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ACCUMULATED GROWING DEGREE DAYS AS A MODEL TO DETERMINE KEY DEVELOPMENTAL STAGES AND EVALUATE YIELD AND QUALITY OF POTATO IN NORTHEAST FLORIDA

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Abstract. **Potato (*Solanum tuberosum* L.) planting in Northeast Florida's Tri-County Agricultural Area (St. John, Putnam, and Flagler counties, TCAA) typically runs early January through mid-March. Six planting dates (PD) (13 January 2004 and every two weeks, thereafter, to 25 March 2004) and two chipping varieties ('Atlantic' and 'Harley Blackwell') were evaluated to determine key growth and development stages (emergence, full flower, and senescence), yield and quality based on accumulated growing degree days (GDD-7C base). 'Atlantic' is preferred for its chipping quality and high yield, but is susceptible to internal heat necrosis (IHN). 'Harley Blackwell' is noted for its resistance to IHN and comparable chipping quality to 'Atlantic'. Growers in the TCAA have historically used calendar days to predict key potato developmental stages. Developing a growing degree day system may be a more accurate predictor of these stages throughout the season to determine optimal planting dates and yields compared to calendar days for chipping varieties in the TCAA. For both varieties and all planting dates, 'emergence' and 'full flower' occurred approximately at 213 and 804 accumulated GDD, respectively. Accumulated GDD at harvest for PD's 1-6 were 1493, 1676, 1951, 2374, 2490 and 2840, respectively. As accumulated GDD at harvest exceeded 2374, total and marketable yields decreased on average 17 and 20%, respectively.**

Potato production in Florida spans from as far south as Miami-Dade County to Suwannee County in the north. The largest area in production is in Northeast Florida's Tri-County Agricultural Area (TCAA) (St. Johns, Putnam and Flagler counties) with 7,682 ha (19,000 acres). Potatoes continually rank among the top five vegetables in production in Florida with annual values of approximately $125 million (Witzig and Pugh, 2004).

'Atlantic' was planted because it is the most prevalent chip variety planted in northeast Florida. 'Atlantic' is noted for its light chip color, relatively high yield and high specific gravity. However, it is susceptible to internal heat necrosis (IHN), a physiological tuber disorder that causes an unacceptable browning of the tuber tissue. 'Harley Blackwell', a new variety resistant IHN, was released in 2003 by the US Department of Agriculture (USDA, Beltsville Md., 2004). Yields and specific gravities of 'Harley' are lower than 'Atlantic' but are acceptable according to chipping standards (Beltsville Agricultural Research Center, 2003; United States Standards for Grades of Potatoes for Chipping, 1978).

Potatoes, a cool season crop, are planted in the TCAA beginning in January when day length is short and temperatures cool. As the season progresses, daylight hours lengthen and temperatures increase as the potato goes through key developmental stages. Winkler (1971) reported that yields may suffer due to extended periods of cooler (below 18 °C) as well as higher temperatures (above 20 °C) for extended periods. Cooler and higher temperatures reduce net assimilation to the tubers while higher temperatures may prevent tuber initiation. Developing a model to more accurately predict planting dates will help growers obtain optimal yields and quality.

Research results have indicated that GDD are a useful tool to determine harvest dates and yield in such crops as broccoli (*Brassica oleracea* L.) (Dufault, 1997), peas (*Pisum sativum* L.) (Hoover, 1955); corn (*Zea mays* L.); cucumber (*Cucumis sativus* L.) (Perry et al., 1986) and taro (*Colocasia esculenta* L. 'Schott') (Lu et al., 2001). Sterrett et al. (1991) evaluated a revised accumulated heat unit system (Lee et al., 1992) to predict when potato tubers would go off-grade. With this system growers could determine when to harvest to avoid economic losses due to tuber quality issues.

Historically, growers in the TCAA have used calendar days and experience to predict key potato developmental stages. Developing and utilizing the growing degree day system may be a more accurate predictor of these stages throughout the season to determine optimal planting dates and yields compared to calendar days. It would also facilitate a more efficient fertilizer and pesticide application schedule.

This experiment was designed to predict key developmental stages and optimal yields over multiple planting dates typically experienced in the TCAA.

Materials and Methods

The experiment was arranged as a randomized complete block with a split-split design with four blocks. Planting dates (1-6) were assigned to main plots. The first split was the N rate at 168 and 224 kg·ha^{-1} (150 or 200 lb/acre). The second split was potato variety, 'Atlantic' and 'Harley Blackwell' (Maine Farmer's Exchange-MFX, Presque Isle, Maine).

The experiment was conducted at the University of Florida, Plant Science Research and Education Unit, Hastings, Fla. on an Ellzey fine sand (sandy, siliceous, hyperthermic Arenic Ochraqualf; sand 90% to 95%, <2.5% clay, <5% silt). Each plot was 4.8 m (16 ft) with a 0.9 m (3ft) buffer. Between and within row spacing was 102 and 20 cm (40 and 8 inches), respectively. Potatoes were planted 12 Jan. 2004 and every 2 weeks thereafter to 25 Mar. 2004 for a total of six planting dates. Potatoes were harvested 26 Apr. 2004 and every 2 weeks thereafter.

Potatoes were cut at planting to an approximate 71 g (2.5 oz) seed piece and dusted with fungicide [1.13 g (0.04 oz) a.i. fludioxonil and 21.82 g (0.77 oz) a.i. mancozeb per 45.4 kg (100 lb) seed pieces (Maxim MZ; Syngenta Crop Protection, Inc., Greensboro, N.C.)]. Azoxystrobin [0.1 L·ha^{-1} (8.0 fl. oz/

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acre) a.i. (Syngenta, Crop Protection, Greensboro, N.C.)] and aldicarb [3.36 kg·ha^{-1} (3.0 lb/acre) a.i. (Temik, Bayer Corp., Kansas City, Mo.)] was applied in-row at planting. All other pesticide applications during the growing season followed recommendations for Florida potato production (Hutchinson et al., 2004). Plots were irrigated with seepage irrigation except during periods of sufficient rainfall throughout the growing season.

Fertilizer application was based on 100 and 75% of recommendations for Florida potato production [224 and 168 kg·ha^{-1} (200 and 150 lb/acre) N, respectively] (Hutchinson et al., 2004). Pre-plant fertilizer (1 day before planting) was applied at a rate of N at 112 kg·ha^{-1} (N at 100 lb/acre) as 14N-2.6P-9.9K. The total P requirement 19.5 kg·ha^{-1} (40 lb/acre, P_2O_5) was fulfilled at pre-plant. One sidedress of remaining N rates [112 and 56 kg·ha^{-1} (100 and 50 lb/acre), 34N-0P-0K] and K [60.4 kg·ha^{-1} (54 lb/acre) 0N-0P-50K] was applied approximately 30 d after each planting date when plants were 10 to 15 cm (4-6 inches) tall.

Growing degree days (GDD) were calculated throughout the season for each planting date. The formula GDD = [(minT + maxT)/2-7 °C (45 °F)] (Sands et al., 1979). GDD were noted at key growth and developmental stages (emergence, ½ flower, full flower, and senescence).

Potatoes from each plot and planting date were harvested at least 100 DAP as required by aldicarb labeling requirements. Potatoes were washed, graded and sized into six classes: C = 1.27 to 3.81 cm (0.5 to 1.5 inches), B = 3.81 to 4.44 cm (1.5 to 1 7/8 inches), A1 = 4.4 to 6.4 cm (1 7/8 to 2.5 inches), A2 = 6.4 to 8.3 cm (2.5 to 3.25 inches), A3 = 8.3 to 10.2 cm (3.25 to 4.0 inches), A4 = >10.2 cm (>4.0 inches). Culls (green, growth cracks, misshapen, sunburn and rotten tubers) were removed and weighed. Specific gravity was calculated from a sub-sample of marketable tubers from each plot using weight in air/weight in air-weight in water method (Burton, 1989a). A 20 tuber sub-sample from each plot was cut into quarters and rated for internal quality (corky ring spot CRS, hollow heart HH, internal heat necrosis IHN, brown center BC, and brown rot BR).

Analysis of variance for a split-split plot design was performed using SAS (2002). Means were separated using Tukey's studentized range test (SAS, 2002).

Results and Discussion

Optimum planting dates to obtain highest yields in the TCAA, based on the results of this research, encompass a 4-week period in the middle of the traditional 12-week planting window. The optimum period for highest yield extended from late January through the last week of February (Tables 1 and 2). This corresponds to 1676 to 2374 accumulated GDD for a 100 d season when planted during this part of the season. Planting before and after this 4-week period results in decreased yields due to colder temperatures early in the season and warmer and wetter weather later in the season.

Emergence and full flower occurred on average across plantings at 213 and 804 accumulated GDD (Table 1), respectively. GDD are a more predictive model compared to calendar days. For instance, full flower occurred from 68 to 40 d after planting. As plantings progressed later in the season, periods between developmental stages were compressed. This is an important concept to communicate to growers. Fertilizer and pesticide applications should be timed by accumulated GDD and not calendar days as commonly done.

Unfortunately, in this experiment, harvest was not determined by accumulated GDD but determined by calendar days. Aldicarb, a common soil applied insecticide/nematicide used in the area has a 100-d harvest interval. Growers time their harvest according to this required harvest interval. The calendar method works better for the mid-season planting because 'Atlantic' and 'Harley Blackwell' both have about a 100-d season. Timing harvest by calendar days does not work late in the season because as the season compresses, harvest should be accelerated. The typically hot and wet weather in June can increase rots in mature tubers. Bulking during hot weather is also reduced as tuber respiration increases.

Tuber defects are influenced more by weather conditions (rainfall) than accumulated GDD, therefore, it is more difficult to relate external and internal tuber defects to an accumulated GDD model. Significant differences in total yields, marketable yields, and specific gravity were observed in response to planting dates (Table 2). Planting 3 (9 Feb.) had significantly higher total tuber yields compared to plantings 1, 5 and 6 (13 Jan., 9 Mar. and 24 Mar., respectively) and higher marketable yields compared to plantings 2, 5 and 6 (27 Feb., 9 Mar. and 24 Mar., respectively). Significant increases in the percentage of tuber rots in plantings 5 and 6, (14% and 10%, respectively) compared to tubers from earlier plantings (data not shown) were apparent. This may have been a result of the warmer temperatures and increased rainfall late in the season.

Tubers in plantings 3 through 6 (2 Feb., 23 Feb., 9 Mar. and 24 Mar.), respectively, had significantly lower gravities compared to planting 2 (26 Jan.) (Table 2). This may be caused by two factors. First, tuber weight in plantings 3 and 4 (2 Feb. and 23 Feb.), respectively had a higher percentage of water that contributed to their higher tuber yields. Rainfall accumulation from tuber initiation through harvest for plantings 3 through 6 (2 Feb., 23 Feb., 9 Mar. and 24 Mar.), respec-

Table 1. Accumulated growing degree days and calendar days to emergence, full flower, and harvest per planting date—Spring 2004.

Planting order	Date of planting	Date of emerg.	Days to emerg.	GDD to emerg.[z]	Calendar days to full flower	GDD to full flower	Calendar days to harvest	GDD to harvest
1	13 Jan	6 Feb	24	240	68	841	104	1493
2	27 Jan	16 Feb	20	226	61	806	104	1676
3	9 Feb	25 Feb	16	178	52	749	106	1951
4	23 Feb	7 Mar	13	218	49	820	106	2374
5	9 Mar	22 Mar	13	202	47	816	104	2490
6	24 Mar	5 Apr	12	211	40	792	104	2840
AVG			16	213	53	804	105	2137

[z]Accumulated GDD = growing degree days [(minT + maxT)/2 – 7 °C (45 °F)].

Table 2. Analysis of variance table for total and marketable yield, and specific gravity for planting date trial 2004.

Planting date	Total yield (t·ha^{-1})[z]	Marketable yield (t·ha^{-1})	Specific gravity
1	28.3 bc[y]	24.1 a-c	1.083 ab
2	29.0 a-c	21.9 bc	1.085 a
3	33.8 a	27.6 a	1.080 b
4	32.6 ab	26.3 ab	1.076 c
5	26.8 c	18.7 c	1.068 d
6	26.7 c	21.9 bc	1.066 d
Variety			
Atl[x]	30.6 a	25.7 a	1.077 a
HB	28.5 b	21.2 b	1.075 b
Significance			
Planting Date	**	***	***
Variety	*	***	**
Planting Date × Variety	NS	NS	**

[z]1 t·ha^{-1} = 8.92 cwt/acre.
[y]Treatment means followed by the same letter within columns are not significantly different at the $P \le 0.05$ using Tukey's studentized range test. NS, *, **, *** nonsignificant or significant at $P \le 0.05$, 0.01, 0.001, respectively using Tukey's studentized range test.
[x]Atl = 'Atlantic'; HB = 'Harley Blackwell.'

tively was three times higher compared to planting 2 (26 Jan.) for the same developmental stages (data not shown). Tubers from plantings 5 and 6 (9 Mar. and 24 Mar.), respectively were bulking under high temperatures which increases respiration and decreases dry matter accumulation compared to early plantings (Burton, 1989b). For the variety main effect, 'Atlantic' total and marketable yields were 7% and 18% higher compared to 'Harley Blackwell', respectively (Table 2). Higher percentages of rots were observed in 'Harley Blackwell' during plantings 5 and 6 (9 Mar. and 24 Mar.), respectively which reduced the overall marketable yield. 'Atlantic' had higher specific gravity compared to 'Harley Blackwell' (1.077 and 1.075), respectively. The planting × variety interaction was not significant for total and marketable tuber yields. However, yields for both varieties decreased as total accumulated GDD at harvest surpassed 2300 (Fig. 1).

The goal of this project is to accumulate yield data over multiple planting dates to develop a model that will allow growers to determine the optimum planting dates for chipping varieties in northeast Florida. In addition, growers can determine the positive or negative potential yield difference between planting dates based on GDD accumulation for a proposed 100-d season. This will help them better schedule production for contract production. Future data will further verify and strengthen the validity of the GDD model for potato planting in northeast Florida.

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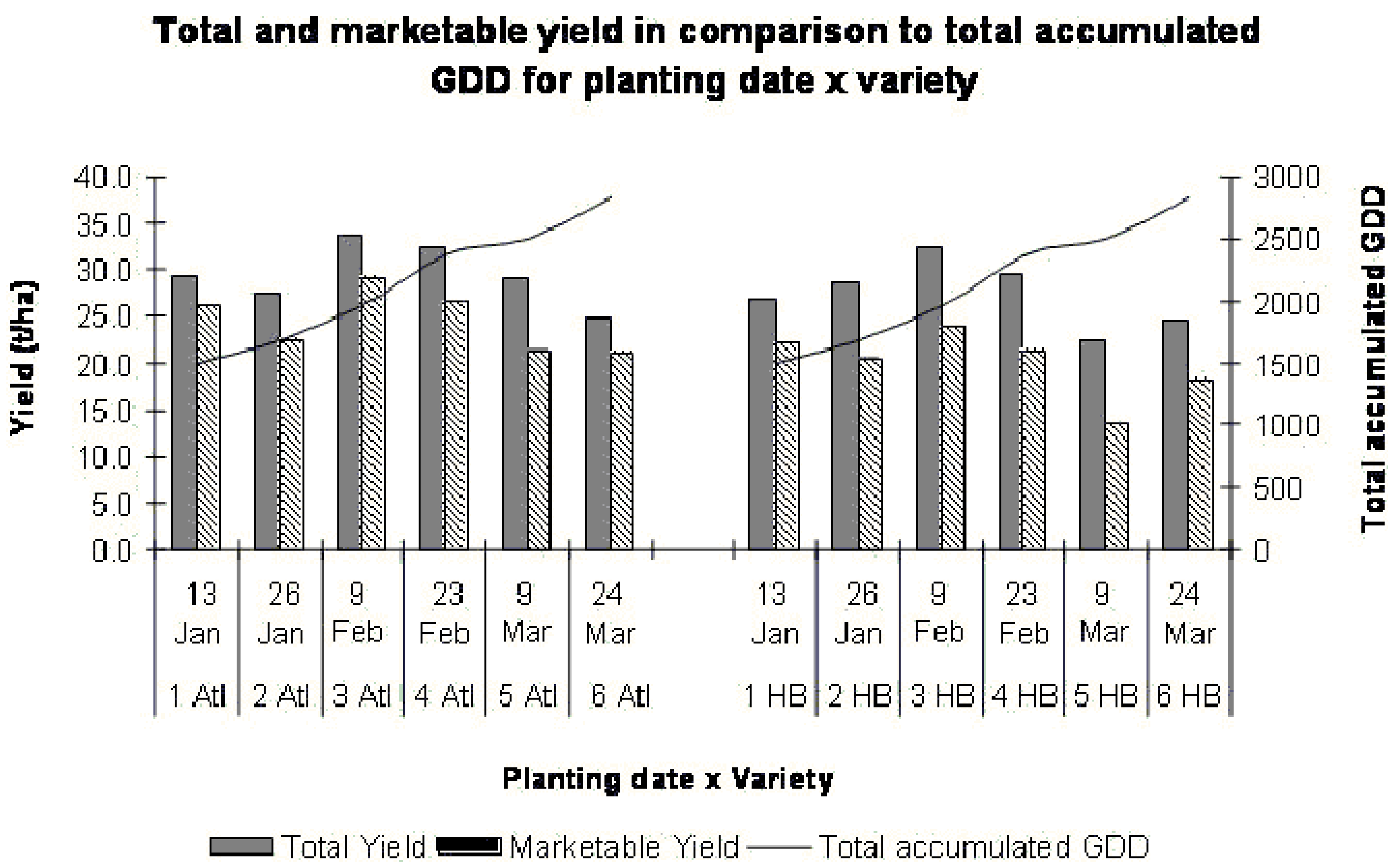

Fig. 1. Total and marketable yield in comparison to total accumulated growing degree days at harvest for planting date × variety—Spring 2004.

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