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Undergraduate students in the Bumpers College of Agricultural, Food and Life Sciences are being educated to seek solutions to today’s societal and food production challenges by applying proper scientific method and research protocols. Public support of higher education enables students to pursue research projects—both quantitative and qualitative—with their faculty mentors. Sixty faculty members presently serve as mentors to students to assist them with their research agendas. Most, but not all, such projects are designed to meet the requirements of an honors thesis in the Bumpers College Honors Program. Whether in the Honors Program or not, students who take advantage of research opportunities gain scientific and professional skills that can strengthen their contributions to society. Conducting a research project and authoring the results add value to their university education.

The Bumpers College encourages student research by awarding undergraduate research grants, including the Carroll Walls Undergraduate Research Fellowship, which provides a grant of $1,000. We awarded 9 Undergraduate Research Grants in the fall of 2003.

DISCOVERY provides a reporting outlet for our student scientists that empowers them to bring the research process to fruition. Being published in DISCOVERY does not supersede publication elsewhere; this journal provides a forum for students and faculty to share their results and findings in a citable publication.

The 17 articles in this fifth annual volume of DISCOVERY cover a wide range of topics. They explore production issues in rice, soybean, swine, poultry, silage, green beans, and blackberries. Topics also include research on wetlands, soils, cognitive processes, and academic performance. We are proud to present these articles as examples of the research accomplishments of our undergraduate students.

I heartily congratulate the student authors on their accomplishments and extend thanks to their faculty mentors and to the editors who reviewed their manuscripts. Thanks also to the Honors Committee for providing a structured program that encourages our students to step up to today’s challenges.

Gregory J. Weidemann, Dean
and Associate Vice President for Agriculture
Effect of pig weaning age and commingling after the nursery phase on humoral and behavioral indicators of well-being and on growth performance

Sarah C. Arthur*, Mari E. Davis†, Jason K. Apple§, and Charles V. Maxwell‡

ABSTRACT

Two hundred and sixteen pigs were weaned at 14 or 21 d of age to determine the effect of weaning age and commingling after the nursery phase on growth and behavior of pigs in a wean-to-finish facility. Pigs were divided into older and younger age groups and allotted 12 pigs/pen with nine replications of each group. At the end of the nursery phase (d 34 after weaning), one-half of the pigs in each group were removed and commingled for the grower/finisher phase and the other half remained in their original pens. Beginning at weaning (d 0), pigs were monitored via camera surveillance following weaning, commingling, and on d 65 after weaning. While in the nursery phase, older pigs had greater gain and feed intake than younger pigs, however, younger pigs were more efficient throughout the nursery phase than older pigs. Toward the end of the grower/finisher period, younger pigs had greater gain, feed intake, and gain:feed than older pigs and reached a common weight 4 d sooner. Younger pigs spent more time standing or moving during the nursery phase than older pigs. Immediately following commingling, the younger, unmixed pigs spent more time feeding. However on d 65 after weaning, the older, commingled pigs and younger, unmixed pigs spent more time feeding than older, unmixed pigs and younger, commingled pigs. In conclusion, younger pigs grew slower than older pigs during the nursery phase; however, younger pigs gained more during the finishing period. Additionally, weaning age and commingling influenced feeding behavior during the grower/finisher period.

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INTRODUCTION

Pigs produced in conventional intensively managed swine production systems are routinely weaned as early as 21 d of age and as early as 10 to 14 d of age in off-site segregated early weaning systems. The industry average weaning age is about 17 d. Although there are no restrictions on weaning age in the U.S., the practice of weaning at an age earlier than 21 d is discouraged in some countries and prohibited in others. Recent studies have shown that early-weaning and removal of pigs to an isolated site for rearing can reduce the potential for disease transfer from the dam. Pigs reared in isolation after weaning have been reported to have reduced immunological stress (Johnson, 1997), resulting in a substantial improvement in growth and efficiency of feed utilization compared with those reared in conventional farrow-to-finish systems (Williams et al., 1997). Similarly, commingling pigs following the nursery phase is a common management practice in the swine industry, and imposes an additional social stress upon the young pig. The advent of wean-to-finish facilities has potentially alleviated commingling after the nursery phase. However, the wasted space of placing weanling pigs in pens with space allowances for market hogs has led to the practice of double-stocking pens at weaning and later moving half of the pigs to another pen (DeDecker et al., 2002), again introducing a commingling stress.

Many food-service companies have come under scrutiny from animal-rights and animal-welfare organizations over the humane care and use of the meat animals from which their products are derived. However, it is inherently difficult to measure an animal's well-being in a manner consistent with quantitative science. Stress is typically measured by evaluating changing levels of serum cortisol as an indicator of activation of the hypothalamic-pituitary-adrenal axis in response to a defined stressor (Dantzer and Mormede, 1983). Although cortisol levels have consistently been reported to elevate in response to stress, the very act of obtaining the blood sample intrinsically alters cortisol response (McGlone et al., 1993). It has been suggested that immunological evaluations such as the neutrophil:lymphocyte ratio in the blood may be a more reliable measure of stress than is cortisol concentration (Gross and Siegel, 1983; Stull et al., 1999).

It is imperative that industry decisions in this country are based on studies determining the well-being and
farrowing room and distributed to their assigned pen. Well-being and performance. Itty as well as effects of post-nursery commingling on ing age in pigs double-stocked in a wean-to-finish facil-
treatments permitted evaluation of the effects of wean-
in original wean-to-finish pens. This arrangement of component of the study. One-half of the pigs remained on weight and commingled for the growing-finishing period from the double-stocked pens and re-randomized based one-half of the pigs in each age category were removed from the double-stocked pens and re-randomized based on weight within age groups and randomly allo-
cated to pens in a double-stocked wean-to-finish facility, with a total of nine replications of each age group for the nursery study. At the completion of the nursery phase one-half of the pigs in each age category were removed from the double-stocked pens and re-randomized based on weight and commingled for the growing-finishing component of the study. One-half of the pigs remained in original wean-to-finish pens. This arrangement of treatments permitted evaluation of the effects of wean-
ing age in pigs double-stocked in a wean-to-finish facil-
ity as well as effects of post-nursery commingling on well-being and performance.

On the day of weaning, the pigs were moved from the farrowing room and distributed to their assigned pen. Pigs were offered ad libitum access to a Phase I nursery diet for 14 d after weaning and a Phase II diet for an additional 20 d. At the completion of the nursery period, the pigs were started on the growing-finishing study. Pigs were fed a four-phase diet with transition from starter to grower I, from grower I to grower II, and from grower II to finisher occurring when the mean weight of each block reached 45, 68, and 90 kg. All diets met or exceeded NRC (1998) requirements for all nutrients and were formulated to simulate diets typical of those used in the swine industry. The study was terminated when the lightest block reached an average weight of 104 kg.

Beginning at weaning, after pigs had been allotted to their respective pens, pigs in four pens/treatment were monitored with mounted camera surveillance equipment for 24 hours to observe initial behaviors following weaning. Time-lapse videos were viewed at a later date in 2-h increments (one AM hour and one PM hour), and the following behaviors were recorded: 1) acts of aggression (head-to-head and head-to-tail body knocks, tail-biting, ear-chewing, pushing and aggressive circling); 2) feeding; 3) drinking; 4) lying; 5) moving; and 6) belly nosing. The duration of time spent by each pig engaged in these behaviors was recorded and percentages of time were calculated based on the 2-h observation. This was replicated on days 7, 14, and 27 post-weaning. Monitoring was continued on day 35 (after commin-
gling at the end of nursery phase), 38, 44 and 65 of the growing-finishing period. Plasma samples were obtained on days 0, 2, 7, 13, 27, 37, 42, and 56 to measure lymphocyte:neutrophil ratio.

Pigs were weighed as each block reached the projected weight for each phase. Feed disappearance from each pen self-feeder was calculated as the difference between feed added and feed weighed back for each period. Gain:feed ratios for each period were calculated.

Performance and behavioral data were analyzed as a 2 X 2 factorial with two weaning ages and two post-nurs-
ery management systems, with pen as the experimental unit. Neutrophil:lymphocyte and behavioural data were analyzed using the PROC MIXED analysis of SAS. Growth performance data were analyzed using GLM procedures of SAS (1988).

**RESULTS AND DISCUSSION**

During the nursery phase of the experiment, pigs weaned at 21 d of age had greater (P < 0.01) average daily gain and average daily feed intake during Phase 1, Phase 2, and in the overall nursery period than did pigs weaned at 14 d of age (Table 1). Pigs weaned at 14 d of age were more efficient (P < 0.01) than pigs weaned at 21 d of age during Phase 2 of the nursery and throughout the overall nursery period (Phases 1-2), (Table 1). At the beginning of the experiment, body weight was greater (P < 0.01) when pigs were weaned at 21 d of age compared to pigs weaned at 14 d of age, and as expected, the older pigs continued to be heavier (P < 0.01) throughout the nursery period; however, the difference in body weight increased from 2.15 kg at the initiation of the experiment to approximately 6.50 kg at the end of the nursery period.

During the growing/finishing phase of the experiment, ADG, ADFI, and gain:feed did not differ between pigs weaned at 21 d of age or those weaned at 14 d of age during Starter, Grower I, or Finisher phases (Table 2). However, during the Grower II, pigs weaned at 14 d of age had greater (P < 0.05) ADG, ADFI, and gain:feed; and greater (P < 0.01) ADG and gain:feed in the overall growing/finishing period than did pigs weaned at 21 d of age. The removal and commingling of one-half of the pigs from each pen at the end of the nursery period and re-sorting for the growing/finishing phase of the experi-
ment did not affect ADG, ADFI, gain:feed, or pig body

**MATERIALS AND METHODS**

A group of gilts farrowing over a 10 d period pro-
duced 30 litters, which were weaned when the average age was approximately 17 d of age. Pigs were divided into equal age groups representing the older (21 d of age) and younger (14 d of age) group of pigs (108 pigs in each group). On the day of weaning, the pigs were divided based on weight within age groups and randomly allo-
cated to pens in a double-stacked wean-to-finish facility, with a total of nine replications of each age group for the nursery study. At the completion of the nursery phase one-half of the pigs in each age category were removed from the double-stocked pens and re-randomized based on weight and commingled for the growing-finishing component of the study. One-half of the pigs remained in original wean-to-finish pens. This arrangement of treatments permitted evaluation of the effects of wean-
ing age in pigs double-stocked in a wean-to-finish facil-
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gling at the end of nursery phase), 38, 44 and 65 of the growing-finishing period. Plasma samples were obtained on days 0, 2, 7, 13, 27, 37, 42, and 56 to measure lymphocyte:neutrophil ratio.

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During the growing/finishing phase of the experiment, ADG, ADFI, and gain:feed did not differ between pigs weaned at 21 d of age or those weaned at 14 d of age during Starter, Grower I, or Finisher phases (Table 2). However, during the Grower II, pigs weaned at 14 d of age had greater (P < 0.05) ADG, ADFI, and gain:feed; and greater (P < 0.01) ADG and gain:feed in the overall growing/finishing period than did pigs weaned at 21 d of age. The removal and commingling of one-half of the pigs from each pen at the end of the nursery period and re-sorting for the growing/finishing phase of the experi-
ment did not affect ADG, ADFI, gain:feed, or pig body
weight. However, ADFI decreased during Phase 3 \((P < 0.05)\) when pigs weaned at 21 d of age were mixed and re-sorted compared to those that remained in original pens, whereas there was no difference in ADFI of pigs weaned at 14 d of age regardless of whether they were commingled or remained in their original pens \((\text{interaction}, P = 0.08; \text{Fig. 1})\). Mixing and re-sorting pigs following the nursery phase of the study had no effect on the number of days required for pigs to reach a common market weight of 104 kg. However, age of pigs at weaning did impact days-to-market, such that pigs weaned at 14 d of age reached a common weight of 104 kg four days sooner than pigs weaned at 21 d \((P < 0.05; \text{Fig. 2})\). There was no effect of weaning age or mixing after the nursery phase on the neutrophil:lymphocyte ratio on any of the sampling day \((\text{data not shown})\).

The lower growth rate during the nursery period of pigs weaned at 14 d of age compared to older pigs conflicts with data from other studies that report either an improvement in ADG of early-weaned \((10 \text{ d})\) pigs compared to late-weaned \((30 \text{ d})\) pigs \((Hohenshell et al., 2000)\), or no effect of weaning age on rate of the growth in the overall nursery period \((Dritz et al., 1996)\). To our knowledge, this is the first experiment to report that early-weaned pigs overcame a deficit in body weight at the end of the nursery period to reach a common market weight in fewer days than pigs weaned at 21 d of age. Others have reported no effect of weaning age when evaluating overall gain from birth to market weight \((Hohenshell et al., 2000)\) and no difference in BW when comparing early- and late-weaned pigs at a common age \((Dritz et al., 1996)\).

Pigs weaned at 21 d of age spent a greater \((P < 0.05)\) percentage of time lying down on the day of weaning \((\text{day 0 post-weaning})\) than pigs weaned at 14 d of age. Although the percentage of time spent standing or moving did not differ between pigs of different weaning ages on any observation day during the nursery period, pigs weaned at 14 d of age spent a greater \((P < 0.05)\) percentage of time standing or moving during the overall nursery phase than pigs weaned at 21 d of age \((\text{Table 3})\). Although there were no differences in the percentage of time that pigs weaned at either age were engaged in aggressive behavior on any of the sampling d, the frequency of aggressive behavior was greater \((P < 0.05)\) at weaning \((\text{day 0})\) than on any other observation d. During the growing/finishing period, the effect of weaning age and post-nursery commingling on feeding behavior was dependent upon the day of observation \((\text{weaning age x mixing x date interaction}, P < 0.05; \text{Fig. 3})\). During the growing/finishing period, pigs that were weaned at 14 d of age and remained unmixed after the nursery period spent a greater \((P < 0.05)\) percentage of time engaged in feeding activity than 21 d-old pigs that were mixed, or mixed pigs regardless of weaning age. The percentage of time spent feeding did not differ among pigs of either weaning age or post-nursery mixing treatment on d 38 or d 44 post-weaning; however, on d 65 post-weaning, pigs that were weaned at 21 d of age and mixed and pigs weaned at 14 d and unmixed exhibited a greater \((P < 0.05)\) proportion of time engaged in feeding behavior than pigs in the other two treatments.

It is difficult to determine why the younger pigs performed poorly during the nursery phase in this study. Behavioral observations indicated that younger pigs spent less time lying down on the day of weaning and more time standing or walking during the overall nursery phase, suggesting that younger pigs were less apt to settle into their new environment than older pigs. This nervousness or curiosity toward the new environment may have contributed to the lower weight gains observed in young pigs in the nursery phase.

The results of this study show that management conditions perceived as stressors, in this case weaning and commingling pigs after the nursery period, do influence behavior, and there is no indication from the results of this study that neutrophil:lymphocyte ratio is quantitative measure of immune or behavioral well-being in pigs. In the present study, neutrophil-to-lymphocyte ratios were similar among pigs regardless of weaning age or mixing treatment. To further compound the difficulty in measuring immune response or behavior as indicators of welfare, there were very few differences in behavioral responses between pigs weaned at different ages or between pigs mixed after the nursery phase and those that remained unmixed, and immune responses were inconsistent depending upon the age of the pig at weaning. Whereas the results of this study raise interesting questions about the effect of management environments and stressors on subsequent performance and health of pigs weaned at varying ages, no measure of growth performance, immunity, or behavior was found to conclusively measure a pig’s welfare in response to wean-to-finish management schemes.

In conclusion, the results of this study indicate that weaning age affects growth performance in a wean-to-finish facility as well as behavioral and immunological responses to weaning and commingling after the nursery phase. Weaning pigs at an early age results in a less immunologically developed pig compared to pigs weaned later, and this may contribute to the benefits of early weaning with respect to an overall improvement in gain and days to a common weight. However, management strategies should be further explored to optimize these benefits without the detrimental effects on health, as observed during the nursery period in this study.
ACKNOWLEDGMENTS

Funding was provided by the Dale Bumpers College of Agricultural, Food and Life Sciences Undergraduate Research Grant Program.

LITERATURE CITED


Table 1. Average daily gain (ADG), average daily feed intake (ADFI), and gain:feed of pigs in response to weaning age during the nursery period.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Weaning age, d</th>
<th>SE</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADG, (g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 1</td>
<td>262</td>
<td>383</td>
<td>15.3</td>
</tr>
<tr>
<td>Phase 2</td>
<td>487</td>
<td>612</td>
<td>14.7</td>
</tr>
<tr>
<td>Phase 1-2</td>
<td>397</td>
<td>521</td>
<td>13.9</td>
</tr>
<tr>
<td>ADFI, (g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 1</td>
<td>273</td>
<td>410</td>
<td>15.9</td>
</tr>
<tr>
<td>Phase 2</td>
<td>617</td>
<td>876</td>
<td>29.1</td>
</tr>
<tr>
<td>Phase 1-2</td>
<td>474</td>
<td>689</td>
<td>24.1</td>
</tr>
<tr>
<td>Gain:feed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 1</td>
<td>0.92</td>
<td>0.94</td>
<td>0.01</td>
</tr>
<tr>
<td>Phase 2</td>
<td>0.77</td>
<td>0.70</td>
<td>0.01</td>
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<tr>
<td>Phase 1-2</td>
<td>0.81</td>
<td>0.76</td>
<td>0.01</td>
</tr>
<tr>
<td>Weight, (kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>4.52</td>
<td>6.67</td>
<td>0.26</td>
</tr>
<tr>
<td>Phase 1</td>
<td>8.17</td>
<td>12.06</td>
<td>0.45</td>
</tr>
<tr>
<td>Phase 2</td>
<td>18.39</td>
<td>24.92</td>
<td>0.72</td>
</tr>
</tbody>
</table>
Table 2. Average daily gain, average daily feed intake, and gain:feed of pigs in response to weaning age during the grower/finishing period.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Weaning age, d</th>
<th>SE</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>ADG, (kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starter</td>
<td>0.76</td>
<td>0.77</td>
<td>0.02</td>
</tr>
<tr>
<td>Grower I</td>
<td>1.01</td>
<td>0.98</td>
<td>0.02</td>
</tr>
<tr>
<td>Grower II</td>
<td>1.04</td>
<td>0.86</td>
<td>0.02</td>
</tr>
<tr>
<td>Finisher</td>
<td>0.88</td>
<td>0.86</td>
<td>0.04</td>
</tr>
<tr>
<td>Overall</td>
<td>0.91</td>
<td>0.87</td>
<td>0.01</td>
</tr>
<tr>
<td>ADFI, (kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starter</td>
<td>1.56</td>
<td>1.61</td>
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</tr>
<tr>
<td>Grower I</td>
<td>2.43</td>
<td>2.30</td>
<td>0.05</td>
</tr>
<tr>
<td>Grower II</td>
<td>2.76</td>
<td>2.59</td>
<td>0.06</td>
</tr>
<tr>
<td>Finisher</td>
<td>3.03</td>
<td>2.88</td>
<td>0.08</td>
</tr>
<tr>
<td>Overall</td>
<td>2.26</td>
<td>2.30</td>
<td>0.04</td>
</tr>
<tr>
<td>Gain:feed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starter</td>
<td>0.49</td>
<td>0.48</td>
<td>0.01</td>
</tr>
<tr>
<td>Grower I</td>
<td>0.42</td>
<td>0.43</td>
<td>0.01</td>
</tr>
<tr>
<td>Grower II</td>
<td>0.38</td>
<td>0.33</td>
<td>0.01</td>
</tr>
<tr>
<td>Finisher</td>
<td>0.29</td>
<td>0.30</td>
<td>0.01</td>
</tr>
<tr>
<td>Overall</td>
<td>0.40</td>
<td>0.38</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 3. Summary of behavioral data (presented as percentage of time engaged in each respective behavior) collected during the overall nursery phase from pigs weaned at either 14 or 21 d of age.

<table>
<thead>
<tr>
<th>Observation, %</th>
<th>Age at weaning, d</th>
<th>SE</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lying</td>
<td>36.1</td>
<td>46.1</td>
<td>4.00</td>
</tr>
<tr>
<td>Standing/moving</td>
<td>30.1</td>
<td>22.6</td>
<td>2.23</td>
</tr>
<tr>
<td>Drinking</td>
<td>1.7</td>
<td>2.5</td>
<td>0.47</td>
</tr>
<tr>
<td>Feeding</td>
<td>11.2</td>
<td>9.1</td>
<td>1.69</td>
</tr>
<tr>
<td>Aggression</td>
<td>2.9</td>
<td>2.1</td>
<td>0.61</td>
</tr>
</tbody>
</table>

Fig. 1. Effect of mixing and age at weaning on average daily feed intake of pigs (ADFI) during Grower II of the growing/finishing period (interaction, P = 0.08; a,b P < 0.05).

Fig. 2. Effect of mixing and age at weaning on the number of d for pigs to reach 230 lb. Effect of weaning age; P < 0.05.
Fig. 3. Percentage of time spent engaged in feeding behavior during the growing/finishing phase by pigs weaned at either 14 or 21 d of age and either subjected to mixing and re-sorting following the nursery phase or remaining in original pens (weaning age x mixing x date interaction, P < 0.05). Bars with an asterisk differ from other bars without asterisks within d post-weaning (P < 0.05).
Method analysis of laboratory measures of stream sediment and water phosphorus equilibrium

Anna L. Erickson*, Stephanie M. Williamson†, and Brian E. Haggard§

ABSTRACT

Elevated phosphorus concentrations in aquatic ecosystems of northwest Arkansas prompted an investigation of the effects of sample preparation and extraction methods on laboratory measures of sediment-phosphorus interactions. Two streams of contrasting phosphorus (P) concentrations were selected to determine the effect of using a CaCl₂ solution instead of filtered stream water, refrigerated or dried sediments instead of fresh wet sediments, and vortexing the suspensions instead of shaking them. Sediment equilibrium P concentration (EPC₀) and P buffering capacity (K) were used to determine differences in extraction methods. EPC₀ and K from extractions using fresh sediments and a CaCl₂ solution matching the electrical conductivity of the stream water were not significantly different from extractions using fresh sediments and filtered stream water. However, using dried sediments instead of fresh, wet sediments in the extraction procedure affected EPC₀ and K estimation. In the P-enriched system, sediment extractions using refrigerated sediments or vortex mixing of the sediment-slurry suspension produced EPC₀ and K estimates that were significantly different than estimates from fresh, wet sediment and filtered stream-water extractions. Overall, method analysis of laboratory measures of stream sediment and water P equilibrium suggested that in low-P-concentration streams, estimates varied little whereas in high-P streams the method of extraction was more important.

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† Stephanie M. Williamson, faculty sponsor, is a program technician II in the Department of Biological Engineering.
§ Brian E. Haggard, faculty sponsor, is an adjunct assistant professor in the Department of Biological Engineering.
MEET THE STUDENT-AUTHOR

I graduated from the Arkansas School of Mathematics and Sciences in 2001 and am currently attending the University of Arkansas, majoring in biological engineering. I have been involved in the Biological Engineering Student Club, Phi Sigma Rho, Women In Engineering, and Campus Civitan. During my junior year, I was selected to be the Biological Engineering Department Mentor for Women in Engineering. I also have worked as a laboratory assistant for Dr. Brian Haggard, my faculty sponsor, for two years. While working on another project, several complications with the method analysis of the laboratory procedures were questioned. Dr. Haggard encouraged me to complete this project to settle those questions and to gain further research and writing experience.

Anna L. Erickson

INTRODUCTION

Elevated phosphorous (P) concentrations in aquatic ecosystems have become one of the greatest water-quality concerns in northwest Arkansas. Phosphorus is essential for plant nutrition and is a crucial nutrient in aquatic ecosystems, often limiting algal growth. Phosphorus originates from a variety of sources, particularly municipal wastewater-treatment plants (WWTP) and runoff from urban and agricultural landscapes. An abundant amount of P acquired in a stream or lake can stimulate excess algal growth, accelerating the natural process of eutrophication. Accelerated eutrophication results in a decline in water quality, as well as economic losses such as limiting irrigation withdrawals, reducing aesthetic value and recreational activities, and increasing drinking water-treatment costs (USGS, 1999).

The effects of increasing P concentrations in aquatic ecosystems may occasionally be altered by the role of benthic sediments (Haggard et al., 1999). Streambed sediments can regulate P concentrations in the water column by adsorbing and desorbing soluble inorganic P (Meyer, 1979). Differences in experimental design and laboratory methods have significantly affected laboratory measures of sediment-P interactions (; Fox, et al., 1989; Klotz, 1988; Meyer, 1979; Taylor and Kunishi, 1971). These cited studies have investigated a variety of different factors in the extraction process.

One of the more common laboratory experiments is a series of extractions to determine the sediment equilibrium-P concentration (EPCo). Sediment EPCo is the dissolved inorganic P concentration in the water column when there is no net sediment adsorption or desorption of PO4 from the water column; EPCo may also indicate if sediments act as a sink or source of P for the water column (Taylor and Kunishi, 1971). Differences in EPCo are often related to particle size, surface-to-volume ratio of sediments, and sediment-to-solution ratio (Klotz, 1988; Meyer, 1979; Taylor and Kunishi, 1971). Although not affected by temperature changes, EPC0 may increase with a decrease in solution pH (Fox, et al., 1989; Klotz, 1988; Meyer, 1979). The effect of extraction time was minimal, and 1 hour equilibration period provided a useful approximation of EPCo (Taylor and Kunishi, 1971). Air drying and the speed the sediments are shaken during the extractions likely affect laboratory measures of sediment-P interactions (Meyer, 1979; Srivastava, 1998).

The objectives of this study were to 1) investigate the effect of varying extraction methods as well as 2) sample handling, storage, and drying on sediment EPCo estimation and P buffering capacity in two streams of contrasting dissolved-P concentrations.
MATERIALS AND METHODS

Study Sites

Two contrasting streams and catchments located in the Ozark Plateau of northwestern Arkansas—Columbia Hollow Watershed and Mud Creek Watershed—were selected for this study. The Mud Creek sampling site is a small urban tributary with relatively low soluble-P concentrations and external-P inputs from urban nonpoint sources. The Columbia Hollow sampling site is a slightly larger catchment with greater soluble-P concentrations and external-P inputs originating from urban and agricultural nonpoint sources and a WWTP approximately 3 km upstream in Decatur, Ark.

Stream Water and Sediment Collection

Stream water and bottom sediments were collected from three lateral transects perpendicular to stream flow at the Columbia Hollow and Mud Creek sampling sites. Three water and sediment samples (A, B, C) were collected from each stream, with A representing the most upstream transect and C being the most downstream transect. Stream water was collected in 1 L acid-cleaned polyethylene bottles at each site. The stream water was refrigerated in the dark until return to the laboratory where the water samples were filtered through a 0.45 µm nylon membrane into clean 1 L polyethylene bottles. Two 20 mL aliquots were also collected at each transect in a syringe and filtered through a 0.45 µm nylon membrane. One of the filtered aliquots was acidified to pH <2 using concentrated HCl and used for measuring dissolved-P concentration. Sediments from the top 10 cm of the streambed were collected using a shovel at each site. The sediment samples were stored in plastic bags and refrigerated until return to the laboratory. The sediments were then sieved, and the fraction less than 4.76 mm was used in the proceeding extractions.

Extraction Procedures

A series of five extraction methods were conducted on the sediments collected at the two streams to determine the effect of solution chemistry and sample handling, storage, and drying on sediment-P interactions.

Sediment-P interactions were evaluated by determining sediment EPC₀ and P buffering capacity. The amount of P sorbed per gram of sediment was regressed against the initial P concentration where EPC₀ was calculated as the x-intercept of this relation (Klotz, 1985; Taylor and Kunishi, 1971). The amount of P adsorbed is the difference between the initial soluble-P concentration in the solution mixed with sediments and the final soluble-P concentration after 1 h of shaking. The slope of this linear relationship between P sorbed and initial P concentration was also calculated to determine the amount of P that may be desorbed or adsorbed per unit increase in initial P concentration. This slope (K) may be interpreted as a measure of the ability of stream sediments to buffer increasing P concentrations, with greater slopes suggesting greater P buffering capacity (Bache and Williams, 1971).

The prototypical extraction procedure consisted of weighing approximately 25 g of fresh wet sediment into 250 mL Erlenmeyer flasks. One-hundred mL of filtered stream water was then added to the Erlenmeyer flasks. Sediment slurries were spiked with a series of P additions resulting in the ambient concentration increasing by 0, 0.5, 1, 2, and 5 mg/L. The flasks were shaken for 1 h at 100 oscillations/minute. Subsequently, an aliquot from the sediment slurry was filtered through a 0.45 µm nylon membrane and then acidified to pH <2 using concentrated HCl. The remaining sediment slurry was poured into pre-weighed aluminum pans and dried for 48 hours at 80°C in order to determine the amount of dry sediments. The acidified, filtered aliquot was used to determine the final soluble reactive P (SRP) in the sediment slurry. SRP was determined using the Skalar SanPlus continuous flow analyzer and the ascorbic acid reduction method in which ammonium molybdate and potassium (K) antimony tartrate react in an acidic medium with reactive PO₄ molecules to form an antimony-phospho-molybdate complex, which is reduced to a blue-colored complex by ascorbic acid (APHA, 1992). The EPC₀ and K estimates of the prototypical extractions were compared to the estimates from four other extractions that differed from the prototypical extractions by one variable.

The effect of solution chemistry was determined by comparing EPC₀ and K from extractions using a solution of CaCl₂ instead of filtered stream water. The CaCl₂ solution was made by diluting 1 M CaCl₂ with deionized distilled water so that its electrical conductivity was equivalent to that of the filtered stream water from each sampling site.

Sample handling effects were ascertained by vortexing the flasks for 3 sec every 10 min for 1 h instead of shaking the samples as described in the prototypical extraction.

Comparison of sample storage effects was completed by refrigerating the sediments for approximately 24 h and completing the prototypical extractions as defined above.

The effect of drying was determined on sediments by drying fresh, wet sediments for 48 hours at 80°C and then completing extractions. The amount of dried sediments added to the 250 mL Erlenmeyer flasks was equal to the dry-matter percentage (approximately 17 g). This

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quantity kept the ratio of the amount of sediment-to-solution volume relatively similar.

Simple linear regressions were used to define the x-intercept (EPC₀) and slope (K) when the slope was significantly different than zero (P < 0.1). Differences in EPC₀ and K for each treatment were evaluated using a one-way analysis of variance (ANOVA) and means separation was determined using least significant difference (LSD) (Statistix 7.1 Analytical Software). The EPC₀ and K means of the prototypical extraction were compared to the results of the other methods to observe any differences (P < 0.1).

RESULTS AND DISCUSSION

These two streams had drastically different concentrations of dissolved P (T-test, T = 2.92, p < 0.001); average SRP concentration in Mud Creek and Columbia Hollow was 0.03 mg/L and 1.00 mg/L, respectively (Fig. 1). The municipal WWTP discharging into Columbia Hollow increased SRP concentration 30-fold compared to a stream without wastewater treatment-plant effluent. This effect has been observed in many northwest Arkansas streams receiving effluent discharges from municipal WWTPs (Haggard et al., 2001).

The amount of P adsorbed and the initial SRP concentration for the transects at the Mud Creek tributary displayed significant linear relationships for all EPC₀ methods (simple linear regression, r² > 0.94, p < 0.01). The EPC₀ estimation of the fresh sediments was only significantly different from extractions using dried sediments (ANOVA LSD, p = 0.01) whereas it was similar to the extractions using refrigerated sediments and extractions using the vortex-mixing technique, as well as the extractions using a CaCl₂ solution (Table 1). The increase in EPC₀ of the dried sediments may be accounted for by the release of P from microbes destroyed by desiccation (Srivastava, 1998). Phosphorus sorption in sediments that contain inhibited microbial growth was less than P sorption in fresh sediments (Haggard, et al., 1999; Klotz, 1985; Meyer, 1979). The buffering capacity (K), however, was only affected by the mixing technique where vortexing instead of shaking resulted in a greater K (ANOVA LSD, p = 0.01).

At Columbia Hollow, extractions involving the dried sediments and the vortexing technique did not display a significant linear relationship (p > 0.1) (Table 1). Estimated EPC₀ from extractions using refrigerated sediments with filtered stream water and from extractions using fresh sediments and a CaCl₂ solution was not significantly different from the prototypical extractions. When comparing K, only the extractions using fresh sediments and a CaCl₂ solution were not significantly different from the extractions using fresh sediments and filtered stream water whereas the extractions with refrigerated sediments were significantly different (ANOVA LSD, p = 0.01).

Some discrepancies were observed between EPC₀ and K when sediments were vortexed, refrigerated, or dried, especially in the high-P concentration stream. Overall, EPC₀ and K estimates were statistically similar between methods using fresh sediments and either filtered stream water or a CaCl₂ solution with a conductivity similar to that of the stream. An increase in the concentration of a CaCl₂ solution may decrease sediment EPC₀ (Klotz, 1988), and a previous study at Columbia Hollow suggested that using a CaCl₂ solution of similar conductivity to that in the stream produced significantly reduced sediment EPC₀ estimates (Popova, 2000). Due to these effects of solution chemistry, EPC₀ estimation using filtered stream water and fresh sediments would best measure the sediment-phosphorus interactions.

EPC₀ estimation of the extractions using fresh sediments and filtered stream water was compared to the SRP concentration in the water column at each stream to determine whether the sediments act as a sink or source of P or are in equilibrium with the water column. At the Mud Creek tributary, there was no significant difference in EPC₀ and the SRP concentration of the water column so the sediments were most likely in equilibrium with the stream. However, at Columbia Hollow, sediments were probably acting as a source of P because sediment EPC₀ was greater than the SRP concentration in the water column (ANOVA LSD, p = 0.01). Sediment EPC₀...
at Mud Creek was much less than at Columbia Hollow (Fig. 2). Contrarily, K was much greater for Mud Creek compared to that observed from the Columbia Hollow sediments. Thus, the Mud Creek sediments have a greater ability to buffer increasing P concentrations in the water column, possibly because this stream does not receive any municipal WWTP discharge. Based on these results, it is suggested that fresh, wet sediments and filtered stream water should be used when evaluating sediment-P interactions, especially in phosphorous-enriched streams.

ACKNOWLEDGMENTS

Appreciation is expressed for financial support for this undergraduate research project provided by the Dale Bumpers College of Agricultural, Food and Life Sciences Undergraduate Research Grant Program.

LITERATURE CITED


Table 1. EPC$_0$ and K means for the Mud Creek Tributary and Columbia Hollow

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Treatment</th>
<th>EPC$_0$ mean</th>
<th>Heterogeneous groups based on EPC$_0$</th>
<th>K mean</th>
<th>Heterogeneous groups based on K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mud Creek Trib.</td>
<td>Dried sediments</td>
<td>0.117</td>
<td>1</td>
<td>0.298</td>
<td>2, 3</td>
</tr>
<tr>
<td>Mud Creek Trib.</td>
<td>Refrigerated sediments</td>
<td>0.086</td>
<td>1, 2</td>
<td>0.240</td>
<td>3</td>
</tr>
<tr>
<td>Mud Creek Trib.</td>
<td>Live sediments</td>
<td>0.007</td>
<td>2, 3</td>
<td>0.268</td>
<td>2, 3</td>
</tr>
<tr>
<td>Mud Creek Trib.</td>
<td>Vortexed sediments</td>
<td>0.004</td>
<td>3</td>
<td>0.378</td>
<td>1</td>
</tr>
<tr>
<td>Mud Creek Trib.</td>
<td>CaCl$_2$ solution</td>
<td>-0.046</td>
<td>3</td>
<td>0.328</td>
<td>1, 2</td>
</tr>
<tr>
<td>Columbia Hollow</td>
<td>Refrigerated sediments</td>
<td>2.864</td>
<td>1</td>
<td>0.224</td>
<td>1</td>
</tr>
<tr>
<td>Columbia Hollow</td>
<td>Live sediments</td>
<td>2.824</td>
<td>1</td>
<td>0.106</td>
<td>2</td>
</tr>
<tr>
<td>Columbia Hollow</td>
<td>CaCl$_2$ solution</td>
<td>3.656</td>
<td>1</td>
<td>0.088</td>
<td>2</td>
</tr>
</tbody>
</table>

Fig. 2. EPC₀ and K from extractions using filtered stream water and fresh, wet sediments from Columbia Hollow (bottom) and Mud Creek (top) tributaries.
Laboratory-scale evaluation of incandescent and compact florescent lamps for poultry house lighting

Leanne M. Gabriel* and Donald M. Johnson†

ABSTRACT
This laboratory-scale study compared 1000- and 2000-h rated 60W incandescent lamps and 6000-h rated 60W-equivalent compact florescent lamps over 6000 h of simulated broiler-house operation. The four original 1000-h incandescent lamps were replaced 22 times and the four 2000-h incandescent lamps were replaced 14 times. None of the four compact florescent lamps failed during the 6000-h experiment, although one was broken due to human error. Both types of incandescent lamps had significantly higher (p < .0001) mean illuminance (lx) than did the compact florescent lamps. The compact florescent lamps used significantly less (p < .0001) power (W) and had significantly higher (p < .0001) efficiency (lx/W) than the incandescent lamps. Despite a higher initial purchase price, the total cost (purchase + replacement + electrical) of operating compact florescent lamps was approximately 36% lower than the total cost of operating either type of incandescent lamp over the 6000 h period. The results of this study indicate that even at a least-cost price for electricity ($0.04/kW/h), growers can reduce total broiler-house lighting costs by replacing incandescent lamps with compact florescent lamps.

*Leanne Gabriel is a 2004 graduate with a major in agricultural education, communication and technology, and a minor in agricultural systems technology management
† Donald M. Johnson, faculty sponsor, is a professor in the Department of Agricultural and Extension Education.
INTRODUCTION

The 1997 Census of Agriculture reported that Arkansas had 3,106 broiler farms and produced slightly more than one billion broilers annually (14.9% of the U.S. total). Nationally Arkansas ranked second, only slightly behind Georgia, in the number of broilers produced (USDA, 1999).

According to Boucher and Gillespie (2002), electricity is the single largest direct expense for Georgia contract broiler growers, representing 26% of total direct expenses. The researchers estimated that operating a single 16,000-ft² (1,486 m²) broiler house would require 20,556 kWh of electrical energy per year, at a total cost of $1850 (at $0.09 / kWh). While a majority of the electrical energy in a broiler house is used to power ventilation equipment, Czarick and Lacy (1997) indicated that producers can significantly reduce electrical costs by making relatively simple and inexpensive changes to their lighting systems.

One recommended change was the use of florescent lamps for broiler house lighting (Czarick and Lacy, 1997). Florescent lamps are more efficient than incandescent lamps in converting electricity into visible light. According to Darre (2000), florescent lamps produce 50 – 59 lumens per watt (lm/W), while incandescent lamps produce 8 – 24 lm/W. Since compact florescent lamps draw less current and have the same Edison-base as do incandescent lamps, no modifications to wiring or fixtures are required in order for growers to use compact florescent lamps in broiler houses. In addition, dimmable compact florescent lamps, which would be required for certain lighting schedules, are now available (Washington State University, 2003). Thus, the use of compact florescent lamps has the potential to decrease electrical use and expenses in broiler production.

Incandescent lamps produce visible light (380 to 780 nm) by passing electric current through a tungsten fila-
ment, heating it to incandescence at approximately 2620°C. Incandescent lamps are widely available and inexpensive to purchase; however, incandescent lamps are the least efficient of all lamps and have the shortest expected service life (Bern and Olsen, 2002). Compact florescent lamps produce visible light when electricity excites mercury-vapor contained in a glass tube. The excited mercury-vapor emits ultraviolet radiation which, in turn, strikes phosphor crystals on the inside of the glass tube, producing visible light. Compared to incandescent lamps, compact florescent lamps have a longer service life and are more efficient; however they are more expensive to purchase (Bern and Olsen, 2002).

Lewis and Morris (1998) reviewed the scientific literature to assess the effects of various artificial light sources on poultry. They found that there were no differences in growth, food utilization, mortality, or live bird quality between broilers grown using incandescent, florescent, or high-pressure sodium lamps.

Despite this potential savings and the lack of documented adverse effects, Dr. Susan Watkins, University of Arkansas Extension Poultry Specialist, estimated that fewer than 25% of Arkansas growers use compact florescent lamps in their broiler houses (personal communication, 14 May 2004). The purpose of this study was to conduct a laboratory-scale evaluation of incandescent and compact florescent lamps and compare them on measures of service life, illuminance, power use, efficiency, and cost of operation.

### MATERIALS AND METHODS

Twelve molded plastic lamp holders (120V AC) were wired in parallel on a 121.9-cm x 243.8-cm x 1.9-cm thick sheet of exterior grade plywood using Type NM 12-2 WG cable. Four of each of three types of 60-W rated lamps were installed in the lamp holders: (a) 1000-h incandescent, (b) 2000-h incandescent, and (c) 6000-h compact fluorescent. All of the lamps were produced by the same manufacturer and were purchased at the same retail outlet. An Intermatic T101 (Intermatic Inc., Spring Grove, IL) mechanical clock-timer was installed in series with the electrical source and was set to energize the lamps for 23-h each day, with a 1-h off period. An SC100A split-core AC current sensor (Pace Scientific, Mooresville, NC) and an XR440 data logger (Pace Scientific, Mooresville, NC) were connected to a computer running Pocket Logger (v3.15A) software (Pace Scientific, Mooresville, NC) to monitor and verify on-off conditions and total “on time.” Circuit current was logged every 0.25 h. For safety, the circuit was protected by a portable ground-fault circuit interrupter.

After each 250-h period of operation, the circuit was de-energized and the electrical consumption (W) and light output (lx) of each lamp were measured and recorded (Fig. 1). Each lamp was placed in a 30.5-cm x 30.5-cm x 48.3-cm long light-tight box constructed from 1.9-cm thick plywood. The interior of the box was painted with flat, black latex paint. A LS-100 light sensor (Pace Scientific, Mooresville, NC) was installed in the center of the fixed end of the box and was connected to the XR440 data logger and computer. The removable end of the box was fitted with a 120V AC molded plastic lamp holder connected to a 61-cm long power cord wired through a Lutron DW-6060 digital watt meter (Lutron Electronic, Taipei, Taiwan). The distance between the light sensor and the bottom of the lamp base was 36.2 cm.

Lamps that failed were replaced at each 250-h interval and the electrical consumption and light output of the replacement lamp were measured and recorded along with the measurements for the lamps still functioning. One compact fluorescent lamp was accidentally broken after 3000 h of operation and was not replaced. The experiment continued, with a full set of readings being taken every 250 h, until a total of 6000 h of operation was reached. Due to time constraints, the experiment was terminated after 6000 h of total operation; however, the three intact florescent lamps were still functioning after 10,000 h of operation.

![Fig. 1. Experimental set-up for lighting study](image_url)
RESULTS AND DISCUSSION

Over the 6000 h of operation, the four original 1000-h incandescent lamps were replaced 22 times for a total (original plus replacements) cost of $6.96. The four original 2000-h incandescent lamps were replaced 14 times for a total cost of $8.86. None of the 6000-h rated compact florescent lamps were replaced during the 6000 h of operation. The total purchase cost for the four compact florescent lamps was $27.92.

Analysis of variance (ANOVA) indicated there was a significant difference in the mean illuminance (lx) for the tree types of lamps, $F(2, 72) = 29.43$, $p \leq .0001$, $R^2 = 0.45$. The Tukey HSD test revealed that the mean illuminance for both types of incandescent lamps was significantly higher than for the compact florescent lamps (Table 1). The compact florescent lamp had a mean illuminance 4.9% less than the 1000-h incandescent lamp.

Fig. 2 shows the mean illuminance for the two types of incandescent lamps and the compact florescent lamps at the start of the experiment and at each 250-h measurement interval. For the florescent lamps, the mean illuminance at 6000 h (1445 lx) was 2.7% less than the initial illuminance (1485 lx). The correlation between hours of operation and mean illuminance ($r = -.90$) explained 81% of the variance in illuminance for the florescent lamps.

There was a significant difference in electrical power use (W) for the three types of lamps, $F(2, 72) = 2631.58$, $p \leq .0001$, $R^2 = 0.99$. Both types of incandescent lamps used significantly more electrical power than did the compact florescent lamp (Table 1).

There was a significant difference between the efficiency (lx/W) of the three types of lamps, $F(2, 72) = 698.17$, $p \leq .0001$, $R^2 = 0.95$. The compact florescent lamp was more efficient than either type of incandescent lamp (Table 1).

Finally, the average total cost (purchase + replacement + electrical) to operate one unit of each type of lamp for 6000 h was estimated. According to Ozarks Electric Cooperative Corporation, the price of electrical energy for broiler houses ranges from approximately $0.04$ to $0.09$ per kW/h, depending on the customer’s total demand and load-use pattern (J. Fitzgerald, personal communication, 12 May 2004). The lowest electrical rate of $0.04$ per kW/h was used in all calculations to produce the most conservative estimate of cost differences between the three types of lamps.

As shown in Table 2, 6.5 of the 1000-h incandescent lamps, 4.5 of the 2000-h incandescent lamps, or one compact florescent lamp would be required in order to operate one lamp holder for 6000 h. However, purchasing the required number of either type of incandescent lamp would be less expensive than purchasing a single compact florescent lamp. The compact florescent lamps were more energy efficient, resulting in an estimated electrical cost savings of almost $11$ per 6000 h of operation, when compared to the incandescent lamps. The total cost to purchase and operate a compact florescent lamp for 6000 h was approximately 36% less than the total cost of purchasing and operating either type of incandescent lamp.

While compact florescent lamps cost more to purchase than incandescent lamps, the overall cost (purchase + replacement + electrical) of operating a compact florescent lamp for 6000 h was 36% less than the overall cost of operating either type of incandescent lamp. This was due to the lower electrical energy use and the higher efficiency of the compact florescent lamp. Considering that cost estimates were made based on a conservative electrical energy cost of $0.04$/kW/h and that the florescent lamps were still operating after 10,000 h, the present study likely underestimates the potential economic advantage of compact florescent lamps.

The compact florescent lamps produced slightly less (4.9%) mean illuminance than did the incandescent lamps. However, this finding may be somewhat misleading considering the experimental procedures used. Failed incandescent lamps were replaced at 250-h measurement intervals and the replacement lamps were measured and included in the mean illuminance. Thus, under conditions of actual use and replacement, the compact florescent lamps may well produce a higher mean illuminance than the incandescent lamps.

This laboratory-scale study indicates that compact florescent lamps provide a clear cost reduction when compared to incandescent lamps. The findings are consistent with those of Czarick and Lacy (1997). Producers should seriously consider replacing broiler house incandescent lamps with compact florescent lamps.

ACKNOWLEDGMENTS

Funding was provided by the Dale Bumpers College of Agricultural, Food and Life Sciences Undergraduate Research Grant Program.

LITERATURE CITED

Table 1. Illuminance, power use, and efficiency for three types of 60-W rated lamps

<table>
<thead>
<tr>
<th>Lamp Type</th>
<th>Illuminance (lx)</th>
<th>Power (W)</th>
<th>Efficiency (lx/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M ± y</td>
<td>SD</td>
<td>M ± y</td>
</tr>
<tr>
<td>1000-h incandescent</td>
<td>1546A</td>
<td>41.47</td>
<td>58.71A</td>
</tr>
<tr>
<td>2000-h incandescent</td>
<td>1531A</td>
<td>45.38</td>
<td>58.12A</td>
</tr>
<tr>
<td>6000-h compact florescent</td>
<td>1470B</td>
<td>15.91</td>
<td>13.17B</td>
</tr>
</tbody>
</table>

z Mean of the 250-h interval means
y Means in the same column with different letters are significantly different (P $\leq$ .05) by the Tukey HSD test

Table 2. Estimated total cost to purchase and operate one of each type of lamp for 6000 h

<table>
<thead>
<tr>
<th>Lamp Type</th>
<th>Number usedz</th>
<th>Cost ($)</th>
<th>kWh/h used</th>
<th>Cost ($)y</th>
<th>Total cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000-h incandescent</td>
<td>6.5</td>
<td>1.74</td>
<td>352.26</td>
<td>14.09</td>
<td>15.83</td>
</tr>
<tr>
<td>2000-h incandescent</td>
<td>4.5</td>
<td>2.22</td>
<td>348.72</td>
<td>13.95</td>
<td>16.17</td>
</tr>
<tr>
<td>6000-h compact florescent</td>
<td>1.0</td>
<td>6.98</td>
<td>79.02</td>
<td>3.16</td>
<td>10.14</td>
</tr>
</tbody>
</table>

z Total lamps (original + replacement) used / 4 lamp holders
y Based on an electrical cost of $0.04 per kWh

Fig. 2. Mean illuminance (lx) for the three types of lamps at 250-h measurement intervals