreased as plant density increased (28). The indications here seem to be that leaf shading may have reduced carbohydrate synthesis disproportionate to the uptake of nutrients and water in the high density planting. The effects of irrigation on dry matter content of tubers are more difficult to summarize. Because of weather differences, arbitrary treatments, such as days between irrigations, date of last irrigation, date of first irrigation or amount of water applied, little insight into their general effects is gained. It has been shown that in Washington and Utah that dry conditions or less frequent irrigations may result in lower dry matter especially when accompanied with high fertilizer application. (8, 23).

Cooling crops by mist irrigation has been shown to increase dry matter content of potato tubers under experimented conditions especially during warm growing seasons (34).

Herbicides, some of which are growth regulators, are suspected at times to reduce or conversely increase dry matter of tubers (33). Killing vines with chemicals or mechanically removing them with a roto beater has been shown to decrease specific gravity of tubers compared to those harvested at the same time from green vines (3).

One of the interesting correlations that occurs but is not readily explained is the relationship between specific gravity and blackspot bruises. It has been shown that the higher the specific gravity, generally, the higher is the susceptability to blackspot. This correlation may exist because of some common factor which affects blackspot and specific gravity in opposite ways or it may be mere coincidence (17, 24). Because the relationship has been observed consistently, it is highly likely that there is a common factor which influences them. It has been shown that potato tubers from low potassium fertilizer plots are higher in tyrosine and tryptophan (39). The enzymatic conversion of these two amino acids to melanin results in the black color in the bruised tissue we refer to as blackspot. As has already been noted, low potassium generally results in higher specific gravity. Thus, the relationship may be explained by this observation.

With this review of the factors normally considered to be grower controllable or at least directly under the influence of management decisions, a look at the basic growth processes of the potato plant is in order. This will help evaluate how the controllable factors may be altered to meet each individual's needs and to demonstrate the influence of some of the non-controllable factors in potato production.

Until emergence, the potato plant lives on reserves stored in the seed piece. For this reason, it is extremely important to use seed that is of high productivity potential. At this point, we do not understand all the factors in the seed piece that determines its potential for high or low production. However, there are many factors which occur during the growth of the seed crop and its subsequent storage which can influence its productivity (4, 10, 13, 14, 15, 16, 24, 35, 36, 38, 39, 40).

After the plant emerges from the soil, it begins the process of photosynthesis which will ultimately determine the yield produced. The rate of photosynthesis can be measured during the growing season. From these measurements, we find that the photosynthetic rate per unit leaf area is not constant throughout the season (28). During active stages of growth, the rate of photosynthesis increases. We do not fully understand whether growth causes an increase in photosynthesis or if increased photosynthesis causes more growth. There is no doubt, however, that dry matter will not be accumulated in the tubers without rates of photosynthesis that will supply the foliage with its needs and have sufficient amounts of carbohydrate to transport to the tubers.

The total leaf area and the total time which the leaves are functional and attached to the plant will determine how much carbohydrate is produced per plant. Figure 2 taken from McCollum (31) shows that leaf area increases rapidly after emergence, reaches a peak, and then decreases dramatically. The time which the leaves remain on the plant is directly related to yield according to McCollum.

Once the carbohydrate is formed in the leaves, the plant has several options as to what can be done with it. The following is a list of those options:

1. Stored in the leaves as starch.
2. Used up by the leaves in respiration.
3. Transported to new vegetative areas for growth.
4. Transported to tubers for growth.
5. Stored in the tubers as starch.
6. Respired away in the tubers.
7. Transported back to the leaves after movement to the tubers.

Any or all of these options are occurring in the plant at any one time. The extent to which each of the options take place will determine the ultimate yield and dry matter composition of the tubers.

Another look at the McCollum's work (as well as many others), shows that tubers begin to form shortly after the leaf area begins to increase rapidly (point A, Figure 3). Tuber development begins to level off shortly after the leaf area begins to decrease (point B, Figure 3). This is total tuber yield, a measure of productivity which is of great value. However, if the dry matter in individual tubers is determined, it becomes apparent that the dry matter has not been divided equally among all the tubers even though they are on the same plant (Table 1). This table shows that there is a range of specific gravity from 1.061 to 1.114 and that there is no relationship between the size of the tuber and its specific gravity. It should be interesting to find out why this is the case. A study by Smith and Nash (39) showed that not only were tubers different in dry matter content, but the dry matter content increased in some tubers and decreased in others during the season (Figure 4). This phenomenon is known to most people who have grown potatoes and is referred to as "reabsorption" or tuber drop. The factors that affect this basic phenomenon dictate the final quality and quantity of tubers produced.

Time of tuber initiation: In order to obtain maximum yields and quality, tubers should be initiated as soon as the plant is large enough to supply carbohydrates to them without adversely limiting foliage development. This period would be at about 50% of the anticipated leaf area as in Figure 3, point A. Some factors which will influence the rate in which 50% of the leaf area is reached are: 1. weather, 2. age of seed, 3. fertility, and 4. irrigation. Assuming that good seed has been procured and there is nothing we can do about the weather (after planting), what affect does fertility and irrigation have? The effects of irrigation on tuber set have not been thoroughly investigated and, therefore, we cannot provide good evidence for its use here. Fertility levels have been studied and it is well known that if one uses high rates of fertilizer, particularly nitrogen, that tuberization is delayed (18, 40). A second effect that is caused by nitrogen and perhaps potassium is that when applied in excessive amounts, they may promote the transport of carbohydrates to the foliage rather than to the tubers. The reasons for this is still not understood although the effect, lower yields and lower dry matter are very evident.

Tuber growth: After the tubers are initiated, they have some ability to control not only the rate of photosynthesis, but also may control partially the movement of the carbohydrate that is produced during photosynthesis. During the tuber bulking period, it is crucial that the plant not be stressed or caused to revert to high foliage growth production at the expense of tuber growth. What are some of the conditions which can influence dry matter production during this phase of growth? The processes of photosynthesis and respiration work are essentially opposite directions (Figure 5a and b). One is manufacturing dry matter and the other is breaking down. Photosynthetic rates of leaves reach a maximum somewhere between 70° and 78°F whereas respiration continues to increase well beyond these temperatures. The net result may be that when temperatures of the potato leaf are greater than 80°F, the rate of dry matter production begins to decrease. There is, of course, a point where photosynthesis completely stops and respiration continues. At this point, dry matter in the tubers is broken down and transported to the foliage and/or the foliage dies due to excessive stress. If dry matter in the tuber is transported to the leaves, yield may not have changed appreciably but the amount of dry matter in the tuber has been altered according to the magnitude of the stress. If, at this time when the tubers may have a momentary cessation of growth, water and fertilizer are added, we may obtain misshapen tubers or we may initiate new vine growth which could further reduce tuber dry matter content or cause a delay in further dry matter accumulation.

There have been many studies which have shown the effects of weather on specific gravity of potatoes. Kunkel et al. (19) showed that while fertility had little effect on specific gravity, the difference between years of experimentation was highly significant. Studies at three locations in Idaho between 1951 and 1955 indicated that not only was total dry matter content of tubers different between years, but dry matter accumulation curves derived from different sampling dates were also of different shapes (2). Results compiled from variety trials conducted in North Dakota, Idaho, New York, California and Washington during the years 1974 through 1977 showed that there were significant differences between years with all states showing a rather marked drop in specific gravities in 1977 (Table 2). The general explanation that can be found for decreased specific gravities in these studies as well as others is that high temperatures occurred during the critical period of tuber bulking. This is also a time in which diseases may greatly affect the crop and could also be a major contributing factor. With limited information available on the subject, it is somewhat likely that a stress incurred by the potato plant during the tuber development stage of growth may actually predispose the potato plant to disease or certainly hasten the effects of the disease organism (2). Soil temperature may affect specific gravity of the tubers as does air temperature. California workers showed that increasing soil temperatures from 65-85°F caused a 37% decrease in specific gravity (44).

Although no explanation was made by the authors, it is likely that increased water uptake and increased tuber respiration may have caused the decrease in specific gravity. This seems apparent because the low specific gravity tubers were generally larger than the high specific gravity tubers from the low temperature treatments.

We have now presented some of the information which is available on this subject although the explanation of the observations are still, in most cases, lacking. However, we can use this information to establish a management tool for obtaining high yields and high dry matter based on what the plant is telling us. The following is a set of observations that can be used to manage a crop. These are not to be used as a set of recommendations that will fit all situations.

1. Potatoes should be planted when the soil is warm enough for germination and subsequent growth of the shoots consistent with anticipated harvest date.
2. Fertilizer should be applied to adequately carry the plant through the full leaf area stage
   a. Measure growth rate of vines (total length).
   b. Count the number of mature leaves.
   c. Count the number of tubers set.
3. If tubers do not set at the appropriate time, i.e., 50% of the leaf area, fertilizer level may be excessive.
4. Continue sampling for:
   a. vine height
   b. leaf number
   c. tuber number

   Begin sampling for:
   a. tuber weight
   b. specific gravity
5. Watch for weather extremes.
   a. Irrigate for optimum water availability during hot weather.
   b. Do not over fertilize as it may accentuate the stress condition.
6. If vine growth continues at a high rate and tuber growth does not, reduction of fertilizer may be appropriate.
7. Continue measurements to predict harvest date according to yield and dry matter content.
8. If the vines die due to disease, subsequent irrigation to maintain tuber turgor and soil moisture may be needed. Sampling at this time is also important to determine if irrigation is affecting yield or dry matter.

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Table 1. Variability

Weight of Tuber Gro.	Spec. Grav.	Weight	Spec. Grav.
70	1.061	219	1.091
73	1.099	272	1.106
89	1.067	317	1.077
96	1.073	333	1.102
97	1.096	378	1.089
115	1.114	439	1.086
132	1.091		

R = .179

Künkel (22)

Table 2. The effect of years on specific gravity of tubers from variety trials at five locations.

	1974	1975	1976	1977
N. Dakota	1.076	1.089	1.091	1.079
Idaho	1.088	1.083	1.079	1.076
New York	1.068	1.076	1.077	1.071
Wash.	1.085	1.078	1.082	1.075
Calif.	----	1.080	1.082	1.079

Compiled from annual reports of the USDA potato breeding program.

Figure 1.

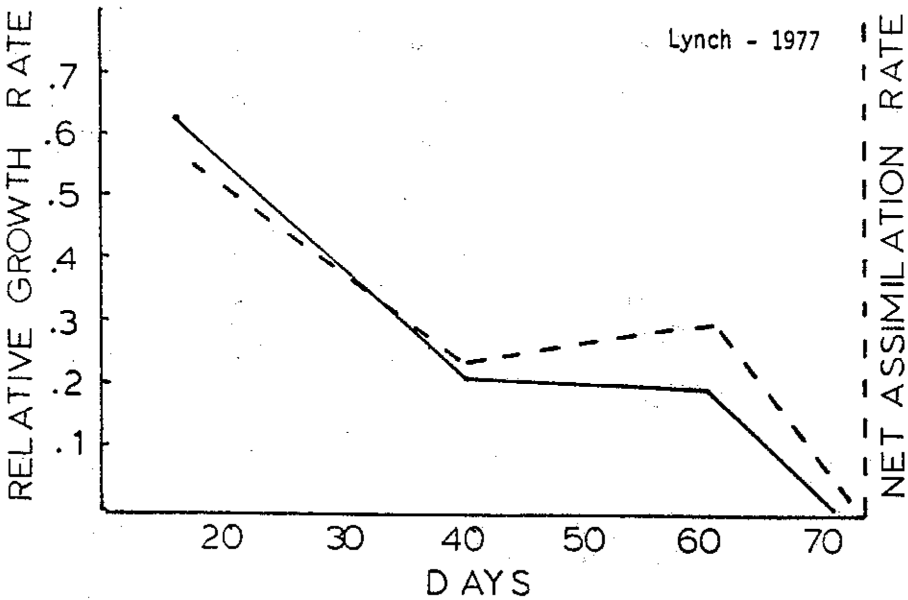


Figure 2.

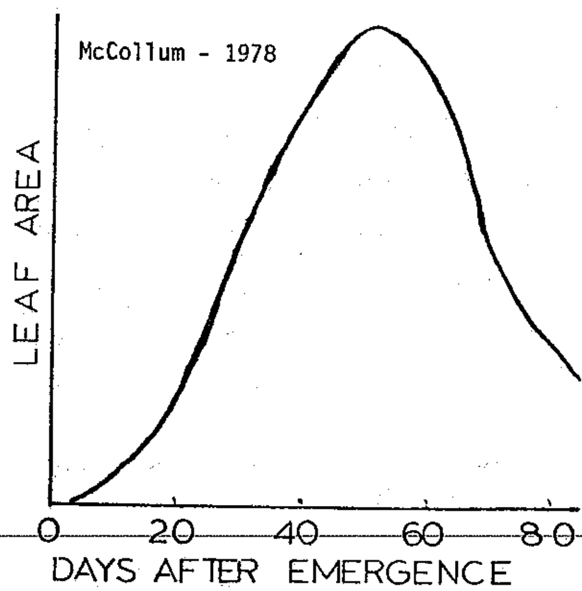
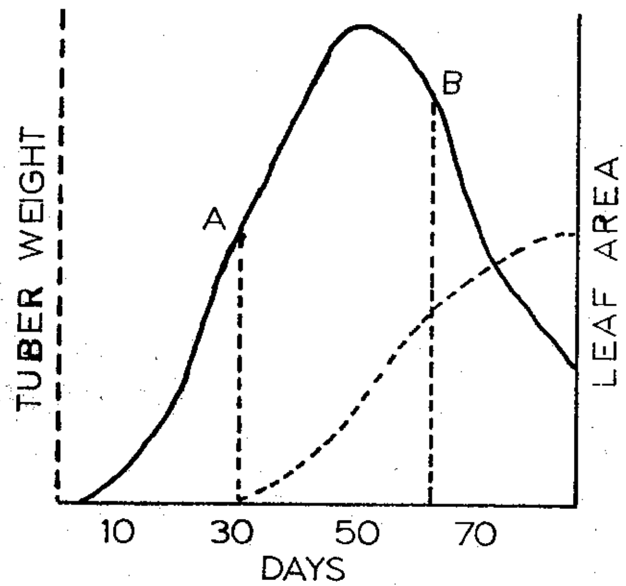


Figure 3.



From McCollum, 1978.

Figure 5a.

Photosynthesis

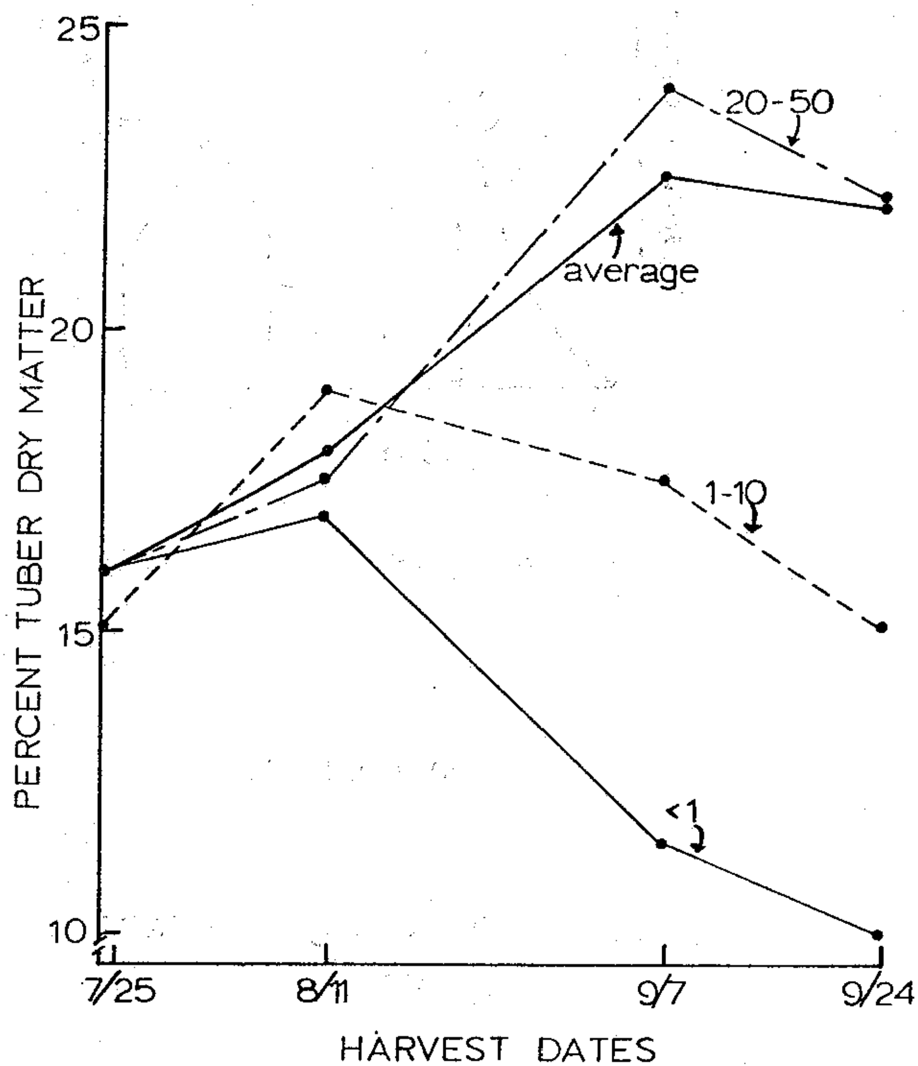
$CO_2 + H_2O$ ------> SUGARS
sunlight

Figure 5b.

Respiration

SUGARS ------> $CO_2 + H_2O$
high
temperatures

Figure 4.



Lines indicate size of tubers in grams.

Smith and Nash (37)