

The Relationship Between Soil Temperature and Sugar Ends in Potato

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Received: 11 August 2010 / Accepted: 24 September 2010 /
Published online: 19 October 2010
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Abstract Sugar ends is a serious defect in processed potatoes. Among the more important factors associated with the development of sugar ends are soil temperature and soil moisture, particularly during early tuber bulking. This 2-year study was designed to examine the effects of soil temperature on the development of sugar ends. Soil temperature was recorded in different zones (0–10 cm and 10–20 cm depths) of potato rows oriented in north–south and east–west directions. At harvest, tubers from four sections in each field were hand excavated from each quadrant of the hill. The rows were divided vertically through the center and horizontally at the 10-cm depth. Tubers from each quadrant were weighed and then evaluated for fry color after 3 months of storage. Temperature profiles within the different regions of the row showed considerable variation throughout the season. Row orientation had a slight effect on soil temperature, but soil depth appeared to be more important. The deeper portion of the row (below 10 cm) was generally cooler throughout the day. East and north facing portions of rows also tended to be cooler than the opposite side that was exposed to more solar radiation. The highest yields and highest incidence of tubers with sugar ends tended to be found in areas below 10 cm in depth. These results contradict the notion that soil temperature is the primary factor leading to development of sugar ends. Therefore, individual tuber growth rate and temperature exposure of the entire plant may be more important in causing the development of sugar ends than was previously thought.

Keywords Row orientation · Soil temperature · Sugar ends · Tuber development

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Introduction

Potatoes with sugar ends fry dark on one end and light on the other, and are a serious problem in processed potatoes. The accumulation of reducing sugars (glucose and fructose) fuels the Maillard reaction which causes the potato to fry dark. There are several factors, both cultural and in storage, that contribute to this condition. Among the more important cultural factors associated with the development of sugar ends are soil temperature and soil moisture, particularly during early tuber bulking (Thompson et al. 2008). Several authors have reported a relationship between soil temperature and tuber carbohydrate status and incidence of the sugar ends disorder. Krauss and Marschner (1984) reported that the temperature around individual tubers directly influenced starch deposition, with tubers exposed to 30 °C having lower starch and higher sugar content than those at 20 °C. Kincaid et al. (1993) found a significant correlation between soil temperature at a depth of 15 cm and incidence of sugar ends in plots under different irrigation frequencies. In contrast, Sojka et al. (1988) reported that row orientation and use of mulches significantly impacted soil temperature, but they could not consistently relate tuber quality or sugar ends incidence to the location of tubers in the row.

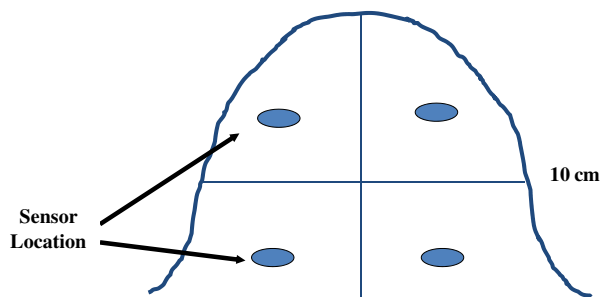
This study was designed to examine the effects of row orientation on soil temperatures, and the subsequent development of the sugar ends disorder.

Materials and Methods

Field studies were conducted during the 2004 and 2005 cropping seasons on commercial potato fields in the Parma, ID, USA area. These fields were all sprinkler irrigated and located on a Greenleaf silt loam soil, which is characteristic for this production area of southern Idaho. Two field sites were identified in each year, one with rows oriented in a north-to-south direction and the other oriented in an east-to-west direction. The fields were managed by the same producer and located within 2 km of each other. All sites were planted with the cultivar Russet Burbank.

At the time of plant emergence, Hobo temperature sensors (Model H8, Onset Computer Corporation, Pocasset, MA, USA) housed in a PVC capsule were buried on both sides of the hill, 22.5 cm from the center, at 10 and 20 cm depths. This configuration resulted in a temperature sensor located in each of the four quadrants (Fig. 1). Soil temperature was recorded at hourly intervals for 120 days, from mid-

Fig. 1 Location of soil temperature sensors within four quadrants of the potato row



May to mid-September. Daily mean (24 h average) and maximum soil temperatures (highest soil temperature in a 24-h period) were calculated from this data. Soil moisture was also monitored in each field using Watermark sensors (Model 6450, Irrrometer Company, Riverside, CA, USA) at 15 and 30 cm depths.

At harvest, tubers from four 3-m sections in each field were hand excavated. If a tuber was located at the intersection of two quadrants, the tuber was placed in the quadrant where the largest portion of the tuber was found. Tubers from each quadrant were kept separate, graded according to United States Department of Agriculture (USDA) standards, and then weighed. All tubers over 113 g in weight that met the specifications for US No. 1 grade were classified as marketable. A subsample of ten tubers in the 113–283 g size range were collected from each replicated sample, and transported to the storage research facility at Kimberly, ID, USA. The subsamples were stored for approximately 3 months at 7 °C prior to evaluation for fry color and incidence of sugar ends.

Tubers were cut into strips using a Keen Kut Shoe Stringer French fry cutter. One fried strip (3.0×0.8 cm) from each of the ten tubers was used for fry color determination (ten strips per replicate). Strips were fried in canola oil at 191 °C for 3.5 min. Fry color was determined within 3 min using a Photovolt Reflection Meter (model 577, Photovolt Instruments Inc., Minneapolis, MN, USA). A green filter was used and calibrated using a black-cavity standard as 0.0% reflectance and a white plaque (Cat. No. 26-570-08) as 99.9% reflectance. Measurements were taken on the bud and stem ends of each strip. A relationship between USDA fry color and photovolt reflectance as measured by our instrument and methodology was previously established. The data produced a scale of a USDA fry color rating where a USDA 1 rating was equal to a 44.0 or greater reflectance reading, a USDA 2 rating was less than 44.0 to 35.0 reflectance reading, a USDA 3 rating was less than 35.0 to 26.0 reflectance reading, and a USDA 4 rating was less than 26.0 reflectance reading. The lower the reflectance measurement, the darker the fry color.

The presence or absence of sugar ends was recorded for each plank. A plank was scored a sugar ends if a predominant color of number 3 or darker when compared with the USDA Munsell Color Chart for French Fried Potatoes, was seen on any two sides extending 1.3 cm or more from the stem end of the fried strip.

Data from the 2004 and 2005 studies were analysed separately using the SAS program (SAS Institute 2004). Soil daily mean and maximum temperatures were statistically analysed by repeated measures analysis to provide a factorial series of comparisons between each quadrant of the row. Tuber yield, grade and sugar ends incidence were analysed by the analysis of variance procedure and means separated by Fisher's Least Significant Difference test when the analysis of variance indicated significance at the $P < 0.05$ level.

Results and Discussion

Both 2004 and 2005 were characterized by periods of high air temperatures (>32 °C) during early tuber development. Temperature profiles within the different regions of the row showed considerable variation throughout the season, particularly at the 0–10 cm depth (Fig. 2). Soil temperatures were highest during July and August when ambient air temperatures were also highest.

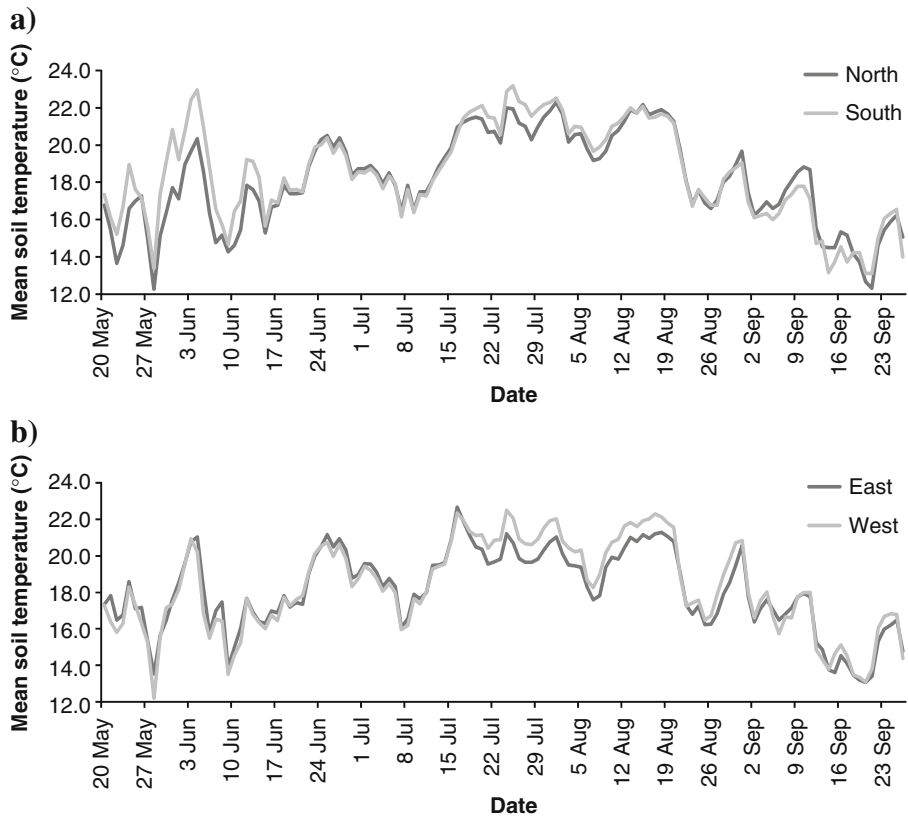
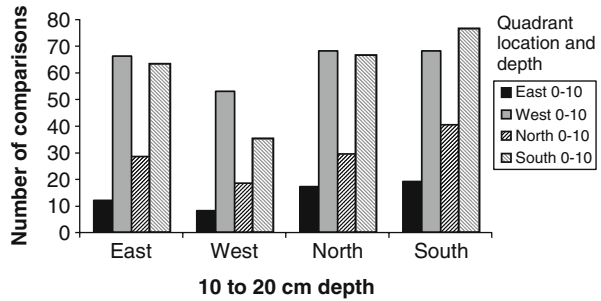


Fig. 2 Mean daily soil temperature (average for 24-h period) at the 0–10 cm depth in the row during 2004; **a** north and south side of the row and **b** east and west side of the row

During the period of soil temperature measurement from mid-May to mid-September, row orientation had less effect on maximum soil temperatures than did soil depth. This is illustrated with data from 2004 where, of the 910 comparisons between the two soil depths that were significantly different, 768 (84.4%) were comparisons where the 0–10 cm depth was warmer than the 10–20 cm depth. The east and north facing side of rows had maximum daily soil temperatures at the 0–10 cm depths that were rarely higher than at the 10–20 cm depths (Fig. 3). In contrast, the south or west facing sides were often warmer at the 0–10 cm depth than at the 10–20 cm depth. This illustrates the importance of solar radiation on soil temperatures. The early morning sun had less effect on warming potato rows than did the late afternoon sun. Also, being in the northern hemisphere, the sun rises and sets on the southern horizon causing the north side of objects, in this case potato rows, to be in shadow for most of the day.

Daily mean soil temperatures did not show as much variability as the maximum daily temperatures. Averaging in the night temperatures appeared to cancel out some of the differences among row locations found in maximum daily soil temperatures, as evidenced by the fewer number of significant comparisons (157 compared to 910). The south facing side of the row at the 0–10 cm depth was much more likely to

Fig. 3 Number of comparisons where the 0–10 cm maximum daily soil temperature was significantly higher than at 10–20 cm depth during the period from mid-May to mid-September of 2004



have significantly higher daily mean soil temperatures compared to the east, west and north facing sides of the row (Fig. 4).

Total and marketable yields were significantly higher at the 10–20 cm depth compared to the 0–10 cm depth (Table 1). This was true for all row locations except the east facing side in 2004 and the north and south facing sides in 2005. The north facing section of the row at the 10–20 cm depth produced significantly more marketable tubers than all other locations in 2004. However in 2005, the east facing section at the 10–20 cm depth produced significantly more marketable tubers than all other locations. As previously indicated, these locations tend to have the lowest mean daily and maximum soil temperatures during the growing season. This data supports reports from other regions that row orientation and depth significantly influence tuber yield and grade (Sojka et al. 1988; O’Brien et al. 1998).

Row orientation had little effect on the incidence of sugar ends (Fig. 5). In contrast, sugar ends were significantly affected by soil depth in both years of the study. Tubers located below 10 cm depth had significantly more sugar ends than tubers above 10 cm. This was true for all locations except the south facing side of the row in 2004 and the east and west facing sides in 2005. Nelson and Shaw (1976) found that total reducing sugars in Kennebec did not increase, but remained constant, with increasing soil depth. However, Stieber and Shock (1989) reported that for potatoes grown in Eastern Oregon there was a trend towards lower percent sugar ends in tubers located in the bottom of the hill. Potato variety (Kennebec versus Russet Burbank) and different production regions (North Dakota versus

Fig. 4 Number of significantly different comparisons of mean daily soil temperature in four quadrants of rows at two depths during the period from mid-May to mid-September of 2004

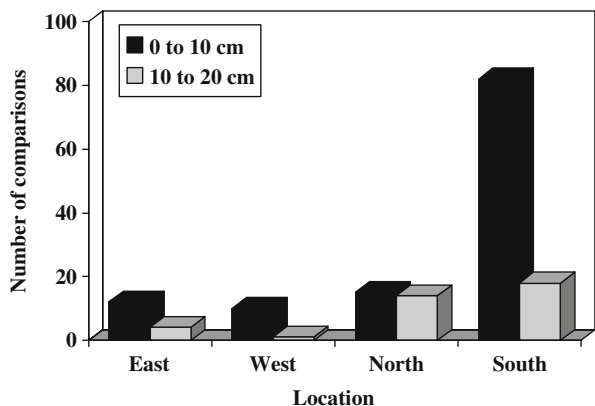


Table 1 Total and marketable yields in grams per 3 m of row for Russet Burbank tubers recovered from four locations and two depths within the row

Location and depth of tubers	Total yield (g)	Marketable yield (g)
2004		
North 0–10 cm	4,258 bc ^a	3,231 bc
South 0–10 cm	2,272 c	1,978 c
East 0–10 cm	2,652 bc	1,639 c
West 0–10 cm	3,215 bc	2,063 c
North 10–20 cm	8,844 a	6,514 a
South 10–20 cm	4,970 b	3,888 b
East 10–20 cm	4,944 b	2,500 bc
West 10–20 cm	7,317 a	3,883 b
LSD (0.05)	2,327	1,672
2005		
North 0–10 cm	6,617 b	4,654 bc
South 0–10 cm	3,286 cd	2,127 cd
East 0–10 cm	4,482 c	3,388 bc
West 0–10 cm	2,250 d	1,592 d
North 10–20 cm	6,793 b	4,169 b
South 10–20 cm	3,528 cd	2,432 cd
East 10–20 cm	9,775 a	7,265 a
West 10–20 cm	4,747 bc	3,339 bc
LSD (0.05)	2,089	1,695

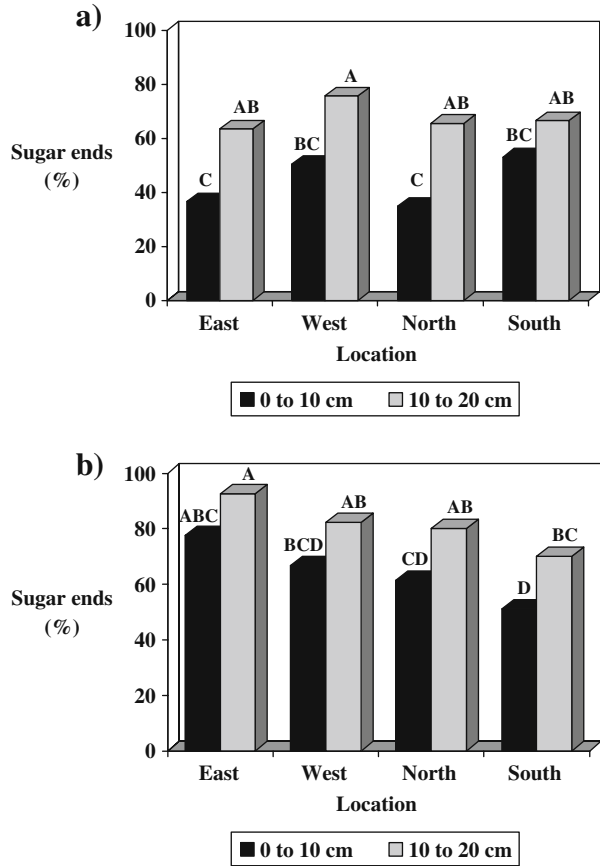
Values are means of four replications per location during 2004

^a Values within a column with different letters are significantly different at $P=0.05$

Eastern Oregon and Idaho) may help explain the discrepancy in these data sets. Management practices may also influence the location of tubers that develop sugar ends as the data from the Oregon study were obtained under furrow irrigation, while our study was sprinkler irrigated.

These results appear to contradict the notion of higher soil temperatures producing a higher percentage of tubers with sugar ends. The row locations with the most sugar ends, all from below 10 cm depth, were the ones that tended to have the lowest mean daily and maximum soil temperatures. Although soil and ambient temperatures are highly related (Sojka et al. 1988), soil temperatures may not be the only source of plant stress for development of sugar ends. It may be that the temperature stress in the entire system, not just the soil temperature immediately surrounding developing tubers, increases the occurrence of sugar ends. It was found that whole potato plants, soil included, grown at 28 °C favored the accumulation of carbohydrates in the above ground foliage at the expense of carbohydrate deposition in tubers, compared to plants grown at 16 °C (Randeni and Caesar 1986). Lower starch level in the tubers generally leads to greater sugar accumulation, and more sugar ends post-harvest.

Fig. 5 Incidence of sugar end defect in fried strips from Russet Burbank tubers at four locations and two depths in potato rows; **a** 2004 crop year and **b** 2005 crop year. Values with different letters within a given year are significantly different at $P=0.05$



Previous research has also shown that most tubers develop in the lower portions of the row (O’Brien et al. 1998). The largest tubers act as sinks for the products of photosynthesis for a longer period during the growing season. Therefore, these tubers may be actively growing through a greater number of stress periods than smaller tubers produced in other regions of the row. This, in turn may result in a higher occurrence of sugar ends. Sojka et al. (1988) also showed that over 3 years, sugar content and fry color varied in relation to differing treatments, among them row orientation. It was suggested that even in controlled field studies, soil temperature can vary considerably among locations due to such things as differences in vine growth and soil type.

Conclusion

Row orientation had a slight effect on soil temperature, but soil depth appeared to be more important. The deeper portion of the row (below 10 cm depth) was generally cooler throughout the day than the shallower portion of the row. East and north facing sides of the rows also tended to be cooler than the opposite side that was

exposed to more solar radiation. It is interesting to note that the highest yields and highest incidence of tubers with sugar ends tended to occur in tubers that were located below 10 cm in depth. This contradicts the notion that soil temperature is the primary factor leading to development of sugar ends. It may be that individual tuber growth rate and temperature exposure of the entire plant are more important in causing the development of sugar ends than was previously thought.

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