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Effects of Long-Day Energy-Efficient Lighting on Milk Production in Dairy Operations

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Effects of Long-Day Energy-Efficient Lighting on Milk Production in Dairy Operations

Final Report

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1 Objective

The objective of this study was to evaluate barn lighting options in a freestall dairy barn. This study compared a long-day (16-hour) photoperiod (LDPP) lighting strategy with light-emitting diode (LED) fixtures, a LDPP lighting strategy with fluorescent (T8) fixtures, and a conventional lighting strategy with fluorescent (T8) fixtures. Barn light levels, milk yield, and energy usage were compared.

Relative duration of light and dark exposure within a day, or photoperiod, is the most common environmental cue used by animals to predict changes in their environment (Gwinner 1986). Seasonal changes in photoperiod result in physiological responses that influence multiple systems, including reproductive status, immune function, and body growth (Dahl and Petitclerc 2003). In poultry, manipulating photoperiod is commonly used to facilitate year-round egg production and in horses increasing light exposure accelerates the return to reproductive competence. In dairy cows, increasing light exposure increases milk production an average 5.1 pounds/cow/day (Dahl et al. 2000). This management strategy is known as long-day photoperiod (LDPP).

Despite these promising findings, implementing LDPP can be challenging for many commercial dairies. To stimulate milk yield, all areas of the barn require a minimum of 114 to 207 lux for 16 to 18 hours each day followed by a sustained dark period (Peters et al. 1978). Due to improper implementation among early adopters of LDPP (e.g., illuminating only the feed bunk, subjecting cows to continuous light exposure, and implementing LDPP during the summer months), it has not been confirmed that this management strategy is effective at increasing milk yield on a commercial dairy. Moreover, increased energy costs associated with LDPP must be analyzed to determine whether this management strategy is cost effective.

High pressure sodium fixtures and fluorescent lighting are commonly used on dairy farms, but farmers are exploring the use of LEDs because of the perception that they provide better lighting and are more energy efficient.

The goal of the project was to investigate the performance of T8 fluorescent fixtures and LED fixtures in the context of LDPP on a commercial dairy in western New York. The study looked at the impact of light source (T8 versus LED) on barn light levels, energy usage, and milk production under a long day lighting strategy compared to a negative control.

2 Experimental Design

This study was conducted on a 1,000-cow commercial dairy between September 2012 and November 2013. Cattle were housed in a conventional 6-row freestall barn with deep bedded sand stalls. Cattle were milked in a double 14 herringbone parlor three times daily and fed a total mixed ration (TMR) once daily with regular feed push up throughout the day. Free choice water was provided to cattle throughout the study through several open trough style waterers located in each pen. Recombinant bovine somatropin (rbST) was not used during this study.

Treatments were assigned to each of three barns. Fixtures used for these treatments replaced the 400-Watt high pressure sodium fixtures that were present in all barns. Barn A was illuminated with T8 lighting and contained a 154 stall pen that housed primiparous lactating cattle and a 154 stall pen that housed multiparous lactating cattle. Thirty-six T8 fluorescent fixtures were required to achieve the requisite light levels and set to be “ON” for 18 hours each day.

Barn B was illuminated with LED lighting and contained a 144 stall pen that housed primiparous lactating cattle and a 144 stall pen containing multiparous lactating cattle. Thirty-two LED fixtures were required to achieve the requisite light levels and set to be “ON” for 18 hours each day.

Barn C served as the control and contained one pen of 155 multiparous cattle illuminated with T8 lighting. The lighting system in this barn was not engineered to meet the minimum light requirements for LDPP with eight T8 Fluorescent fixtures set to be “ON” 12 hours each day.

As cows gave birth and began lactation, they were moved to a fresh pen where they were housed for 3-4 weeks. They were then moved to a treatment group based upon availability of space in the groups. Cattle were kept in their original group throughout the duration of the trial. Cattle were only moved as necessary to the treated pen if their milk was non-saleable due to medical therapy or as they were moved to the dry cow barn where they would not be milked for two months, awaiting the birth of their next calf.

Light was measured using a Lutron LX-107 digital light meter. Each barn was set up in a 3×4 grid with light measurements collected in the far alley, directly over the stalls, in the near alley, and over the feed bunk. This was repeated at the east end, middle, and west end of each barn. Light levels from each barn were then averaged to determine the overall light level for each barn. Light was measured after sunset at cow eye level to ensure that the light being measured was solely from the artificial light sources.

Body condition score (BCS) was measured once a month for the duration of the study. In dairy cows, BCS is an indicator of the amount of stored energy reserves and changes with the stage of lactation. Fresh cows in peak lactation tend to be in a negative energy balance and lose body condition, whereas cows in late lactation, dry cows, and low producing cows tend to be in a positive energy balance and gain body condition.

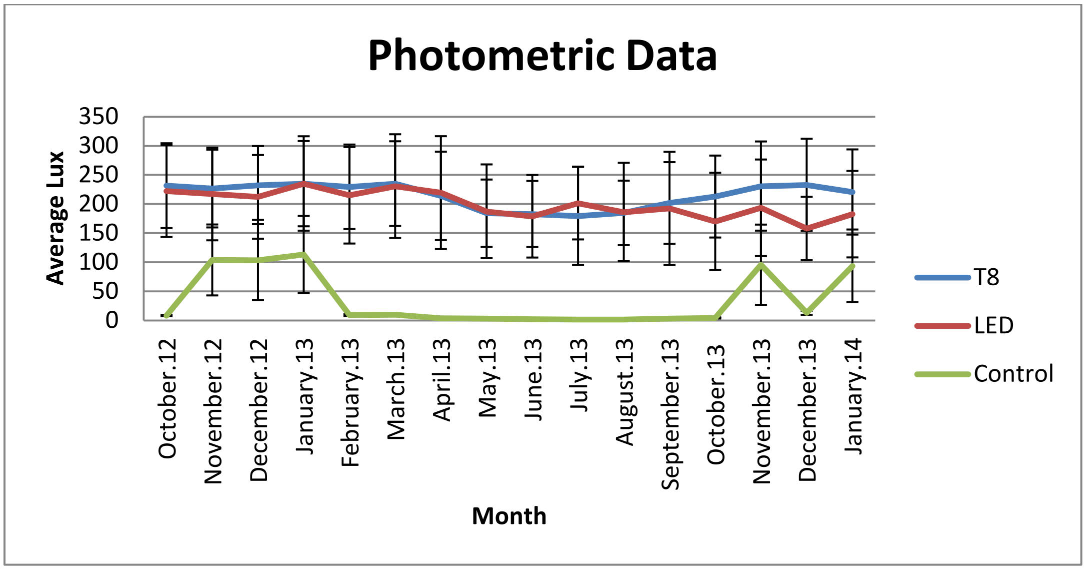
In dairy cows, BCS is usually quantified on a 1 to 5 scale. A score of 1 is an animal that is severely under conditioned with a deep cavity around the tail head, pelvic bones and short ribs that are sharp and easily felt, and no fatty tissue in the pelvic or loin area. A score of 5 is an animal that is severely over conditioned with the tail head buried under a thick layer of fatty tissue, pelvic bones that cannot be felt with firm pressure, and the short ribs covered with a thick layer of fatty tissue. BCS less than 2 are associated with reduced milk production and poor lactation persistency. BCS greater than 4 are associated with calving difficulties, fatty liver syndrome, impaired reproduction, and metabolic disorders. Because studies have shown that cows exposed to LDPP consistently increase milk production, these animals have greater metabolic demands associated with lactation and may lose body condition (Dahl et al. 2000). Therefore, BCS was monitored in all treatment groups to ensure animal wellbeing throughout the study. To assess BCS 40 cows in each group were selected at random and scored by two dairy specialists from Cornell Cooperative Extension's North West New York Dairy, Livestock, and Field Crops team. Scores were then averaged to give an overall score for each animal.

Milk production was measured through independent testing by DHIA (Dairy Herd Improvement Association) on a monthly basis with data being imported into Dairy Comp 305 (Valley Ag Software) and Excel (Microsoft) for analysis. Milk production average, standard deviation, and 95% confidence interval were evaluated. Milk production was compared by treatment group (T8, LED, and Control), season of calving (summer for animals calving April 1 though September and winter for animals calving October 1 through March) and parity (primiparus/first lactation versus multiparous/mature cows). Production statistics were evaluated with all cows in the trial grouped by test day (first month of lactation equals MILK 1, second month of lactation equals MILK 2, etc.). Milk was evaluated for 10 test day periods, roughly 300 days, for each cow.

3 Photometric Data

In the T8 and LED barns, average light levels never dropped below 150 lux, demonstrating that both the T8 and LED fixtures were capable of meeting the required light levels to stimulate milk yield in all areas of the barn based on current research (Dahl et al. 2000). In the Control barn light levels never exceeded 115 lux which did not meet the required light levels to stimulate milk yield based on current research (Dahl et al., 2000). Light measurements were collected monthly for the duration of the study and are illustrated in Figure 1. Note that the electrical lights in the Control barn were off when photometric measurements were made during the months when the light levels are recorded as at or near 0 lux.

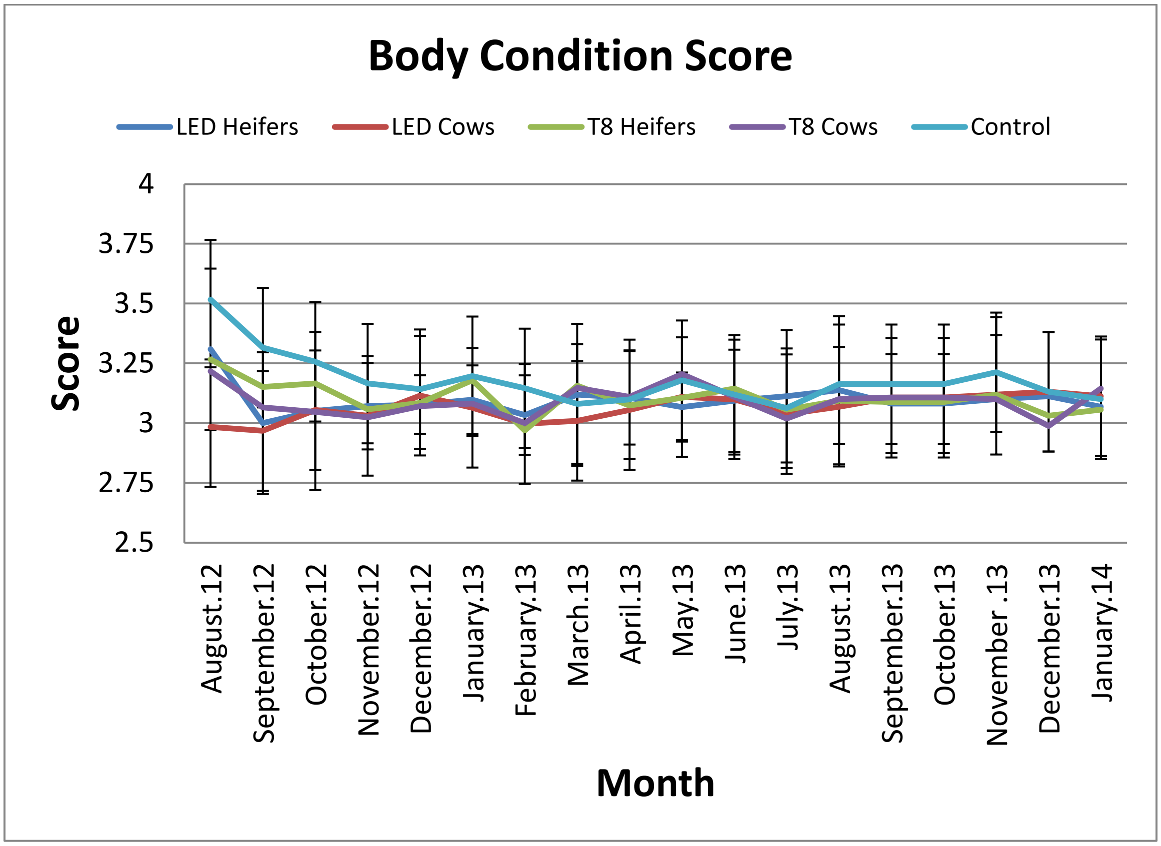
Figure 1. Photometric Data from T8, LED and Control Barns Expressed in Lux



4 Body Condition Score Data

Figure 2 illustrates the results of the body condition scores taken throughout the study. No animal ever scored less than 2.5, indicating that cows involved in the study were not under excessive metabolic stress. Cows in the Control group had a tendency for a higher BCS than cows exposed to LDPP, however cows in this group cows tended to be in the later stages of lactation where they are producing less milk and more likely to gain condition.

Figure 2. Average BCS for Cows and Heifers in the T8, LED, and Control groups



5 Milk Data

No statistical difference in milk production was detected in first lactation animals between the LED and fluorescent lighting treatment groups during either the summer or winter, as shown in Table 1, Table 2 and Figures 3, 4, 5, and 6.

Table 1. Average Milk Production, Standard Deviation, and 95% Confidence Interval for Milk Production by Season and Treatment Group for First Lactation Animals

Summer

First Lactation		MILK1	MILK2	MILK3	MILK4	MILK5	MILK6	MILK7	MILK8	MILK9	MLK10
LED	# animals	158	145	128	124	123	121	120	117	101	48
	average milk production	74.8	81.8	84.6	86.7	86.7	84.1	82.2	77.3	75.3	74.0
	standard deviation	25.8	23.0	19.9	17.8	14.4	17.9	14.7	13.9	13.6	13.0
	95% confidence interval	70.8-78.8	78.2-85.4	81.6-87.6	83.3-90.1	83.5-89.9	81.1-87.1	78.9-85.5	73.3-81.3	69-81.6	68.1-79.9
Fluorescent	# animals	126	125	119	109	94	81	54	43	22	17
	average milk production	70.7	80.0	81.0	79.5	77.0	77.3	75.9	69.6	69.1	72.2
	standard deviation	23.0	20.3	16.7	18.0	15.8	13.6	12.3	13.6	15.0	12.3
	95% confidence interval	67-74.4	75.6-83.4	77.8-83.2	76.2-82.8	73.1-80.9	73-81.6	71.7-80.1	64.4-74.8	62-76.2	68.1-75.3

Winter

First Lactation		MILK1	MILK2	MILK3	MILK4	MILK5	MILK6	MILK7	MILK8	MILK9	MLK10
LED	# animals	117	105	89	87	86	86	86	85	76	32
	average milk production	74.5	83.6	84.5	85.2	86.0	84.8	79.7	75.6	71.3	63.4
	standard deviation	22.8	21.3	17.9	15.0	16.6	15.1	11.3	11.8	12.8	20.1
	95% confidence interval	70.4-78.6	79.5-87.7	80.8-88.2	82.1-88.3	82.5-89.5	81.6-88	77.3-82.1	73.1-78.1	68.4-74.2	56.4-70.4
Fluorescent	# animals	158	145	128	124	123	121	120	117	101	48
	average milk production	74.8	81.8	84.6	86.7	86.7	84.1	82.2	77.3	75.3	74.0
	standard deviation	25.8	23.0	19.9	17.8	14.4	17.9	14.7	13.9	13.6	13.0
	95% confidence interval	70.8-78.8	78.1-85.5	81.2-88	83.6-89.8	84.2-89.2	80.9-87.3	79.6-84.8	74.8-79.8	72.6-78	70.3-77.7

Figure 3. Milk Production by Test Day and Treatment Group for First Lactation Animals During the Summer

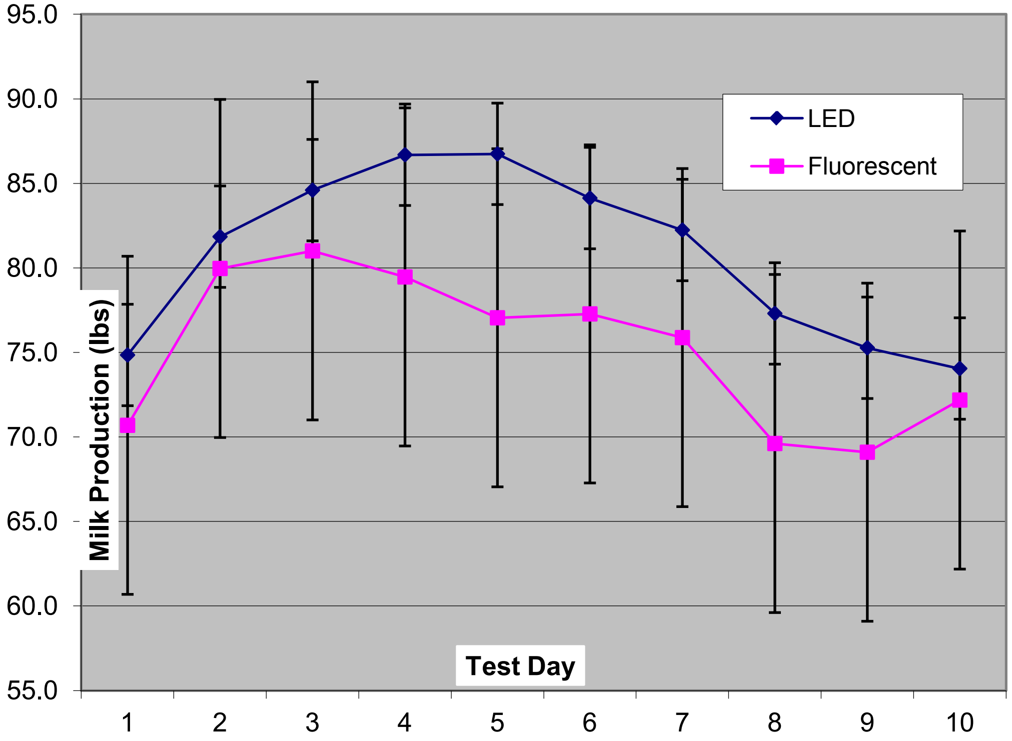


Figure 4. Milk Production by Test Day and Treatment Group for First Lactation Animals During the Winter

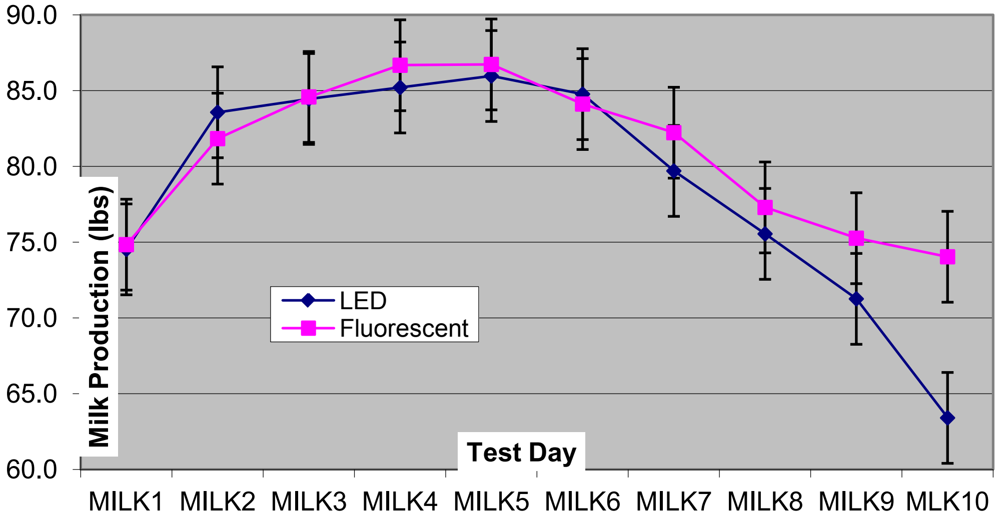


Table 2. Average Milk Production, Standard Deviation, and 95% Confidence Interval for Milk Production by Season and Treatment Group for Mature Cattle

Mature Cows	Summer	MILK1	MILK2	MILK3	MILK4	MILK5	MILK6	MILK7	MILK8	MILK9	MLK10
LED	Number of animals	178	177	173	160	140	116	89	69	51	40
	Average milk production	103.7	109.5	105.6	101.5	94.1	89.3	82.2	77.3	71.5	66.8
	standard deviation	20.4	19.7	20.8	19.5	18.4	16.6	17.8	21.2	21.9	22.8
	95% confidence interval	100.7-106.7	106.6-112.4	102.5-108.7	98.5-104.5	91.1-97.1	86.3-92.3	78.5-85.9	72.3-82.3	66.5-76.5	59.8-73.8
Fluorescent	Number of animals	179	177	168	160	132	116	89	67	38	29
	Average milk production	104.9	110.8	105.2	101.7	96.0	91.2	78.9	74.0	68.9	62.3
	Standard deviation	21.4	19.0	21.7	19.4	16.8	18.0	19.3	22.8	17.3	25.5
	95% confidence interval	101.8-107.7	108-113.6	101.9-108.5	98.7-104.7	93.1-98.9	87.9-94.5	74.9-82.9	78.5-79.5	63.4-74.4	53-71.6
Control	Number of animals	103	102	96	84	62	37	33	19	n/a	n/a
	Average milk production	106.9	111.1	108.5	107.5	100.5	95.8	85.2	77.3	n/a	n/a
	Standard deviation	20.7	19.2	18.6	17.5	16.5	13.8	16.9	16.2	n/a	n/a
	95% confidence interval	102.9-110.9	107.4-114.8	104.8-112.2	103.8-111.2	96.4-104.6	91.4-100.2	79.4-91	70-84.6	n/a	n/a

Table 2 continued

Mature Cows	Winter	MILK1	MILK2	MILK3	MILK4	MILK5	MILK6	MILK7	MILK8	MILK9	MLK10
LED	Number of animals	121	102	88	87	87	84	83	81	77	52
	average milk production	104.9	109.5	107.6	98.6	96.2	94.2	87.1	78.3	70.6	68.5
	standard deviation	20.1	18.0	22.0	21.3	18.9	19.0	18.6	19.4	20.4	21.6
	95% confidence interval	101.3-108.5	106-113	103-112.2	94.1-103.1	92.2-100.2	90.2-98.2	83.1-91.1	74.1-82.5	66-75.2	62.6-74.4
Fluorescent	Number of animals	102	88	76	76	74	73	71	71	68	41
	average milk production	104.4	107.1	104.6	102.9	101.0	98.5	88.6	82.2	71.7	65.3
	standard deviation	19.5	21.6	20.1	20.6	20.0	20.9	20.6	22.3	25.1	23.3
	95% confidence interval	100.6-108.2	102.6-111.6	100.1-109.1	98.3-107.5	96.5-105.5	93.7-102.3	83.8-93.4	77-97.4	65.7-76.7	58.2-72.4
Control	Number of animals	178	150	132	130	127	124	124	122	110	69
	average milk production	103.3	111.8	107.2	105.4	101.1	96.8	91.8	80.5	71.5	62.5
	standard deviation	20.4	20.6	23.2	18.5	20.0	15.2	17.0	20.0	19.7	21.8
	95% confidence interval	100.3-100.6	108.5-115.1	103.2-111.2	102.2-108.6	97.7-104.6	94.1-99.5	88.8-83.5	76.9-84.1	67.8-75.2	57.4-67.6

Figure 5. Graph of Milk Production by Test Day and Treatment Group for Mature Cattle during the Summer

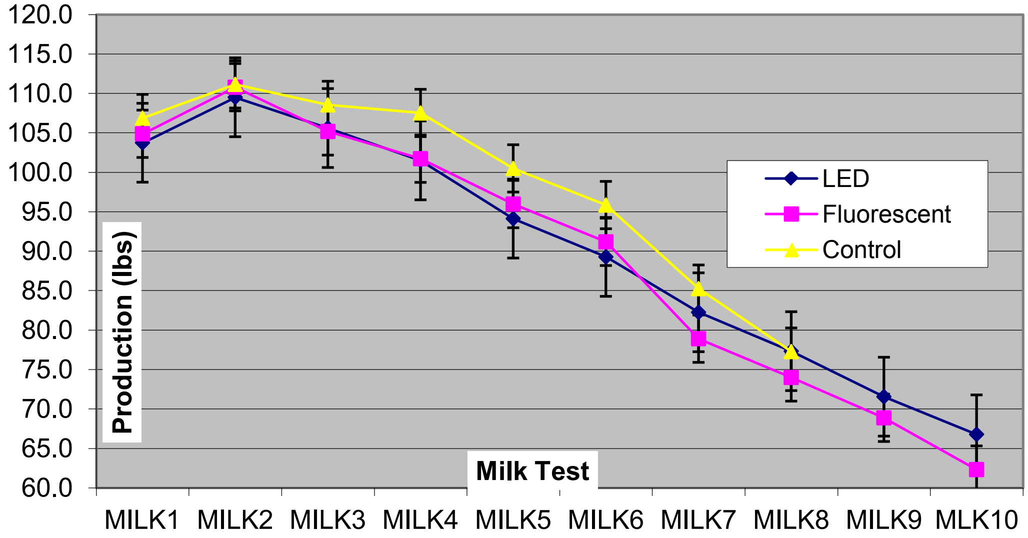
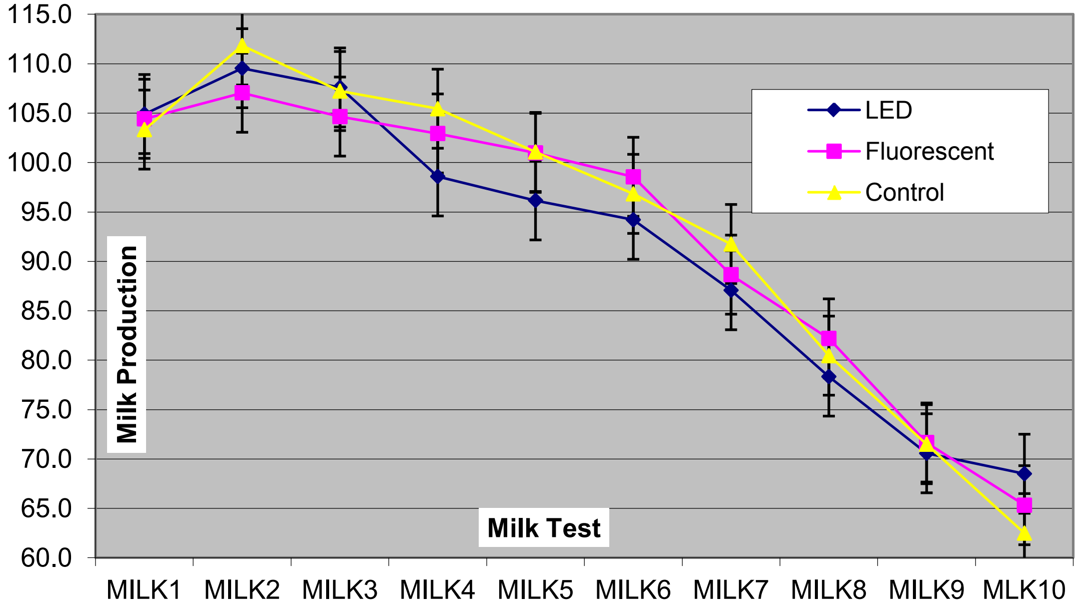


Figure 6. Milk Production by Test Day and Treatment Group for Mature Cattle during the Winter



6 Economic Analysis

Reduced energy use associated with LED and T8 fixtures relative to using the existing 400-Watt high pressure sodium fixtures before the study is shown in Table 3.

Table 3. Percent Change in Energy Use for Barns A, B, and C by Technology vs. 400-Watt High Pressure Sodium Lights Before Study

	LED, LDPP Barn A 18 hr/d; 32 fixtures	**T8, LDPP Barn B 18 hr/d; 36 fixtures**	**T8, non LDPP Barn C 13 hr/d; 12 fixtures**
Basis for Comparison -- Existing, Before Study, 400W HPS Fixtures	Minus 47 Percent	Minus 56 Percent	Minus 52 Percent

Partial budgeting and net present value (NPV) analysis were used to evaluate economic aspects associated with LDPP and alternative technologies. Analysts used the partial budget approach to estimate the change in profit associated with a change in the farm business, for example, in Barn A, a change to LED LDPP from T8 non LDPP, proposed vs. current, respectively. NPV analysis considers the time value of a stream of net cash flows, net cash incomes over the life of the investment. If the net present value of an investment is greater than or equal to zero, then the investment is attractive to the decision maker.

All analyses are at the barn level, and reflect roughly 2012 price levels. Capital investments required to fit Barn A with LED LDPP, Barn B with T8 LDPP, and Barn C, the control barn, with T8 non LDPP totaled $43,758, $12,383, and $4,128, respectively. Analysts obtained net milk price, and expenses for dairy grain and concentrate and other purchased inputs per hundred weight of milk from the Dairy Farm Business Summary Program (Cornell University).

For the LED LDPP vs. T8 non-LDPP control comparison, given an expected milk response of 0 pounds per cow per day and a LED lifetime of 80,000 hours, partial budget analysis yielded an expected change in profit for an average future year of negative $8,400. Expected changes in profit for all 15 combinations of LED lifetime and electric cost evaluated via sensitivity analysis were negative (Table 4).

Table 4. Expected Change in Annual Profit, LED LDPP vs. T8 non-LDPP Control by LED Lifetime in Hours by Dollars per kWh

	LED Lifetime in Hours		
$ per kWh	**50,000**	**80,000**	**100,000**
		-- Dollars --	
0.08	-9,796	-7,627	-6,916
0.09	-10,183	-8,013	-7,303
0.1	-10,569	-8,400	-7,690
0.11	-10,956	-8,787	-8,077
0.12	-11,343	-9,173	-8,463

Results are sensitive to expected milk response. For example, if the response equals 3 pounds per cow per day, then expected change in profit for Barn A is $10,325, and NPVs for all three LED lifetimes are greater than zero.

For the T8 LDPP vs. T8 non-LDPP control comparison, given a milk response of 0 pounds per cow per day and a T8 lifetime of 24,000 hours, partial budget analysis yielded an expected change in profit for an average future year of negative $6,846. Expected changes in profit for all 15 combinations of electric cost and T8 lifetime were negative, ranging from a low of negative $8,095 annually for the $0.12 per kWh, 20,000 lifetime hours combination to a high of negative $5,597 for the $0.08 per kWh, 30,000 hours combination. Analysis yielded an NPV of negative $22,138 for the 24,000 hour life. Results are sensitive to expected milk response. For example, if the response equals 3 pounds per cow per day, then the expected change in profit for Barn B is $11,879, and the NPV for the 24,000 hour T8 lifetime is positive.

A second set of analyses evaluated LED and T8 technologies compared to the before study, 400W HPS High Bay system. Analyses reflected equal numbers of fixtures and annual hours of operation for the study and before study comparisons. For example, for the Barn A study vs. before study comparison of LED vs. HPS, fixture numbers and hours of operation per day were constant at 32, and 18, respectively.

Given a milk response of 0 pounds per cow per day, partial budget, NPV and sensitivity analyses comparing LED and T8 systems to the before study 400W HPS system for Barns A, B, and C yielded expected increases in profit over a range of hours of lifetime and dollars per kilowatt-hour, and NPVs greater than zero. Note that the analyses developed do not reflect marginal internal or external economic and environmental benefits and, or costs associated with the different technologies, for example, those potentially attributed to mercury contained in fluorescent fixtures.

7 Conclusions

7.1 Milk Production

Despite previous research results, LDPP did not result in an increase in milk yield in this study. There was no statistical difference in milk production detected between the first lactation animals in the LDPP LED and the LDPP T8 treatment groups, nor between the mature cattle in the LDPP LED, the LDPP T8 and the control T8 treatment groups. In theory, LDPP sounds like an easy way to make more milk. In practice, implementing LDPP on commercial dairy farms can be challenging. LDPP requires 6 to 8 hours of *uninterrupted darkness* following the 16 to 18 hours of light, which can be a difficult condition to meet when milking three times per day. Although the lights were placed on timers to achieve the necessary 6 to 8 hours of darkness, sometimes part of a group was exposed to light during their “dark” period, because they were still in the holding area or milking parlor. In addition, part of the study took place during the extreme cold of the winter of 2013-2014. This weather caused two of the waterers to freeze in the LED barn, therefore providing inadequate access to water for part of the season.

The dairy manager suggested that to make LDPP work on this farm, they might need to only use it in one or two barns and focus on the high producing cows that have the potential to gain the most in milk production. Then the milking schedule could be arranged so that the group or groups not on a LDPP schedule could be milked during the middle of the night, when lights would be off in the LDPP groups.

Other comments from the dairy manager on the nature of the LED and T8 fixtures were positive. He felt that both produced excellent quality light that was a huge improvement over the high pressure sodium fixtures that they replaced. Although data were not collected to prove this opinion, he felt that having better lighting in the barns allowed him and his employees to be more efficient when working with cows; they now find it much easier to read ear tag numbers and to notice cows that are in heat or injured.

Both the LEDs and the T8s were relatively maintenance-free during the period of the trial. There were a few problems with water damage and condensation and algae growth in the LEDs, which required unexpected maintenance. The T8s do require routine maintenance in changing the bulbs, but this is expected to occur only every few years.

7.2 Economic Analysis

Given the milk response conclusions, LDPP using LED or T8 technology cannot be expected to increase profit or to yield net present values (NPVs) greater than or equal to zero when compared to the T8, non-LDPP control. Results are sensitive to bulb lifetime, energy costs, expected milk response, expected rebates, and others. T8 and LED fixtures can be expected to increase profit, and yield NPVs greater than or equal to zero when compared to 400W high pressure sodium high bay fixtures. For the latter analysis, results suggest that the overall economic advantage goes to the T8 technology because of the LED system's greater initial capital investment combined with greater uncertainty surrounding LED expected useful life in hours when compared to the T8 technology.

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