PHYSIOLOGY OF HEAT AND WATER STRESS

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The past few years have not been particularly good in terms of overall potato yield and quality for many growers. The most common explanation for this situation is that uncharacteristic stretches of hot weather have caused heat and water stress to damage the crop. However, this basic premise does not explain why some growers tend to have good crops almost every year, while their neighbors may struggle to produce a saleable crop. What are these successful growers doing to minimize the impacts of stress on the yield and quality of their potato crops? To answer this question it is important to understand three things: what stress is, how it affects some of the basic physiological plant processes and how crop management impacts the response to stress.

WHAT IS STRESS?

Stress can be defined as any condition that is above or below the optimum for plant growth and tuber production. Potatoes actually have a fairly low optimum growth temperature and it is likely that they experience some heat stress even during seasons when temperatures are more "normal." The optimum day/night temperatures for potato growth are generally considered to be 77/54^{o}F. However, at any given daytime temperature there is a corresponding optimum night temperature. As the day temperature increases, a larger difference between day and night temperatures is required for optimum growth.

There is also a very close association between heat and water stress. In fact, it is very difficult to separate these two types of stress. Crop water use increases greatly with increasing temperature, resulting in rapid depletion of soil moisture. As the soil dries out a couple of things happen. First, the pores on the leaf responsible for evaporative cooling start to close, resulting in an increase in leaf temperature. Evaporative cooling is also an important factor in soil temperature, so the drier the soil, the closer the soil temperature will be to the air temperature. Kleinkopf (1988) was able to show that increasing soil temperatures by as little as 6 to 9^{o}F during tuber initiation was enough to greatly reduce tuber yield and quality (Figure 1).

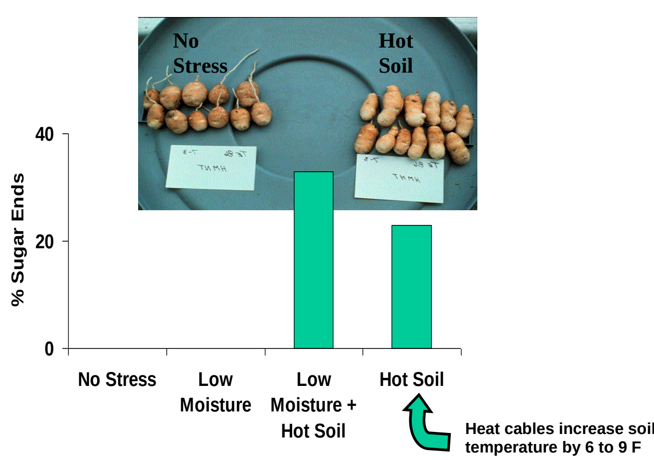

Figure 1. Effect of increasing soil temperatures on tuber yield and quality

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HOW DOES STRESS AFFECT PHYSIOLOGY?

The potato plant is basically a starch factory. In fact, over 90% of the dry weight of a potato tuber is a direct result of a process called photosynthesis by which the plant uses sunlight, carbon dioxide and water to produce starch. Part of this starch gets broken down and used to keep the plant alive through a process called respiration. Respiration is also important in the growth processes that produce new leaves, tubers and other tissues. As temperature increases, the rate of respiration goes up dramatically, while at the same time photosynthesis declines. Respiration continues at night, while photosynthesis drops to zero. So, during warm nights much of the starch produced during the day is burned up in respiration. The net result is that at high temperatures there is less starch available to drive plant and tuber growth. Because high temperatures promote vine growth, there is also a tendency for more of the starch available for growth to go towards the vines, at the expense of tuber growth.

At the same time that photosynthesis is decreasing due to high temperatures, the demand for water by the plant for cooling is increasing. As evapotranspiration increases, available soil moisture decreases more rapidly resulting in plant stress. Plants will experience stress sooner at a high evapotranspiration rate as compared with a lower rate. As a result of high evaporative demand, plants respond by closing the leaf pores, further limiting photosynthesis due to lack of carbon dioxide inside the leaf. People often comment that the plant has “shut down” when daytime temperatures exceed a certain point, usually around 90^{o}F. In fact, this statement is a little bit misleading. Dwelle (1981) showed that even on a warm day there is a substantial period of time in the morning when photosynthesis churns along at a very high rate (Figure 2). In the afternoon, the photosynthesis rate dropped dramatically when leaf temperatures exceeded 85^{o}F, a period he called the “mid-day depression”. However, it is important to note that the plant never completely shuts down in the sense that photosynthesis did not drop to zero. The net result is that, even on warm days, there is some net starch production that should be available to drive growth and keep the plant alive.

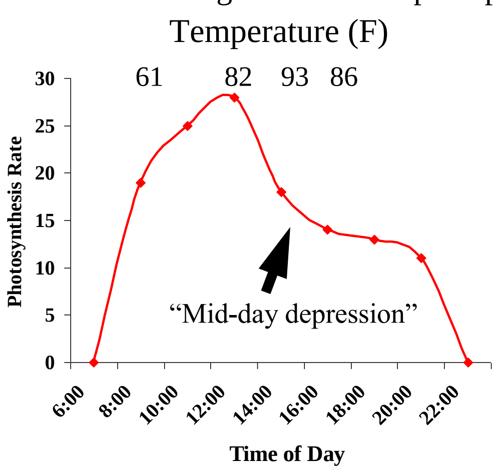

Figure 2. Profile of photosynthetic rates of potato leaves during a typical day in Eastern Idaho

So if there is starch available for tuber growth, why do high temperatures result in lower yield and specific gravity? The answer may be tied to recent evidence that high soil temperatures have a direct effect on the fate of sugars that are transported from the leaf to the tubers. High soil temperatures reduce the activity of the enzyme that converts sucrose (the form of sugar transported from leaves to tubers) to starch (the main storage form of carbohydrate in the tuber). Sucrose is transported to various organs within the plant along a gradient. When the tuber has trouble converting sucrose into starch it results in a signal being sent back to the leaves to divert resources to other plant parts that can use it. The damage to the enzyme system seems to be permanent, as even a transient stress during the period of early to mid bulking can result in a reduction in tuber quality due to sugar ends. The work of Kleinkopf shown in figure 1 clearly illustrates that high soil temperature by itself is adequate to cause this kind of damage to the starch production system within the tuber. Water stress combined with high soil temperatures makes the problem even worse.

Stressed potatoes often exhibit high levels of internal and external defects, as well as low specific gravities. Stress that occurs during the early part of tuber bulking, when tubers are about the size of a golf ball, causes the highest incidence of sugar ends (Figure 3). One of the most obvious signs that potatoes have been stressed is an increase in the proportion of misshapen tubers, such as pointed ends, knobs and dumb bells. During stress, the low availability of starch and/or nutrients may temporarily stop tuber growth. When growth resumes, it occurs at the site of most active cell growth. The end result is malformed tubers.

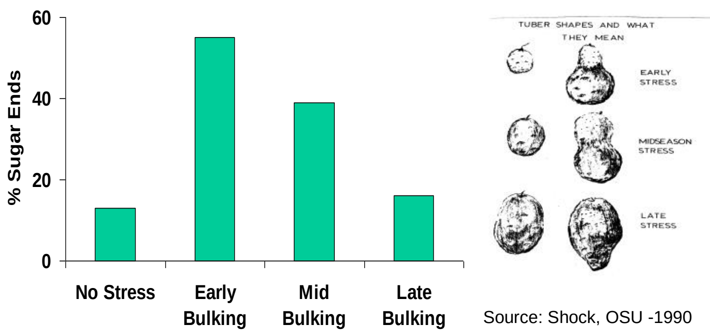

Figure 3. The timing of stress as it relates to percent of tubers with sugar ends.

HOW DOES CROP MANAGEMENT AFFECT THE RESPONSE TO STRESS?

Stress conditions can be imposed by the environment (heat, hail, frost) or by management practices (over-or under-fertilization, root pruning during cultivation, irrigation scheduling). Growers do not have any control over the environmental stresses that occur during a season, but they can compound these problems by some of the management decisions they make. The management practices that are most important are those that impact root development (ability to supply water to the plant from the soil), early and late ground cover (provides shading to cool the soil), or that results in excessive vine development (increases the demand for water).

Most of the attention on early season management has been on avoiding irrigation management mistakes that result in water stress. However, water supply is only one piece of the equation. The plant also has to have an adequate root system to be able to extract enough water from the soil to supply plant needs. Recent research in Europe shows that soil compaction has a much greater effect on early season root growth than previously thought (Stalham and Allen, 2001). The first 60 days after planting is a critical time for root growth. It has been shown in Russet Burbank that the majority of the root system develops during this time period. It is important to note that maximum root system development occurs prior to the time of highest water demand, and before most of the nitrogen is taken up by the plant. Anything that prevents the full development of the root system (compaction, root pruning, disease), will limit the plant's ability to get enough water during periods when demand is high.

A secondary effect of practices that limit root growth is that they will also slow the rate of vine growth. Compaction and dry soil conditions have been shown to directly reduce the rate of root growth, which results in a delay in the date of row closure (Figure 4). Leaf shading is a key determinant of soil temperature, and we have already shown that relatively small increases in soil temperature can have a direct effect on tuber quality. The date of row closure is dependent on many factors. One factor that may be overlooked is planting accuracy, especially the proportion of skips in a field. There is no doubt that a poor stand will take longer to reach row closure, increasing the time that the soil is exposed to heating from sunlight.

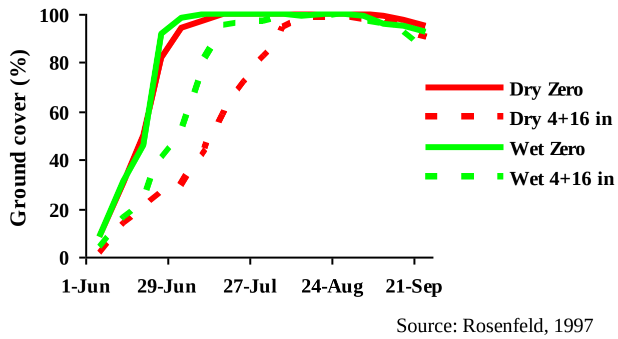

Figure 4. Effect of compaction and soil moisture on date of row closure.

A final management practice that should not be overlooked is the nitrogen fertilizer program. Excessive application of nitrogen tends to stimulate vine growth, but has very little impact on development of roots. The end result is a plant that has high demand for water due to a large leaf surface, but no additional root system to supply that demand. This effect on plant development is very similar to the response that occurs during periods of high temperature. Therefore, the combination of high temperature and high nitrogen availability will further compound the imbalance between shoot and root growth, and will increase the plants susceptibility to injury from stress.

SUMMARY

- Heat and water stress alter plant growth and restrict the availability of the starch that drives tuber growth.

- Stress that occurs during the early tuber bulking period is most damaging, and results in lower yields, reduced tuber quality and lower specific gravity.

- Management practices that result in rapid canopy and root system development can be big factors in improving yield and quality during stress.

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