EFFECT OF WATER STRESS ON POTATO GROWTH AND DEVELOPMENT

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The above-ground vegetation of potato consists of about 90% water. A very small portion (1%) of this water is actually required for metabolic processes in the plant. The remainder is used for transpiration, the process of water movement into the roots, up the stems to the leaves, and out the leaves to the atmosphere. Water exits the leaves through small pores, called stomata, on the upper and lower leaf surfaces. Transpiration serves as a thermal regulator for plants by cooling them down when temperature becomes excessive.

Potatoes are very sensitive to drought and water stress (Van Loon, 1981). Compared to other crop plants, they close their stomata at very minor soil moisture deficits. This prevents carbon dioxide from entering plant leaves through the stomata and therefore inhibits photosynthesis. Photosynthesis is a series of chemical reactions which occur in plant tissues and converts carbon dioxide into carbohydrates. In potatoes, the carbohydrates are used for vegetative growth and tuber bulking. Therefore, when the stomata are closed the growth of the potato plant is retarded or stopped. Under increasing soil moisture stress, the relative transpiration rate of potatoes decreases faster, movement (diffusion) of gasses through leaf stomata slows sooner, photosynthesis rate declines more quickly, and leaf water potential recovers more slowly in potatoes compared to other crops. In addition, potatoes are a relatively shallowed rooted crop. For these reasons, potatoes are categorized as very susceptible to soil moisture stress and require relatively narrow extremes in soil water content for maximum growth and development.

Water stress may affect the development of potato vines, foliage, roots and tubers. It influences development of potato plants during each growth stage: 1) vegetative, 2) tuber initiation, 3) tuber bulking, and 4) tuber maturation. In addition, several diseases and disorders of potato interact with water stress, often increasing their severity.

VEGETATIVE

Seedpieces planted in dry soil may have retarded sprout emergence and inhibited root growth. Dry soil conditions interact with Fusarium dry rot of seedpieces, typically increasing the severity of this disease and causing erratic emergence and reduced vigor of young plants. The vegetative period of growth has been reported to be shortened during soil moisture stress. Potato seedpieces should be planted in moist (60 to 80% available soil moisture) soil. Avoid irrigating up potatoes by applying a pre-plant irrigation in drought years.

One of the early effects of a constant water stress on potato plants occurs in the development of vegetative and root growth. Leaf enlargement is inhibited earlier than either photosynthesis or respiration. The rate of leaf enlargement may not return to normal after the water stress is removed. Water stress causes reduced leaf area and foliage weight due in part to reduced leaf, stem and root elongation. Leaves are typically smaller in size and darker in color. Plants have lesser height and canopy coverage of soil. In the field, potato plants with these symptoms are easily found on the perimeter of center pivots where the end-guns cannot apply sufficient water to avoid stress conditions.

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TUBER INITIATION

Tuber initiation (TI) is the period of potato development when tubers are just beginning to swell on the stolen tips and ending 10 to 14 days later. Tubers have not appreciably grown in size during this period. There are many reports of water stress during TI causing reduced number of tubers (Van Loon, 1981), although not all research consistently demonstrates this trend. For example, Miller and Martin (1987) demonstrated no effect of deficit irrigation during TI on number of tubers produced by Russet Burbank, although average tuber size and specific gravity were significantly reduced.

Mild water stress during early and midseason decreases the yield of U.S. No. 1 potatoes (Larsen, 1984) (Fig.2). Mild water stress during late season does not appear to influence U.S. No. 1 yield. The percentage U.S. No. 1 yield of Russet Burbank potatoes was most sensitive to mild water stress early in the growing season. Lemhi Russet and Nooksack showed this same general trend to mild water stress as Russet Burbank. Although both Russet Burbank and Nooksack percentage U.S. No. 1 yield are most sensitive to severe water stress during early growth stages, Lemhi Russet U.S. No. 1 yield appears most susceptible to severe stress during midseason.

Common scab of potato is a serious disease that reduces external tuber quality. It is caused by Streptomyces scabies, a soilborne filamentous bacterium which invades tubers early in the growing season following tuber initiation. One of the factors favoring common scab is dry soil during early tuber development. High soil moisture (75% available soil moisture in a silt loam) in the upper 9 inches of the soil profile for 2 to 7 weeks after emergence suppresses this disease (Davis and Garner, 1978). High soil moisture alone may be a sufficient control on fields where common scab is not a severe problem.

Brown center is a widely occurring physiological disorder of potatoes. It is characterized by pith tissues near the center of the tuber turning brown in color. Available soil moisture during TI can have a profound influence on the severity of this disorder (Ojala, et.al., 1989). Higher soil moisture during TI increases the incidence of brown center (Fig. 3). If other adverse conditions are present, brown center will develop into hollow heart. A sound water management strategy would be to avoid excessive soil moisture from irrigations during TI stage of plant growth, but also not allow soil water reserves to fall below 65% available moisture. Further information is available in University of Idaho Extension Bulletin No. 691 entitled Brown Center and Hollow Heart in Potatoes.

TUBER BULKING

Tuber bulking is the period of potato development where increases in tuber weight are constant (linear) with time if all growth factors are optimum. Fig. 4 demonstrates the influence of water deficit, expressed as a percentage of evapotranspiration (ET) applied from full canopy until harvest, on growth rate of potato top (vegetative), tuber and total biomass. The growth rate of each of these plant components decreased with increasing water stress. Tuber growth rate decreased at a greater rate than top growth rate. The inset graph in Figure 4 demonstrates partitioning between tubers and total plant biomass for two separate years. Increasing water deficit increased partitioning to tubers, but the degree of partitioning was considerably different between the two years due to high top dry matter loss from senescence (leaf dying) in the upper curve. This figure helps to explain why water stressed plants, such as those that often occur on pivot perimeters, have larger tubers early in the growing season than well watered plants inside the pivot.

A one-time mild water stress appears to influence total yields of Russet Burbank potatoes very little if it occurs during early or late season (Fig. 1). Both Russet Burbank and Lemhi Russet total yield appears most sensitive to one-time water stress (mild or severe) during midseason (Larsen, 1984).

However, in a drought year water supplies are limited. Insufficient water application may have to be allocated more than once and over more than one stage of potato growth. A study (Stark and Dwelle, 1989) was conducted in Aberdeen to determine the influence of limited water application on Russet Burbank potatoes during more than one growth stage. Irrigation deficits were imposed either full season, or during two of the three growth stages: early bulking (EB), mid bulking (MB) and late bulking (LB). Total and U.S. No. 1 yields decreased linearly for each water allocation treatment (Fig. 5). Total and U.S. No. 1 yields were most sensitive to water stress when it was allocated over the growth stages MB and LB or EB and MB. Allocation of limited water during the entire season or over both EB and LB resulted in less loss of total and U.S. No. 1 yield. This study indicates that when more than one stage of growth must receive limited water, avoid applying the water stress during mid bulking.

A study (Stark and Dwelle, 1989) was conducted last year in Aberdeen to determine if nitrogen fertilizer rates for potatoes should be reduced under conditions where water supply is limited during the entire growing season. Russet Burbank potatoes were irrigated at rates ranging from 6.3 to 23.1 inches of water for the season. Irrigation timing was the same for all treatments. Each irrigation treatment was fertilized to produce total nitrogen (i.e., soil + fertilizer N) rates ranging from 100 to 260 lbs N per acre. Severely water stressed (6.3 inches seasonal water) potatoes had little total yield response to available nitrogen (Fig. 6). Adequately watered potatoes (23.1 inches seasonal water) had much greater response to available nitrogen. Maximum yield appeared to peak at 220 lbs N per acre for most irrigation treatments. The net economic return per additional unit of nitrogen applied would be much lower for severely stressed potatoes because of the lesser response to available nitrogen.

Nitrogen and water availability separately influence specific gravity of potatoes. A study (Stark and Dwelle, 1989) was initiated last year using a line source irrigation system to evaluate the influence of these two factors on trends in specific gravity. Total water applied during the season ranged from approx. 6.3 to 23.1 inches on either side of the mainline. Total nitrogen availability (soil + fertilizer N) was placed across each water level and ranged from 100 to 260 lbs N per acre. In general, the highest specific gravity was obtained at the highest seasonal water application level (Fig. 7). When water availability was greatest (23.1 inches seasonal water), specific gravity tended to decrease with higher nitrogen application rates. The amount of decrease ranged from 4 to 8 units (1 unit = 0.001 change in specific gravity) for the two best watered treatments. The moderately water stressed treatments showed similar trends except that the extremes in specific gravity between low and high nitrogen level were smaller. Specific gravity declined as seasonal water availability decreased. At the very lowest seasonal water levels (6.3 and 10.7 inches), specific gravity tended to increase slightly with higher nitrogen application rates. The amount of increase ranged from 2 to 3 units. This study indicates the importance to specific gravity of applying adequate but not excessive nitrogen to potatoes that are either well watered or under season-long water stress.

A74114-4 and A7411-2 are two promising advanced selections in the ARS/UI Potato Breeding Program in Idaho. A study (Stark and Dwelle, 1989) conducted last year compared the responses of Russet Burbank and these selections to late-season drought. Two water stress treatments were imposed on these cultivars: full irrigation all season long and late-season (no water from August 3 to August 19) water stress. Total yields for the two advanced selections were not significantly affected by late-season water stress (Fig. 8). However, Russet Burbank total yield was reduced 49 cwt per acre by late-season stress. Specific gravity for each cultivar increased in response to the late-season stress.

MATURATION

Maturation occurs late in the growing season when leaves begin to yellow and die, and tuber growth is mainly from translocation of assimilates from leaves and roots into the tubers. Soil water deficits during this growth period increases the rate of maturation. Leaf death will occur faster under water stress conditions than if soil moisture levels are maintained high. Vine desiccation by sulfuric acid and other commonly used chemicals (except diquat) will be more effective when potato plants are water stressed.

EFFECT ON TUBER SHAPE

Water stress can influence the shape and external quality of tubers. These changes in tuber shape and appearance are called physiological disorders. Malformations are one type of physiological disorder and in general include secondary growth, misshapen or rough tubers. Secondary growth can be divided further into longitudinal (along the length of the tuber) or lateral (growths laterally away from the tuber). These types of disorders are not caused by living organisms and typically involve interactions between physiological factors and adverse environmental or growing conditions. Many types of physiological disorders are associated with, but not necessarily solely caused by, water stress. Below is a brief description of some of the more common of these disorders affecting external tuber shape of the Russet Burbank variety.

The Marketable Potato - The shape of an ideal russet potato will depend on its market destination and consumer preferences. Freshpackers often prefer a smooth, oblong potato with few shallow eyes so it is easy to peel by the housewife. Potatoes destined for french fry processing are desired to be longer and larger. Both uses require a potato with few external defects from malformed growth or diseases. Seed potatoes in a lot are preferred to be uniform size and shape and with few malformations so that seedpiece size distribution is more uniform during cutting. Eyes in seed potatoes would be numerous and well distributed across the tuber.

Pointed Stem-end - A type of longitudinal secondary growth. Pointed stem-end potatoes have normal tuber appearance except that the stem-end narrows in diameter. Cause: Restricted growth of tubers early in the growing season, often but not necessarily only caused by water stress. Control: provide uniform soil moisture availability and uniform growing conditions during early tuber bulking growth stage.

Bottleneck - Both bottlenecks and pointed stem-ends occur when early season stress restricts the development of tubers. When bulking begins again at normal rates, the stem-end is smaller than the bud-end of the tuber. Bottlenecks are a type of secondary longitudinal growth that frequently have a curve shape and starch content partially or completely depleted in the stem-end. Translucent end or jelly-end may develop in bottleneck potatoes. Bottlenecks occur less frequently do to superior irrigation management than used in the past. Cause: Moisture stress during early stages of tuber growth. Control: Proper timing and duration of irrigations to avoid soil moisture stress during early plant development.

Dumbbells - A type of longitudinal secondary growth. The typical dumbbell potato has a constriction near the center of the tuber with stem-end and bud-end bulbous and approximately the same size. Often the tuber is curved. Cause: Interruption of tuber growth during midseason promotes the development of dumbbell shaped potatoes. Control: Proper irrigation scheduling during midseason to maintain adequate soil moisture levels. Other environmental factors that affect midseason bulking rates may also be involved.

Pointed Bud-end - A type of secondary longitudinal growth. Pointed bud-end potatoes have normal tuber appearance except that the bud-end narrows in diameter. The bud-end may constrict to the size of a pencil or develop into a bulbous growth. In many cases there is a nipple-like growth of the distal rosette of buds. Cause: Restricted growth of tubers late in the growing season, often associated with water stress. Control: Provide uniform soil moisture and bulking rates during late-season potato development.

Protruding Eyes - A type of secondary lateral growth where buds are growing away from the tubers longitudinal axis. Typically gives the tuber an uneven appearance. Cause: Environmental stresses which have halted tuber growth. When growth resumes, the eyes begin to swell and eventually develop into knobs. Low soil moisture, high soil temperature, nutrient imbalances and defoliation (e.g., hail, frost or beetles) which interrupt normal bulking promote knobbiness. Knobbiness increases as the amount of top growth increases relative to the number of tubers, and with wider spacing between plants. Control: Uniform stands, uniform soil moisture and fertility levels. Proper irrigation during hot weather important. Avoid applying excess nitrogen fertilizer.

Knobby Tubers - A type of secondary lateral growth. Knobs develop from protruding eyes. In severe cases, knobs may develop on knobs, and may grow even larger than the primary tuber. Cause and Control: same as protruding eyes.

Growth Cracks - Growth cracks are splits in the outer flesh and skin of the tuber. Usually these splits run lengthwise with the tuber, may be quite deep, and heal over during the growing season. Cause: Rapid increases in volume of internal tuber tissue, resulting in internal pressures which split the skin, are thought to cause growth cracks. Heavy rain or irrigation following dry periods, or irregular moisture conditions, promote this disorder. Control: Provide uniform soil moisture and fertility conditions especially mid to late season. Plant the correct number of stems per hill through proper seedpiece spacing and stand establishment.

SUMMARY

Tables 1 and 2 summarize the influence of early-season and late-season soil moisture on several factors important for producing high potato quality and yields. A considerable range in opinion may occur among researchers as to the influence of these moisture levels on some factors. This indicates further investigations are needed to more clearly define the impact water stress may have on yield and quality criteria. These recommendations are specific for Idaho and will vary for other locations, particularly those with longer growing seasons.

Many studies reported in the literature re-emphasize that seldom is there only one factor solely limiting yield or quality at any one time under field conditions. Interactions between factors influencing plant development are constantly present. Management decisions based on these interactions are an important way to improve quality, yield and net return on investment.

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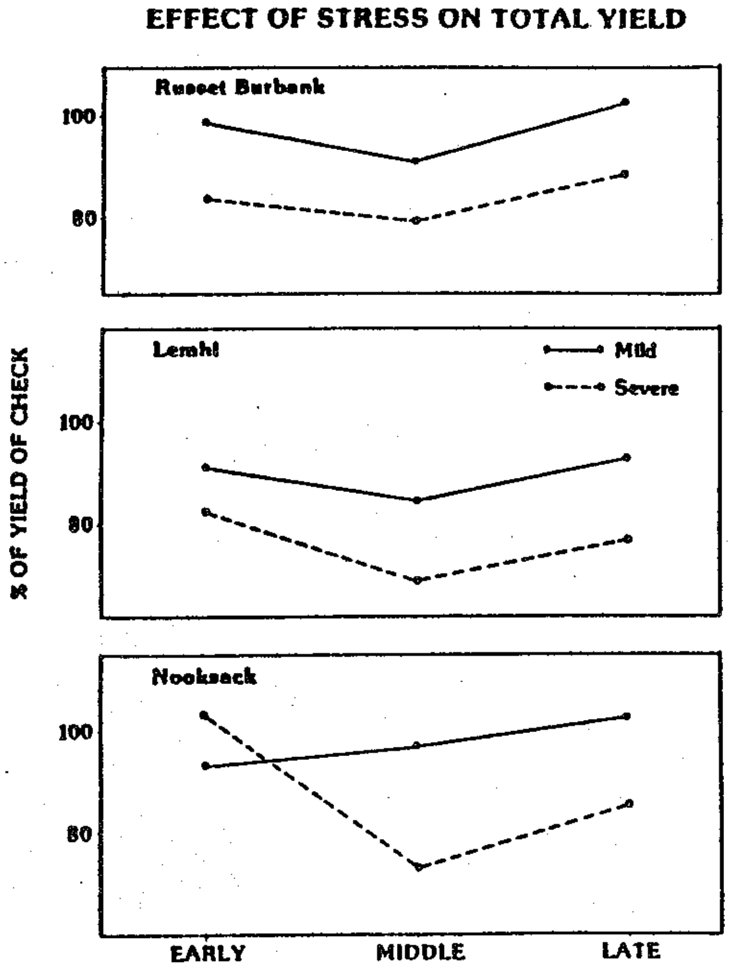

FIG. 1. Effect of mild and severe moisture stress on the total yield of three potato varieties at three growth stages. Aberdeen—Longley 1981. (The check plot was irrigated for maximum yield and quality production.) (Larsen, 1984)

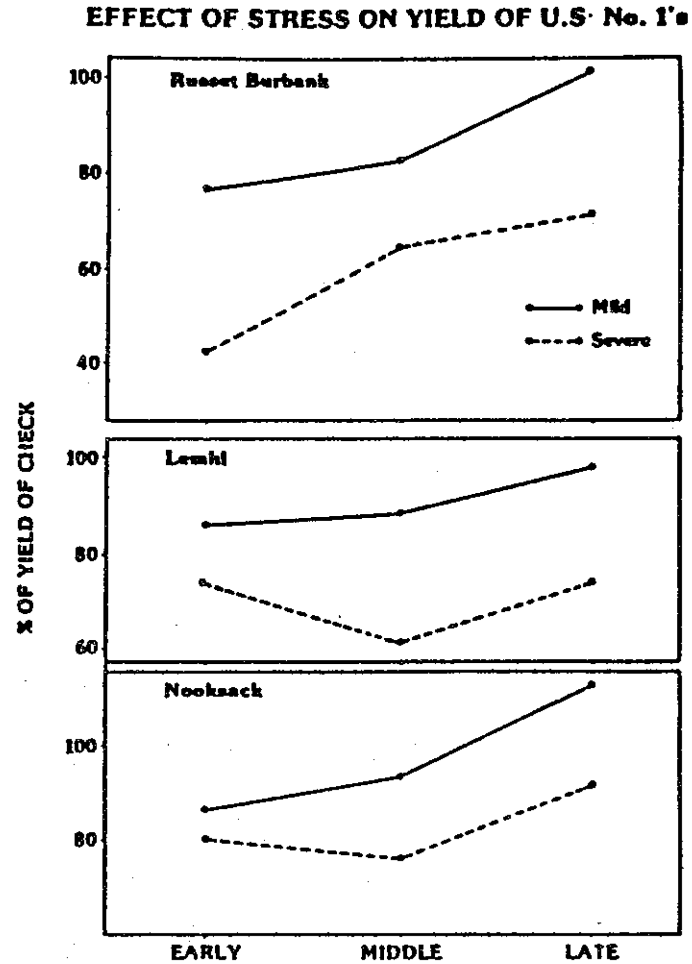

FIG. 2. Effect of mild and severe moisture stress on the yield of U.S. No. 1's of three potato varieties at three growth stages. Aberdeen—Longley 1981. (The check plot was irrigated for maximum yield and quality production.) (Larsen, 1984)

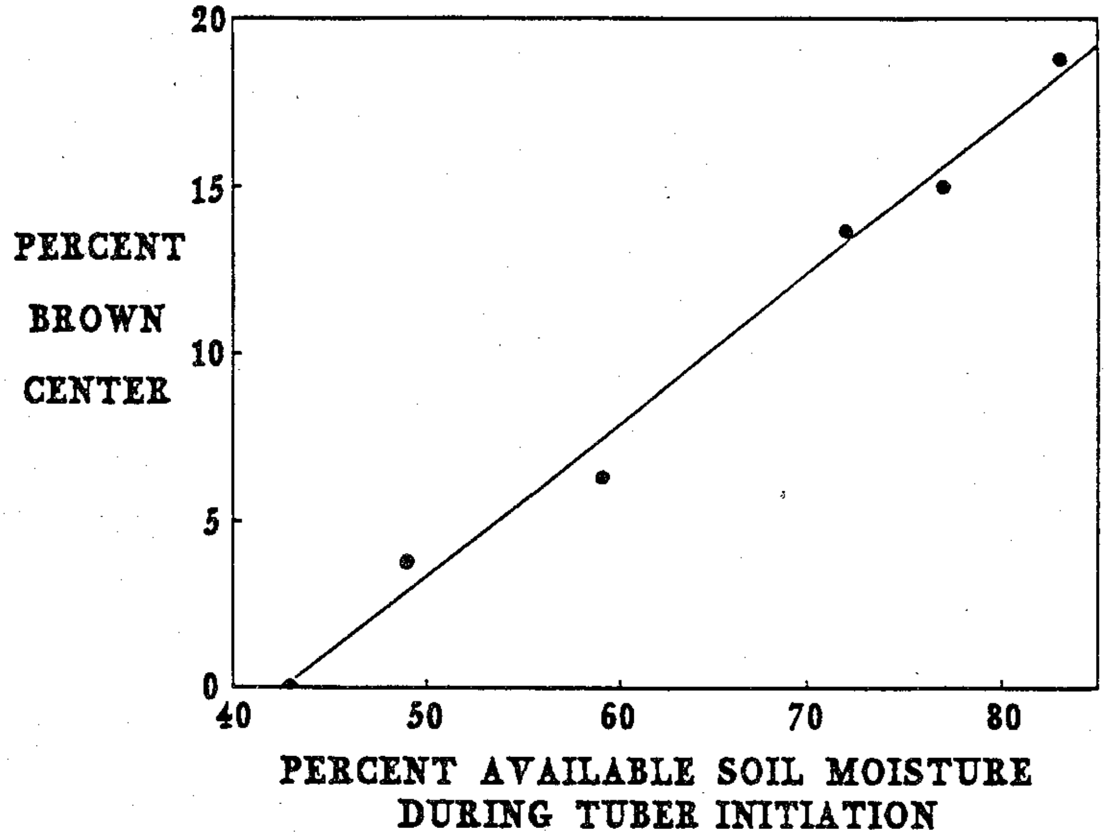

FIGURE 3

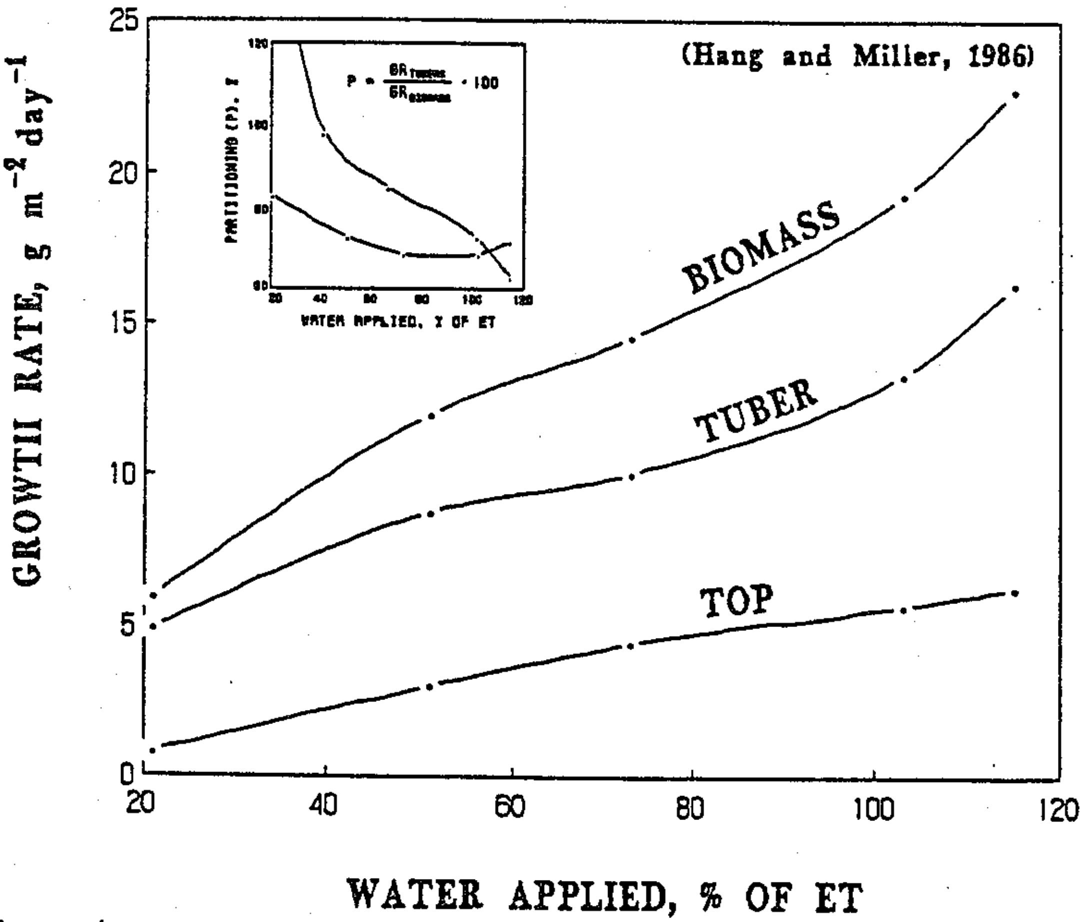

FIGURE 4

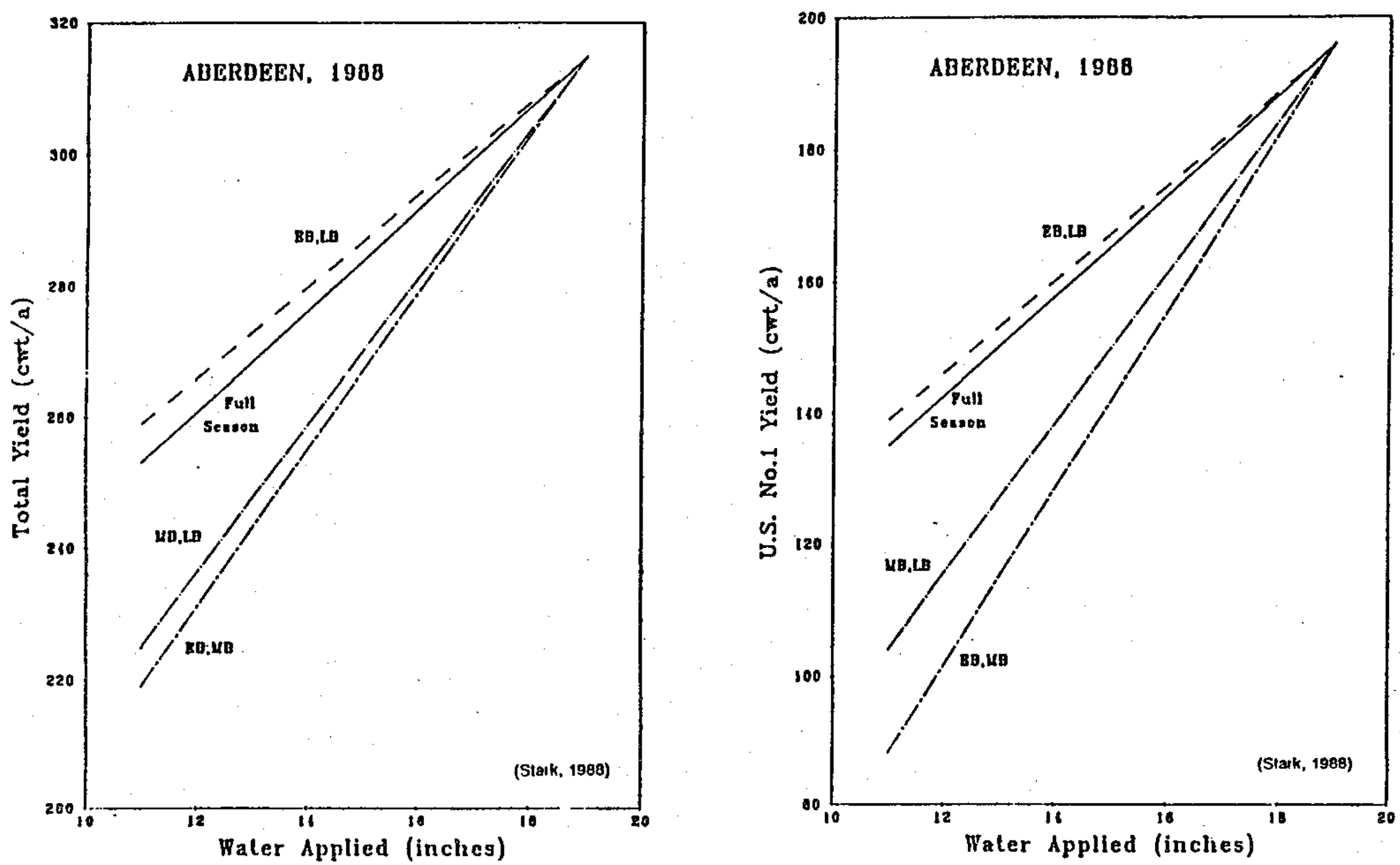

Figure 5. Total yield and U.S. No. 1 yield of Russet Burbank potatoes as affected by irrigation timing and amount. The abbreviations EB, MB, and LB denote water stress during early bulking, mid bulking and late bulking, respectively.

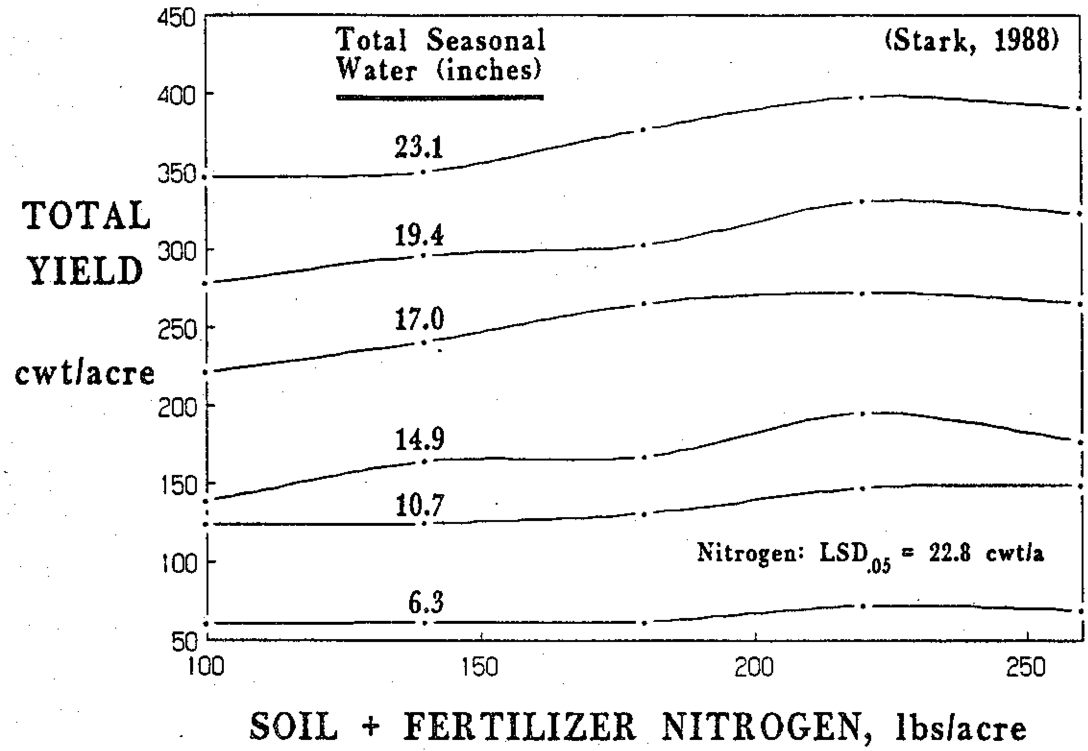

FIGURE 6

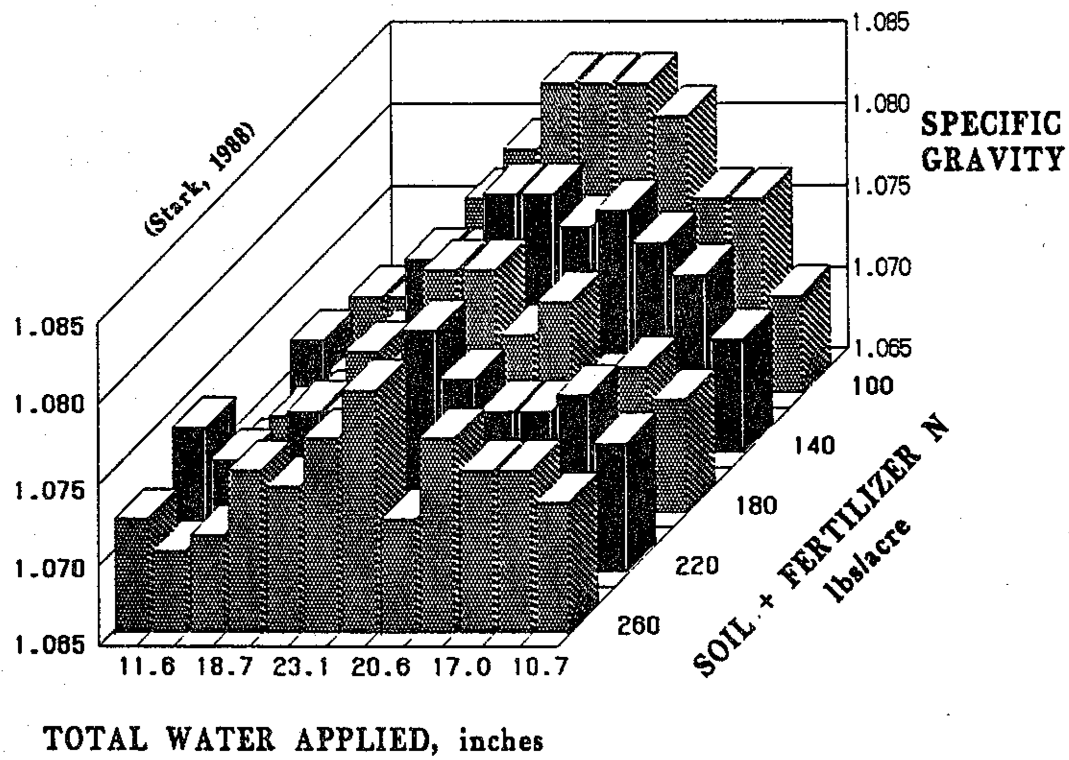

FIGURE 7

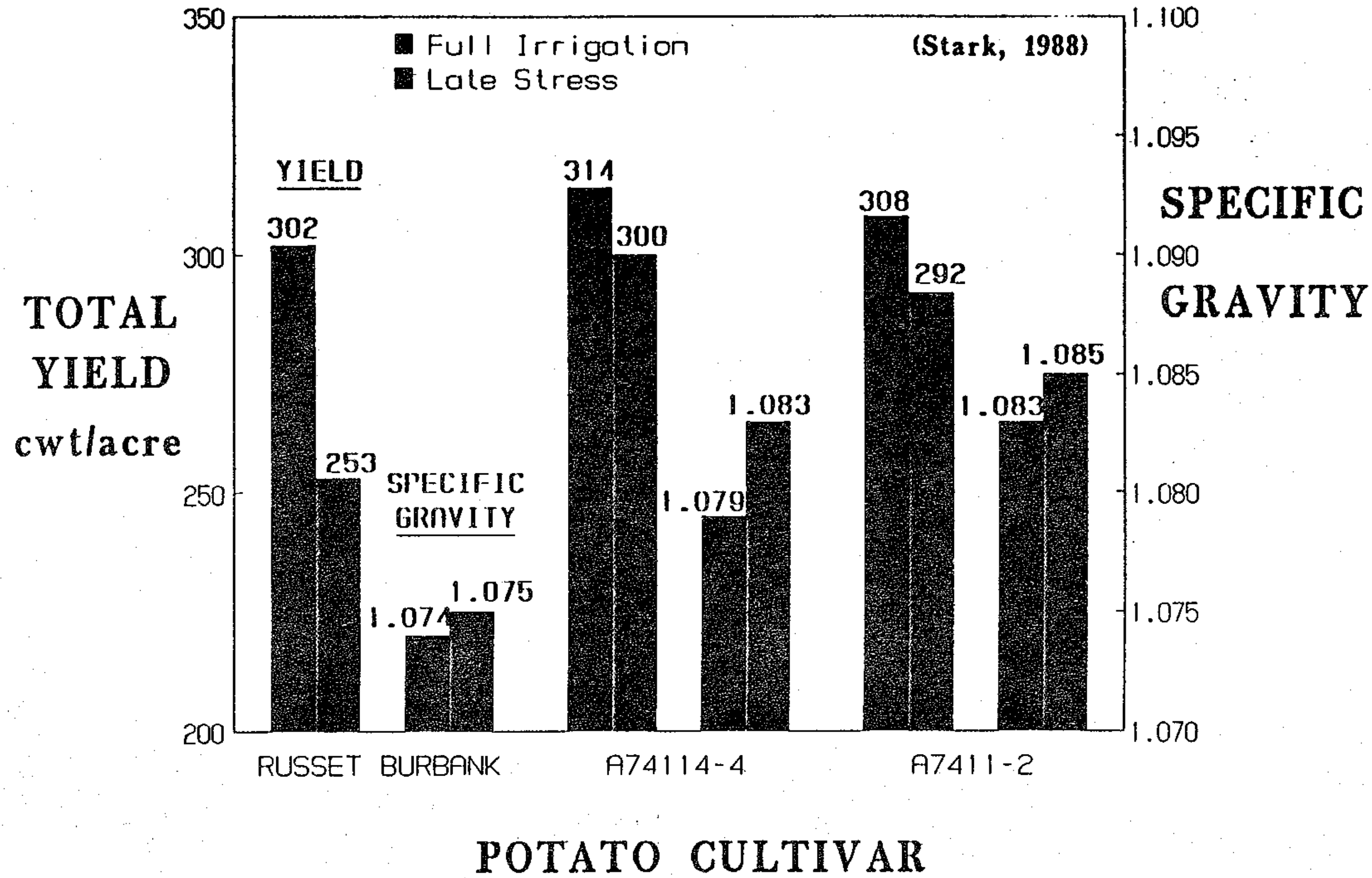
Full Irrigation
Late Stress
(Stark, 1988)
YIELD
SPECIFIC GRAVITY
302
253
1.074
1.075
314
300
1.079
1.083
308
292
1.083
1.085
350
300
250
200
1.100
1.095
1.090
1.085
1.080
1.075
1.070
TOTAL YIELD cwt/acre
SPECIFIC GRAVITY
RUSSET BURBANK
A74114-4
A7411-2
POTATO CULTIVAR

Figure 8.

TABLE 1.

EARLY-SEASON SOIL MOISTURE

FACTOR	>80%	<50%
Total Yield	Increase?	Decrease
U.S. No.1 Yield	Increase?	Decrease
>10 oz Yield	No Effect	Decrease
Specific Gravity	No Effect	Decrease
Hollow Heart	Increase	Decrease
Brown Center	Increase	Decrease
Translucent End	No Effect	Increase
Tuber No. per Hill	No Effect	Decrease
Misshapen Tubers	No Effect	Increase
Common Scab	Decrease	Increase

Early Season = tuber initiation + 3 weeks.

TABLE 2.

LATE-SEASON SOIL MOISTURE

FACTOR	>80%	50%
Total Yield	No Effect	No Effect
U.S. No.1 Yield	No Effect	No Effect
>10 oz Yield	No Effect	Decrease?
Specific Gravity	No Effect	No Effect
Brown Center	No Effect	No Effect
Hollow Heart	No Effect	No Effect
Translucent End	Decrease	Increase
Blackspot Bruise	Decrease	Increase
Shatter Bruise	Increase	Decrease
Water/Soft Rot	Increase	Decrease

Late Season = late August to harvest.
Compared to 65% ASM.