TIMING AND VALUE OF WATER IN COTTON PRODUCTION

James P. Bordovsky
Joe T. Mustian
Texas A&M AgriLife Research
Halfway/Lubbock, TX

Abstract

Within the Ogallala Aquifer region of Texas, the available irrigation capacity for a given field can change within a single growing season due to declines in well capacity, diverting water to higher value crops in dry years, or pumping volume restrictions. To better manage available water resources in the Texas High Plans, there is a need to determine cotton lint yield and irrigation water productivity as a function of changing irrigation capacities during major cotton growth periods. LEPA irrigated cotton was evaluated at the Texas A&M AgriLife Research Center at Halfway, Texas from 2010 to 2012. The treatment factors included in-season irrigation capacity (maximums of 0 in/d – **L** (low); 0.125 in/d – **M** (medium); and 0.25 in/d – **H** (high)) and irrigation application within cotton growth periods determined by heat unit (hu) accumulation, early vegetative/juvenile (< 950 hu); reproductive (950-1350 hu); and maturation (>1350 hu). Combinations of these factor levels resulted in 27 irrigation regimes or treatments. In all years, cotton yield and water productivity indicated that attempting to add water to the profile, or irrigating in excess of the evapotranspiration rate of the cotton plants early in the growing season, reduced irrigation water value compared to applying irrigation later in the growing season. This was attributed to water loss from excessive evaporation (high wind, low humidity) that often occurs in May and June in the Texas High Plains. Irrigation water value during reproductive and maturation periods resulted in water productivity in excess of 100 lb/ac-inch of water applied.

Introduction

Within the Ogallala Aquifer region of Texas, the available irrigation capacity for a given field can change within a single growing season. Typically this is due to declining water tables. More recently, it is due to growers diverting irrigation from one crop (cotton) to other crops (corn) which may have higher value, or are at a more critical growth stage than cotton, particularly in a year of low rainfall. Furthermore, groundwater conservation districts in the Texas High Plains will begin enforcing pumping restrictions which could cause abrupt changes in irrigation rates as limits are reached. Timing of irrigation applications using available water is becoming very critical and is further complicated by erratic rainfall.

Maximum water use efficiency as a function of irrigation volume and timing has been determined by applications at different cotton growth stages using the furrow method (Newman, 1966). This experiment as well as others showed large yield reductions when water deficits occurred during peak flowering periods as compared to earlier or later in the flowering period (Jordan, 1983). More recent deficit irrigation studies, using Low Energy Precision Application (LEPA) and subsurface drip irrigation (SDI) delivery systems, evaluated treatments having somewhat uniform irrigation deficits over the entire growing season, either as a percent of evaporative demand (Bordovsky and Lyle, 1992) or at uniform, limited irrigation capacities (Bordovsky and Porter, 2003). Recent research of non-uniform timing of limited irrigation with LEPA and SDI has focused on pre-plant irrigation, diverting water from cotton to grain sorghum, and the timing of irrigation termination. Full pre-plant irrigations significantly increased cotton yield over treatments with limited pre-plant irrigation, however, water value was higher when those pre-plant water units were applied closer to peak consumptive periods (Bordovsky and Porter, 2004). An evaluation of irrigation termination based on physiological cotton development was conducted at the Halfway and New Deal research sites with results showing fiber quality increases and lint yield declines with early irrigation termination (Sneed, 2010). An overall systematic evaluation of cotton response to center pivot irrigation as a function of growth stage at several deficit irrigation capacities is not available.

The immediate objective of this project is to determine cotton lint yield, fiber quality, and irrigation water productivity as a function of combinations of irrigation capacities during three cotton growth periods. The overall objective is to improve water management and water value in a semi-arid environment where proposed regulations may restrict irrigation volume and pumping capacities are declining.

Method and Materials

Irrigated cotton was evaluated at the Texas A&M AgriLife Research and Extension Center at Halfway, Texas (3514 ft elev., 34^0 10’ N, 101^0 56’ W). The treatment factors included in-season irrigation capacity (maximums of 0 in/d – **low**, 0.125 in/d – **medium**, and 0.25 in/d – **high**) and irrigation application within specific growth periods. Periods were defined by heat unit (hu) accumulation and were designated as early vegetative/juvenile (< 950 hu), reproductive (950-1350 hu) and maturation (>1350 hu). Combinations of these factor levels resulted in 27 irrigation regimes or treatments. Table 1 provides a summary of all irrigation treatments and treatment names. The extreme treatments were 0 in/d, or **Low** irrigation capacity, in all growth periods (**LLL** or dryland treatment) and 0.25 in/d, or **High** irrigation capacity, in all growth periods (**HHH** treatment) which approached full irrigation in years of average rainfall. Within each treatment, water was applied at designated irrigation capacities in the specific growth periods according to a soil water balance that allowed increases in soil profile water to 80% of field capacity subject to a protocol described by Bordovsky and Lyle (1996). Therefore rainfall events reduced or terminated irrigations if soil water calculations indicated that the soil profile was above 80% field capacity.

The field used for this experiment was in a transitional soil changing from a Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls) to an Olton loam (fine, mixed, thermic Aridic Paleustolls). Average annual rain for the site is 18 inches with approximately 11 inches occurring from May to September; however, precipitation amount and timing is extremely variable. Limited and unpredictable rainfall as well as the high evaporative demand in spring and early summer necessitates supplemental irrigation for consistent crop production in the region.

A 4-span LEPA pivot was used to irrigate 9.5 acres in this test. The pivot was modified so that each 8-row width (40-in, circular rows) along the lateral length could automatically be provided with different irrigation amounts depending on the treatments being irrigated and pivot position. Changes in irrigation treatments occurred as frequently as every 16 degrees of pivot movement. Figure 1 shows a schematic of the plot plan for this experiment. Irrigation quantities within an 8-row section were governed by irrigation applicator (nozzle) orifice size and on/off cycling of the applicator. Pivot position was determined by corrected GPS signal located at the distal end of the pivot. Pivot speed was constant for all applications. Each nozzle was controlled by a solenoid valve located in the drop line near the lower cord of the pivot span truss. Groups of four valves (irrigating an 8-row plot) were actuated using signals from a variable-rate irrigation controller (Farmscan 7000, Dothan, Alabama) with specific time sequences for each irrigation treatment and distance from the pivot point. Electrical systems for power distribution and valve control (to signal on/off sequences) were designed and installed along the length of the pivot lateral. Appropriate control and evaluation software was developed for the irrigation controller and flow monitoring systems. Inputs to the controller were pivot location (via GPS signal) and irrigation quantity (via application map) for each 8-row x 16-degree area irrigated by the pivot. View of the site-specific controller and irrigated plots are in figures 2 and 3. The research protocol and field design provided a complete randomized block experimental design with three replications. The pivot modification, pivot evaluation, and software development were conducted in 2009. The field experiment was initiated in 2010 and continued in 2011 and 2012 with refinements in the irrigation system during these years.

Prior of each crop year, treatment areas were grouped by lint yield of the previous year and soil nutrient samples obtained from plots of each grouping. Nitrogen, phosphorus and trace elements were applied in a site-specific manner and in amounts to prevent yield reductions from nutrient limitations with average rainfall and expected irrigation (Table 2). In each year, pre-plant LEPA irrigations were uniformly applied in all plots for plant establishment. Due to the high air temperatures and elevated wind speeds at planting, additional applications were made by low elevation spray to insure seed germination in 2011 and 2012. Cotton was planted in early May of each year (Table 2). Prior to each in-season irrigation, daily soil water balances were calculated for each treatment using information from the Texas High Plains ET Network (Porter, et al., 2005), local rainfall, irrigation quantity from previous irrigations and a locally derived crop coefficient. The water balance calculations determined irrigation amounts, subject to treatment limitations, for that set of irrigations. Irrigation frequency was generally every 2 to 4 days. Following irrigation, water volume applied in each plot was determined from water meters and data loggers at each 8-row section. Volumetric soil water content and cotton canopy temperatures were monitored in selected treatments during the growing season. The three growth period dates for each year are in Table 2.

Seed cotton sample weights (4-row x ~ 80 ft) were obtained by using an automated weighing system on a modified 4-row John Deere 7445 cotton stripper. Cotton sub-samples (~2.0 lb) from each harvested sample were ginned to determine lint percentage at the Texas A&M AgriLife Research and Extension Center in Lubbock, Texas. Fiber quality parameters of lint samples were determined by the High Volume Instrument (HVI) system at the Fiber and Biopolymer Research Institute, Texas Tech University in Lubbock. Commodity Credit Corporation (CCC) cotton loan values were determined from fiber quality parameters of lint samples. Cotton lint yield, fiber quality and water productivity were determined for each treatment. Data analysis was with standard AOV and means separation.

Results

The growing seasons of 2010, 2011, and 2012 were quite different in terms of rain and temperature. Monthly rain is charted in Figure 4. In 2010 above average rain occurred with twice the average rainfall from January to April. This provided an excellent soil water base to begin the irrigation season. 2011 was a record setting year in terms of heat, low rain, and high wind speeds, particularly in April through July. The 2012 rain was below average with rains that occurred in June and September being large, but ineffective due to high rain intensity and runoff in June and being too late for yield enhancement in September.

Table 3 contains the 3-year average seasonal irrigation quantities, lint yield, seasonal irrigation water use efficiency, and cotton fiber loan values from the 27 irrigation treatments. Over the 3-year period, cotton lint yield ranged from 326 lb/ac/yr in the **LLL** treatment (dryland) to 1218 lb/ac/yr in the **MHH** (0.125 in/d, period1; 0.25 in/d, period2; and 0.25 in/d period3). Seasonal irrigation water use efficiency (SIWUE) ranged from 0.4 lb lint/ac-in for the **MLL** treatment to 74.4 lb lint/ac-in for the **LHH** treatment. Fiber quality, as indicated by loan value, was significantly lower in treatments irrigated in the vegetative period (period2) but not the maturation period (period3) than other treatments. Loan values ranged from $0.469 in the **LHL** treatment to $0.560 in the **MMH** treatment.

A common irrigation strategy, where pumping capacities are less than the peak evaporative demand, is to irrigate at full capacity early in the growing season in an attempt to store water in the soil profile so that profile water is available later in growing season during peak water use periods. Insight into the effectiveness of this strategy is obtained by contrasting treatments having uniform irrigation application rates through the growing season, **MMM** and **HHH** treatments, with those with lower rates early and increased rates as crop water requirements increase, **LMM** and **MHH** treatments. The **MMM** treatment resulted in a 772 lb/ac 3-year average yield using 8.7 in/yr of seasonal irrigation compared to the **LMM** treatment having a 762 lb/ac/yr yield with 29% less seasonal irrigation (8.7 in/yr vs. 6.1 in/yr, respectively). The **HHH** treatment resulted in an average of 1154 lb/ac/yr with 13.8 in/yr of irrigation compared to **MHH** at 1218 lb/ac with 12.8 in/yr or a 6% yield increase with 7% less irrigation volume (Table 3). Data from individual years follow these same trends (data not shown). These results support the theory that a large portion of the pivot irrigation water is lost due to high evaporative demand early in the growing season and the highest water productivity occurs when irrigation application is more proportional to crop water demand of the crop.

Comparisons of other treatments provide quantitative yield responses resulting from irrigation volume changes during the reproductive (period2) and maturation (period3) periods. For example, the only difference in the **MLH**, **MMH**, and **MHH** treatments were the irrigation amounts during period2, a 3-year average of 0.0, 2.2, and 3.9 in above that of the **MLH** treatment, respectively, resulting in yields of 613, 964, and 1218 lb/ac/yr (Table 3). The yield increase resulting from the first 2.2-inch increase in irrigation volume above that of **MLH** during period2 was 351 lb/ac (or 160 lb lint/ac-in), the additional irrigation quantity of 1.7 in above that of **MMH** resulted in a further yield increase of 254 lb/ac (or 149 lb lint/ac-in). Similarly, the differences in treatments **HHL**, **HHM**, and **HHH** were increases in irrigation amounts above the **HHL** treatment of 0, 3.5, and 5.0 inches, respectively, in period3. The yield increase from the first 3.5 inch increase was 423 lb/ac/yr (or 120 lb lint/ac-in), and with the further increase in irrigation of 1.5 inches, the yield increased by 240 lb/ac/yr (or 160 lb/ac-in). Irrigations in period2 and period3 resulted in very high water productivity during the three year test period.

Conclusions

Test results to date were obtained from years representing record breaking extremes - high rainfall in 2010 and low and ineffective rainfall in 2011 and 2012. In all years, cotton yield and water productivity data indicated that trying to store water in the soil profile, or irrigating in excess of the evapotranspiration rate of the cotton plants, early in the growing season reduced irrigation water value compared to applying irrigation later in the growing season. This was attributed to water loss from excessive evaporation (high wind, low humidity, and high temperatures) that often occurs in May through June in the Texas High Plains. Irrigation water value during reproductive and maturation periods resulted in water use efficiencies in excess of 100 lb/ac-inch of irrigation applied. Additional field tests can provide the foundation for in-season irrigation recommendations that will optimize lint yield (and water value) based on irrigation pumping and volume restrictions.

Acknowledgements

The authors would like to gratefully acknowledge the contributions to this project by David Winters, Cora Lea Emerson, and Casey Hardin and his staff. This project has been supported by the Texas State Support Committee of Cotton Incorporated as well as the Ogallala Aquifer Program, a consortium between USDA-Agricultural Research Service, Kansas State University, Texas A&M AgriLife Research, Texas A&M AgriLife Extension, Texas Tech University, and West Texas A&M University. Portions of the weather data used in this experiment were obtained from the Texas High Plains Evapotranspiration Network, T. Marek, D. Porter, and T. Howell, Directors.

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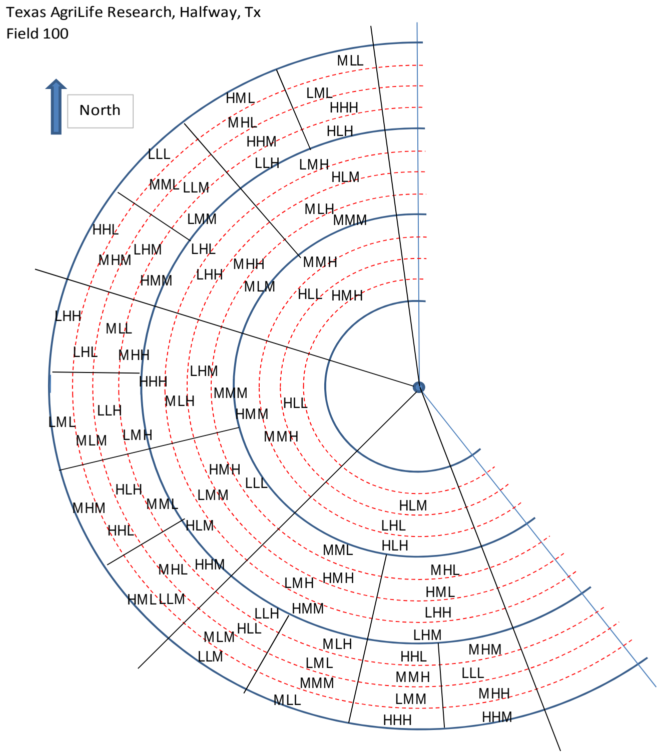

Figure 1. Schematic of plot plan to accommodate 27 irrigation treatments with replication on a 9.5-acre, LEPA irrigated field.

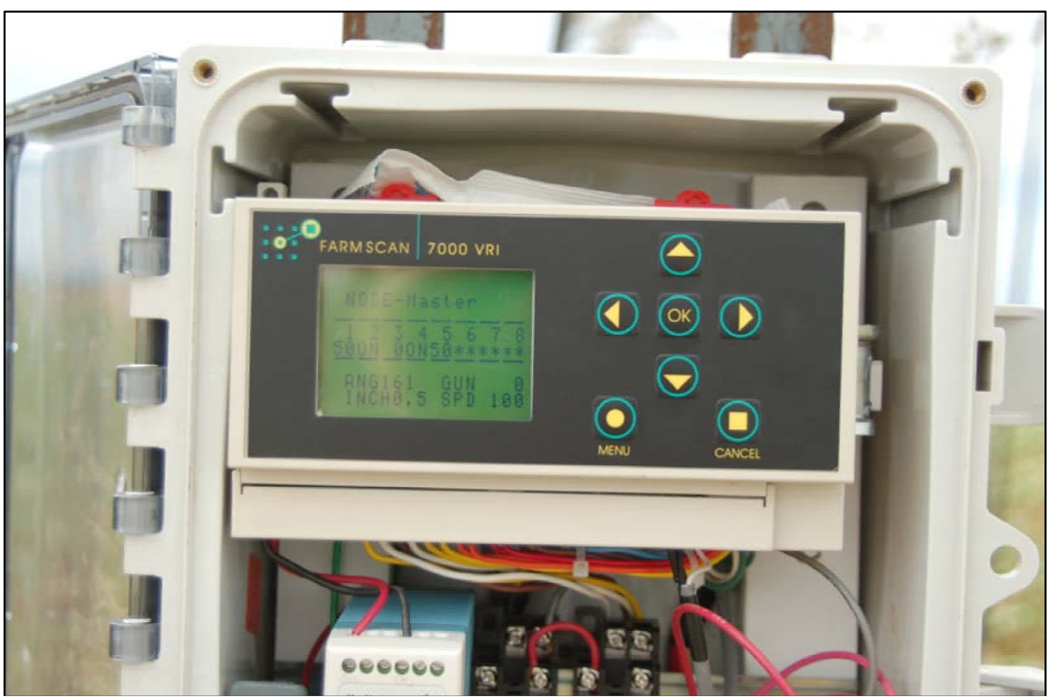

Figure 2. Site-specific irrigation system controller programmed with application maps that applied different irrigation rates on 8-row plots every 16 to 64 degrees of the pivot arc.

Figure 3. Site-specific LEPA irrigation system used to water three replicates of 27 different irrigation treatments in experiments conducted at the Texas A&M AgriLife Research Center at Halfway, 2010-2012.

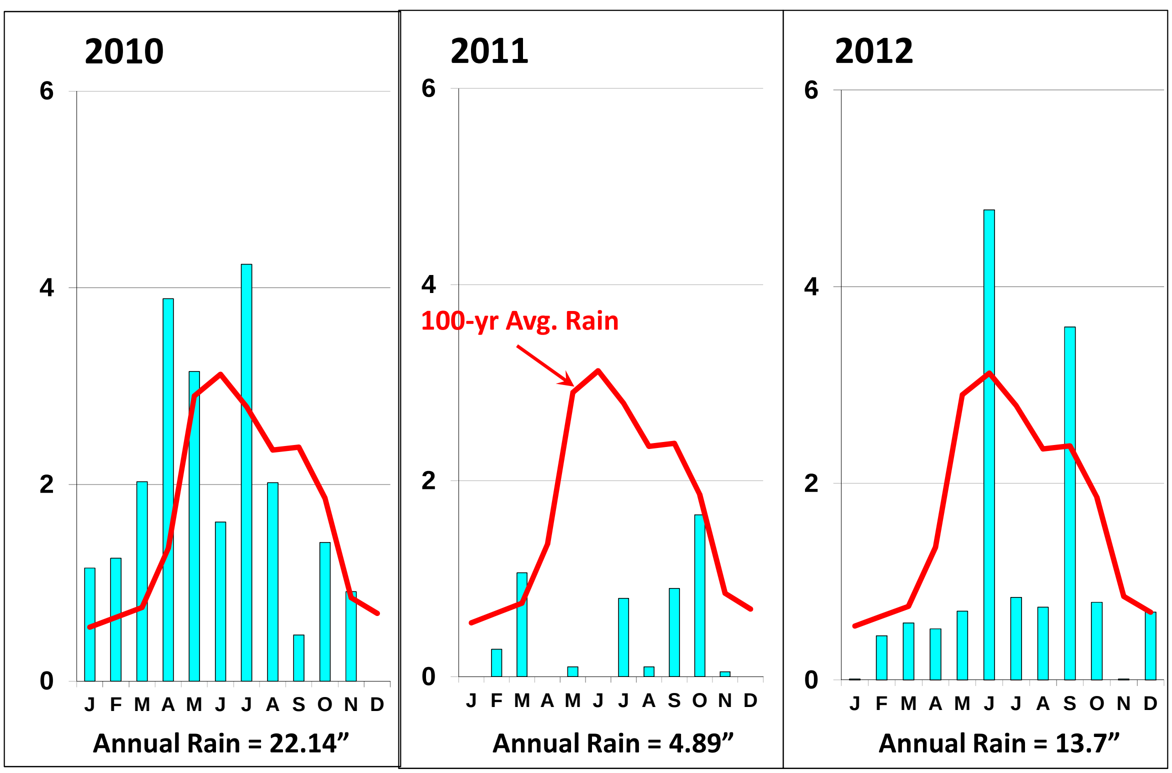

Figure 4. Monthly rain totals and 100-year average rainfall at the Texas A&M AgriLife Research Center at Halfway, 2010-2012.

Table 1. Irrigation capacities at cotton plant growth stages of 27 irrigation treatments.

Treat. No	Treat Name	Crop Development Periods		
		Period 1 - Vegetative	Period 2 - Reproductive	Period 3 - Maturation
1	LLL	Low	Low	Low
2	LLM	Low	Low	Medium
3	LLH	Low	Low	High
4	LML	Low	Medium	Low
5	LMM	Low	Medium	Medium
6	LMH	Low	Medium	High
7	LHL	Low	High	Low
8	LHM	Low	High	Medium
9	LHH	Low	High	High
10	MLL	Medium	Low	Low
11	MLM	Medium	Low	Medium
12	MLH	Medium	Low	High
13	MML	Medium	Medium	Low
14	MMM	Medium	Medium	Medium
15	MMH	Medium	Medium	High
16	MHL	Medium	High	Low
17	MHM	Medium	High	Medium
18	MHH	Medium	High	High
19	HLL	High	Low	Low
20	HLM	High	Low	Medium
21	HLH	High	Low	High
22	HML	High	Medium	Low
23	HMM	High	Medium	Medium
24	HMH	High	Medium	High
25	HHL	High	High	Low
26	HHM	High	High	Medium
27	HHH	High	High	High

Table 2. Agronomic data for irrigation timing experiment at the Texas A&M AgriLife Research Center at Halfway, TX, 2010-2012.

	2010	2011	2012
Fertilizer			
Maximum (lb of N-P-K-S-Zn/ac)	50-115-0-0-0	131-77-0-7-0	134-74-0-0-1
Date(s)	26-May, 10-June	11-Mar	23-Feb
Pre-plant Irrigation Amt			
Amount (ac-in/ac)	0.00	3.45	2.88
Irr. Period Dates	-	5 Apr - 6 May	24 Apr - 4 May
At-plant Irrigation Amt.			
Amount (ac-in/ac)	0.00	2.00	0.73
Irr. Period Dates	-	12 May - 24 May	11-May
Seasonal Irrigation			
Total Amount Range (ac-in/ac)	0.00 - 9.15	0.00 - 17.60	0.00 - 14.60
Period1 Dates	26 Jun - 17 Jul	14 Jun - 10 Jul	21 Jun - 13 Jul
Period2 Dates	18-Jul -7 Aug	11-Jul -3 Aug	14-Jul -4 Aug
Period3 Dates	8 Aug -6 Sep	4 Aug -30 Aug	5 Aug -4 Sep
Planting			
Variety	FM9180B2F	FM9180B2F	FM9180B2F
Date	11-May	11-May	10-May
Seeding Rate (seed drop/ac)	50000	54000	54000

Table 3. Average cotton lint yield, seasonal irrigation quantity, water productivity, and lint loan values of 27 irrigation timing treatments at the Texas A&M AgriLife Research, Halfway, TX, 2010-2012.

Treat No.	Treat Name	Seasonal Irrigation Amt (ac-in/ac)	Yield (lb/ac)	SIWUE (lb/ac-in)	Lint Loan Value ($/lb)
18	MHH	12.8	1218 a**	69.5 abc	0.542 abcd
27	HHH	13.8	1154 a	60.2 abcd	0.552 ab
9	LHH	10.7	1121 a	74.4 a	0.537 abcd
24	HMH	12.9	1016 b	53.7 bcde	0.553 ab
15	MMH	11.1	964 bc	57.4 abcd	0.560 a
17	MHM	10.8	936 bcd	56.4 abcd	0.549 abc
26	HHM	12.3	924 bcd	48.9 defg	0.518 abcd
6	LMH	8.7	882 cd	64.0 abcd	0.554 ab
8	LHM	8.5	853 de	62.3 abcd	0.536 abcd
23	HMM	10.4	838 de	49.1 defg	0.526 abcd
14	MMM	8.7	772 e	51.2 cdef	0.532 abcd
5	LMM	6.1	762 e	71.6 ab	0.541 abcd
21	HLH	10.6	657 f	31.3 ghij	0.537 abcd
12	MLH	8.9	613 fg	32.5 ghij	0.524 abcd
3	LLH	6.3	551 gh	35.9 efgh	0.533 abcd
20	HLM	7.7	545 ghi	28.4 hij	0.539 abcd
2	LLM	3.4	516 ghij	56.3 abcd	0.526 abcd
25	HHL	8.8	501 hij	19.9 hijk	0.478 cd
11	MLM	6.0	480 hij	25.7 hij	0.527 abcd
7	LHL	5.1	450 hij	24.5 hij	0.469 d
13	MML	5.3	448 ij	23.1 hij	0.483 bcd
16	MHL	7.4	446 ij	16.3 ijkl	0.493 abcd
22	HML	7.0	434 jk	15.4 jkl	0.486 bcd
4	LML	2.7	418 jkl	33.9 fghi	0.478 cd
19	HLL	4.3	343 kl	3.9 kl	0.547 abc
10	MLL	2.6	327 l	0.4 l	0.531 abcd
1	LLL		326 l		0.513 abcd

** Means within a column followed by a common letter are not significantly different (Tukey, $p<0.05$)