AN ECONOMIC ANALYSIS OF NITROGEN AND PHOSPHORUS
FERTILIZATION ON SEVERAL UTAH RANGE AND MEADOW SITES
by
Thomas M. Quigley

A thesis submitted in partial fulfillment of the requirements for the degree
of
MASTER OF SCIENCE
in
Range Economics

Approved:

[Signatures]

Major Professor

Committee Member

Committee Member

Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah
1972
ACKNOWLEDGMENTS

I wish to express my appreciation to my major professor, Dr. John P. Workman, for his help and encouragement while directing this research. Without his initiation and continual advisement of this study, this thesis would not be possible. Special thanks are given to the other members of my graduate committee, Dr. Darwin B. Nielsen and Dr. John C. Malechek, for their suggestions and aid. Thanks are also extended to Utah Agricultural Experiment Station Project 820 and the U. S. Steel Corporation for the funds which made this project possible.

I am especially grateful to Kerry, my wife, for her support and help throughout my graduate studies and for typing the rough draft of this thesis.

Thomas M. Quigley
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INTRODUCTION</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>REVIEW OF LITERATURE</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>DESCRIPTION OF EXPERIMENTAL AREAS</strong></td>
<td>9</td>
</tr>
<tr>
<td>Plot locations</td>
<td>9</td>
</tr>
<tr>
<td>Physical and biological characteristics</td>
<td>9</td>
</tr>
<tr>
<td><strong>METHODS AND PROCEDURES</strong></td>
<td>14</td>
</tr>
<tr>
<td>Soil analyses</td>
<td>14</td>
</tr>
<tr>
<td>Harvesting of forage</td>
<td>17</td>
</tr>
<tr>
<td>Price determinations</td>
<td>18</td>
</tr>
<tr>
<td>Production functions</td>
<td>18</td>
</tr>
<tr>
<td><strong>RESULTS AND DISCUSSION</strong></td>
<td>20</td>
</tr>
<tr>
<td>Soil analyses</td>
<td>20</td>
</tr>
<tr>
<td>Precipitation</td>
<td>22</td>
</tr>
<tr>
<td>Early growth initiation</td>
<td>23</td>
</tr>
<tr>
<td>Prices and costs</td>
<td>25</td>
</tr>
<tr>
<td>Production functions</td>
<td>29</td>
</tr>
<tr>
<td>Determination of optima</td>
<td>38</td>
</tr>
<tr>
<td>Sensitivity analysis</td>
<td>49</td>
</tr>
<tr>
<td><strong>SUMMARY AND CONCLUSIONS</strong></td>
<td>56</td>
</tr>
<tr>
<td><strong>LITERATURE CITED</strong></td>
<td>59</td>
</tr>
<tr>
<td><strong>APPENDIXES</strong></td>
<td>64</td>
</tr>
<tr>
<td>Appendix A. Range Condition for Jensen, Swan, Theurer, and White Sites</td>
<td>65</td>
</tr>
<tr>
<td>Appendix B. Yearly and average precipitation on Sites</td>
<td>69</td>
</tr>
<tr>
<td><strong>VITA</strong></td>
<td>70</td>
</tr>
</tbody>
</table>
**LIST OF TABLES**

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Treatment numbers assigned to rates of nitrogen and phosphorus</td>
<td>15</td>
</tr>
<tr>
<td>2.</td>
<td>Soil analysis results</td>
<td>21</td>
</tr>
<tr>
<td>3.</td>
<td>Soils Laboratory fertilizer recommendations</td>
<td>21</td>
</tr>
<tr>
<td>4.</td>
<td>Fertilizer rates which caused early growth initiation</td>
<td>24</td>
</tr>
<tr>
<td>6.</td>
<td>Summary of prices and costs</td>
<td>30</td>
</tr>
<tr>
<td>7.</td>
<td>Results of initial regression analysis on each site</td>
<td>31</td>
</tr>
<tr>
<td>8.</td>
<td>Estimated production functions where significance of variables and model was at least at the .10 probability level</td>
<td>32</td>
</tr>
<tr>
<td>9.</td>
<td>Maximum profit rate of fertilizer application, pounds of forage produced, and profit per acre when forage is cut and baled</td>
<td>45</td>
</tr>
<tr>
<td>10.</td>
<td>The optimum rate of nitrogen fertilization, forage produced, and profit per acre when forage is used for grazing</td>
<td>47</td>
</tr>
<tr>
<td>11.</td>
<td>Optimum rates of N/ac at various prices of forage ($P_Y$) and nitrogen ($P_N$) for the Curlew spring application</td>
<td>54</td>
</tr>
<tr>
<td>12.</td>
<td>Optimum rates of N/ac at various prices of forage ($P_Y$) and nitrogen ($P_N$) for the Jensen fall application</td>
<td>54</td>
</tr>
<tr>
<td>13.</td>
<td>Optimum rates of N/ac at various prices of forage ($P_Y$) and nitrogen ($P_N$) for the White fall application</td>
<td>55</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Map of Utah showing experimental areas</td>
<td>10</td>
</tr>
<tr>
<td>2.</td>
<td>General outline of experimental design</td>
<td>16</td>
</tr>
<tr>
<td>3.</td>
<td>Production function for Curlew spring application</td>
<td>33</td>
</tr>
<tr>
<td>4.</td>
<td>Production function for Jensen fall application</td>
<td>34</td>
</tr>
<tr>
<td>5.</td>
<td>Production function for Jensen spring application</td>
<td>35</td>
</tr>
<tr>
<td>6.</td>
<td>Production function for White fall application</td>
<td>36</td>
</tr>
<tr>
<td>7.</td>
<td>Production function for White spring application</td>
<td>37</td>
</tr>
<tr>
<td>8.</td>
<td>Graphical optimization for Jensen fall application</td>
<td>43</td>
</tr>
</tbody>
</table>
ABSTRACT

An Economic Analysis of Nitrogen and Phosphorus Fertilization on Several Utah Range and Meadow Sites

by

Thomas M. Quigley, Master of Science

Utah State University, 1972

Major Professor: Dr. John P. Workman
Department: Range Science

Previous research has shown that rangeland forage production can be increased through fertilization. A study was conducted to determine if fertilization of various Utah range sites was economically feasible. Six range sites were selected for analysis. The addition of nitrogen increased forage production on three sites. Phosphorus had no effect in increasing production. Production functions of the form, \( Y = a + bN - cN^2 \), where \( Y \) is pounds of forage per acre and \( N \) is pounds of nitrogen per acre, were estimated for both fall and spring applications. Using current prices of \( Y \) and \( N \) the optimum rates of fertilization for maximum profit were determined. By comparing the profit per acre for fall and spring applications the most effective season of application was determined. On an irrigated tall wheatgrass (Agropyron elongatum) pasture the fall application was most profitable and the optimum rate of \( N \) was 215 lbs./ac (assuming \( P_N = $ .1207/lb. \) and \( P_Y = $ .0073/lb. \)). On an intermediate
wheatgrass (*Agropyron intermedium*) foothill site, fall was the most profitable season of application and 127 lbs./ac of N was the optimum rate. On a crested wheatgrass (*Agropyron cristatum*) site (average precipitation of 11 to 12 inches) only the spring application was analyzed and the most profitable rate of application was 7 lbs. N/ac. The optimum rates of N were determined for various prices of nitrogen and forage in a sensitivity analysis.

(77 pages)
INTRODUCTION


There has been limited work done in this area. Hooper (1969) subjected biological data, collected by researchers in California, to economic analysis. However, this study was restricted to the annual grasslands of California. This study found range fertilization economically feasible on many soil types. A
study by Hooper et al. (1969) dealt with only one level of nitrogen application and did not address itself to the problem of determining the optimum rate and combination of fertilizer materials.

Researchers working with annual ranges have found that fertilization causes early growth initiation and extends the growing season into the dry period (Hoglund et al. 1952, Woolfolk and Duncan 1962, and Conrad et al. 1966). Unfortunately, this research was limited to the annual rangelands of California. This poses another question, "Does Fertilization of Utah rangeland cause early growth and an extended green period?"

The purpose of this study was to examine the effects of fertilization on several Utah range sites. Production functions were employed to test the economic feasibility of range fertilization and to determine optimum fertilization rates.
REVIEW OF LITERATURE

Research in range fertilization had its beginning in the late 1940's. This work emphasized changes in species composition, forage quality, and forage production.

Hoglund et al. (1952), found that application of ammonium phosphate-sulfate increased forage production, advanced grazing readiness, doubled the length of the green feed period, and reduced fluctuation in forage production from year to year on California annual ranges. Duncan and Reppert (1960) reported that animal days of grazing per acre in a drought year were three and a half times greater on areas fertilized with nitrogen and sulfur. Woolfolk and Duncan (1962) found that sulfur-nitrogen fertilization increased herbage production, livestock utilization and weight gains of animals grazing annual ranges. Fertilization minimized the effects of weather on vegetation composition and induced earlier plant growth, as well as sustaining growth at a more rapid rate during the winter.

Williams et al. (1956), found that California rangeland could be improved by seeding annual clovers, fertilizing, and improving grazing management. The grazing capacity was increased by three times and forage quality was improved on lands where these improvements were implemented. Conrad et al. (1966), found that the average length of the green season increased from 96 to 113 days, and the average grazing capacity of the green season increased from 22.8 days
per acre to 55.5 days per acre when sulfur and nitrogen fertilizers were
applied to the California annual range.

Jones (1960) applied urea at various dates (September through March) to
an annual range to study responses to date of application. For summer grazing
the date of application made no significant difference in production except that
the March application was too late to produce maximum yields.

Seamonds (1971), working with mountain meadows in Wyoming, used
three sources of nitrogen and six different application dates, from September
through May, to study the effects of source and time of application on production.
Slow release urea showed a 3 percent yield advantage to fall application.
Ammonium nitrate and liquid urea each showed a 10 percent yield advantage in
favor of spring application. Birch and Lang (1961) applied nitrogen on Wyoming
soils at rates of 50 and 100 pounds per acre to examine seed production of
various grasses. The results indicated that Russian wildrye (Elymus junceus)
and Mandan rice grass (Stiporyzopsis caduca) produced an additional 10 pounds
per acre, while fertilized stands of intermediate wheatgrass (Agropyron
intermedium) and Whitmar beardless blue bunch wheatgrass (Agropyron spica-
tum var. inerme) resulted in a decrease in seed production. In Oregon, Cooper
(1955) found that forage production was greatest when 60 to 80 pounds of nitro-
gen per acre were applied to wet meadows and when 40 to 60 pounds of phos-
phorus per acre were applied to pastures with abundant white-tip clover
(Trifolium variegatum).

Moore et al. (1968), found that phosphorus fertilization on two Nebraska
sub-irrigated meadows resulted in higher dry matter yields and a greater
percentage phosphorus content when fertilizer was applied to the surface as
compared with drilling phosphorus to a depth of 3 to 4 inches.

Lawrence and Ashford (1969) working with intermediate wheatgrass
found that dry matter yield increased with increasing rates of nitrogen and
with longer intervals between clipping. The greatest yields were obtained with
8 week clipping intervals and 335 pounds of nitrogen per acre. Seamonds and
Roehrkassee (1971) working with mountain meadow hay in Wyoming found that
both crude protein content and forage production increased with increasing
rates of nitrogen. With heavy nitrogen rates it was determined that the ac­
cumulation of nitrates did not reach the danger level of 1.00%.

Research in New Mexico indicates that range fertilization can be used
as a means of manipulating ranges towards a more desirable species compo­
sition. Dwyer (1971) found that nitrogen fertilization of native blue grama
(Bouteloua gracilis) range increased production of desirable forage grasses
for use by grazing animals.

Increases in forage quality and quantity from nitrogen fertilization have
been reported by researchers working with mountain meadows in Wyoming
(Lewis, 1957) and pure grass stands in North Dakota (Carter, 1955).

Research conducted on drier sites have resulted in differing conclusions.
Some found that the addition of nitrogen increased forage production (Seamonds
and Lang, 1960; Thomas, 1964; Lang and Landers, 1968) while others found that
fertilization caused no increase in production (Smith and Lang, 1962; Hull, 1963).

Seamonds and Lang (1960) reported that fertilization of created wheat­
grass (Agropyron cristatum) in Southeastern Wyoming at a rate of 66 pounds
per acre increased forage production by 88%. They also reported that nitrogen application would be unprofitable except during years of above average precipitation or when hay or other livestock feeds are priced extremely high. Thomas (1964) working with bromegrass (*Bromus inermis*) crested wheatgrass (*Agropyron desertorum*) hay found that nitrogen fertilizer significantly increased hay yield. Nitrogen content of the grass increased with increasing rates of nitrogen and decreased with increasing amounts of seasonal precipitation. Lang and Landers (1968) recommended that crested wheatgrass stands in northeastern Wyoming be fertilized every year with approximately 20 pounds of nitrogen per acre.

Smith and Lang (1962) found the addition of nitrogen increased the crude-protein content of Idaho fescue (*Festuca idahoensis*) and increased forage palatability. They reported that forage production as a result of fertilizer was increased in only one of the five years studied. Hull (1963) found nitrogen treatments of a seeded mixture of grasses in southeastern Idaho resulted in no significant increase in total forage, but did result in significant increases in nitrogen and protein contents of the herbage.

Cook (1965) reported that fertilization of seeded foothill ranges in Utah resulted in increased palatability, production, and protein content. The application of 20 to 80 pounds of nitrogen per acre resulted in increases in forage production during the first year and increases in production as much as 3 years after fertilization. The application of phosphorus on some sites increased the number of seed heads but did not increase total forage production. Palatability was increased by nitrogen fertilizer, thus improving cattle utilization on
fertilized sites. The application of phosphorus had no effect on increasing the palatability. The carryover of increased utilization due to nitrogen fertilization varied from 2 to 3 years depending upon the site. Nitrogen caused increases in total protein, available carbohydrates, phosphorus, and gross energy and caused decreases in ash and cellulose.

Cook (1965) also reported results from fertilization of seeded and native mountain ranges in Utah. The application of 40 to 80 pounds of nitrogen per acre caused significant increases in production for 2 years on seeded mountain range. The total protein produced on these areas increased during the 2 years and over 90% of the nitrogen was recovered. On native mountain range the application of nitrogen increased the production of both forbs and grasses.

Increases in forage production and quality along with changing species composition are not the only benefits derived from range fertilization. Research has been conducted on the possibility of improving livestock distribution through range fertilization. Increases in forage utilization due to nitrogen fertilization have been reported in Wyoming (Lang 1956; Smith and Lang 1958). Cook (1965) found that the use of occasional cattle drifting and fertilization of areas normally not utilized would improve cattle distribution and utilization. Hooper et al. (1969) analyzed Cook's results from an economic standpoint and listed three potential benefits of range fertilization: (a) increased forage production on treated areas; (b) increased utilization on treated areas; (c) increased utilization of the range surrounding the areas fertilized. On the Utah rangelands considered in this study, fertilization was profitable.
Extensive research has been conducted on the economics of fertilization of agricultural cropland (Paschal and French 1956; Heady et al. 1955; Munson and Doll 1959; Pesek and Heady 1958; Doll et al. 1958; Heady and Pesek 1954; Baum et al. 1956; Brown et al. 1956; Heady et al. 1963; Orazem and Smith 1958; Pesek et al. 1958). Limited research has been conducted on the economics of range fertilization on California ranges. Hooper (1969) subjected the biological data from grassland fertilization experiments in California to economic analysis and determined the economic optimum for many of the range soils in California.

The next logical step in range fertilization research is to determine for various range sites whether or not it is profitable to increase forage production through fertilization.
DESCRIPTION OF EXPERIMENTAL AREAS

Plot locations

Six range sites were selected for fertilization, five in Utah and one in Idaho (Figure 1). Three criteria were used in selecting the range sites: (1) fertilizer had not been applied to the area within the last six years, (2) uniform and representative vegetation, and (3) slope did not exceed 15%. Sites selected were, White (.5 miles west of Paradise, Utah), Jensen (.5 miles north of Young Ward, Utah), Theurer (1 mile west of Logan, Utah), Swan (15 miles northeast of Huntsville, Utah, Junction (20 miles southwest of Snowville, Utah), and Curlew (11 miles north of Snowville, Utah, near the Utah-Idaho border).

All the sites were located on privately owned land with the exception of Curlew which is federal land administered by the United States Forest Service, and Junction which is federal land administered by the Bureau of Land Management. The Junction area has been used for a number of years by Utah State University for range research purposes.

Physical and biological characteristics

The White plot is located on the Provo level of the Pliostocene sediments of Lake Bonneville at an elevation of 4800 feet. The soil is a silt loam that has weathered from the sediments deposited by streams flowing into Lake Bonneville. The plot slopes slightly to the north. The vegetation is composed mainly of
Figure 1. Location of experimental areas (a, Curlew; b, Jensen; c, Junction; d, Swan; e, Theurer; f, White).
intermediate wheatgrass with a small percentage of northern sweet broom (Hedysarum boreale) mixed in. The usual land practice on this pasture is to graze in early summer and late fall. The annual precipitation averages between 16 and 17 inches, with approximately 6 inches occurring during the summer (U.S. Geological Survey, no date). The growing season averages 154 days (U.S. Dept. of Commerce 1971).

The Jensen plot is located on improved irrigated land surrounded by alfalfa and wheat fields at an elevation of 4420 feet. The soil is a silt loam derived from alluvial deposits of the flood plain of the Logan River. The vegetation of the pasture is composed almost exclusively of tall wheatgrass. The recent management practice for this pasture has been the harvest of forage as hay in July followed by late fall grazing. The annual precipitation averages between 14 and 15 inches. The growing season averages 126 days (U.S. Dept. of Commerce 1971).

The Theurer plot is also located on improved irrigated bottom land of Cache Valley at an elevation of 4450 feet. East of the plot is a perennial stream. A continuously flowing artesian well is also located near the plot. During the early spring and in years of high stream flow the water table often is higher than the land surface. The plot is sometimes flooded for periods as long as six weeks. The soil is a silt loam that has developed from the sediments of the Logan River. The vegetation includes a mixture of pasture grasses, including reed canary grass (Phalaris arundinacea), timothy (Phleum pratense), redtop (Agrostis alba), and foxtail (Hordeum jubatum). The management practice has been to harvest hay in July followed by late fall grazing. The annual
precipitation averages between 14 and 15 inches. The growing season averages about 126 days (U.S. Dept. of Commerce 1971).

The Swan plot is located on a southwest facing slope of 10% at an elevation of 7200 feet. The soil is a silt loam. The grasses on this high mountain meadow are primarily of Great Basin wildrye (Elymus cinereus), Kentucky bluegrass (Poa pratensis), bearded wheatgrass (Agropyron subsecundum) June grass (Koeleria cristata), and Idaho fescue (Festuca idahoensis). The forbs on this site include butterweed (Scnecio), wild onion (Allium acuminatum), mules ear (Wyethia amplexicaulis), Oregon checkermallow (Sidalcea oregana), yarrow (Achillea lanulosa), spurred lupine (Lupinus caudatus), and wild pink geranium (Geranium fremontii). The land has been managed as a grazing area for cattle during late summer and fall. The annual precipitation averages between 22 and 23 inches, with 16 to 17 inches occurring during the winter (U.S. Geological Survey, no date.)

The Junction plot is situated at an elevation of 4700 feet in Curlew Valley, Utah, a broad lacustrine valley. The site originally supported big sagebrush (Artemisia tridentata) and various native grasses but currently supports a stand of seeded crested wheatgrass with scattered plants of big sagebrush and Halogeton (Halogeton glomeratus). The soil is a silt loam. The land is used primarily as an early winter and spring grazing area. The annual precipitation averages between 9 and 10 inches. Extreme seasonal fluctuations in temperature are common (Visher 1946). The number of frost free days averages 96 days (U.S. Dept. of Commerce 1971).
The Curlew plot is located on the Idaho portion of Curlew Valley at an elevation of 4800 feet. The plot is a former sagebrush grass site that has been seeded to crested wheatgrass. The soil is a silt loam. The vegetation of the site consists almost exclusively of crested wheatgrass. The land is grazed on a rotation basis from April through December. The annual precipitation averages between 11 and 12 inches. The growing season averages 96 days (U.S. Dept. of Commerce, 1971). Extreme seasonal fluctuations in temperature are common (Visher, 1946).
METHODS AND PROCEDURES

During the summer of 1970, the White, Theurer, Jensen, and Swan plots were established. The Curlew and Junction plots were established during the winter of 1970-71. The experimental design was a randomized block factorial which allowed for three replications of 36 treatments (six rates of nitrogen and six rates of phosphorus and every combination of rates) (Table 1). The dimensions of the subplots (each containing one treatment) were 10 feet by 15 feet with the exception of the White plot where 10 feet by 10 feet subplots were used. Two application dates were tested on each plot (Figure 2).

During the fall of 1970, fertilizer was applied to the White, Jensen, Theurer, and Swan plots. In the Spring of 1971, fertilizer was applied to all six plots. The Junction and Curlew plots received only a spring application. The fall application on these two plots will be considered in a later analysis.

Between the fertilization date and the date of harvest, periodic measurements of plant height were taken. This made it possible to determine if any of the fertilizer rates caused the forage to initiate growth earlier than the unfertilized plots.

Soil analyses

Prior to fertilization, soil samples were collected from each plot. These samples were analyzed by standard laboratory procedures at the Soils Laboratory, Utah State University. Each sample was analyzed for available
Table 1. Treatment numbers assigned to rates of nitrogen and phosphorus

White Plot

<table>
<thead>
<tr>
<th>Pounds P per acre</th>
<th>0</th>
<th>25</th>
<th>50</th>
<th>100</th>
<th>200</th>
<th>400</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>12.5</td>
<td>12</td>
<td>11</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>25</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
</tr>
<tr>
<td>50</td>
<td>24</td>
<td>23</td>
<td>22</td>
<td>21</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>100</td>
<td>25</td>
<td>26</td>
<td>27</td>
<td>28</td>
<td>29</td>
<td>30</td>
</tr>
<tr>
<td>200</td>
<td>36</td>
<td>35</td>
<td>34</td>
<td>33</td>
<td>32</td>
<td>31</td>
</tr>
</tbody>
</table>

Swan, Theurer, Jensen Plots

<table>
<thead>
<tr>
<th>Pounds P per acre</th>
<th>0</th>
<th>50</th>
<th>100</th>
<th>200</th>
<th>400</th>
<th>800</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>12.5</td>
<td>12</td>
<td>11</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>25</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
</tr>
<tr>
<td>50</td>
<td>24</td>
<td>25</td>
<td>22</td>
<td>21</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>100</td>
<td>25</td>
<td>26</td>
<td>27</td>
<td>28</td>
<td>29</td>
<td>30</td>
</tr>
<tr>
<td>200</td>
<td>36</td>
<td>35</td>
<td>34</td>
<td>33</td>
<td>32</td>
<td>31</td>
</tr>
</tbody>
</table>

Junction, Curlew Plots

<table>
<thead>
<tr>
<th>Pounds P per acre</th>
<th>0</th>
<th>12.5</th>
<th>25</th>
<th>50</th>
<th>100</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>6.25</td>
<td>12</td>
<td>11</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>12.5</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
</tr>
<tr>
<td>25</td>
<td>24</td>
<td>23</td>
<td>22</td>
<td>21</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>50</td>
<td>25</td>
<td>26</td>
<td>27</td>
<td>28</td>
<td>29</td>
<td>30</td>
</tr>
<tr>
<td>100</td>
<td>36</td>
<td>35</td>
<td>34</td>
<td>33</td>
<td>32</td>
<td>31</td>
</tr>
</tbody>
</table>
Figure 2. General outline of experimental design.
potassium, available phosphorus, pH, soluble salts, lime, and texture. Based
upon the analysis of the samples, the Soils Laboratory also recommended
fertilizer rates.

Harvesting of forage

During the summer of 1971 each plot was harvested to determine the
total forage production for each treatment. Each plot was harvested at the
approximate time of grazing or field harvest under the usual management
conditions.

The harvest procedure began with the removal of a buffer strip 3 feet
wide between each treatment. There were two exceptions to this 3 foot buffer
strip: One, the Jensen plot had a five foot buffer strip because the dense growth
of the forage made it impossible to mow a narrow strip. Two, the Theurer
plot produced reed canary grass which was over seven feet tall. This made
it impossible to use a mower to cut a straight line. Therefore, only a three
foot square area was sampled for each treatment using hand clippers.

After the removal of the buffer strip, the remaining forage was clipped
and weighed to establish a wet weight. A subsample of about 400 grams was
taken from at least one replication of each treatment each day. This subsample
was placed in a paper bag, weighed, dried in an oven for 24 hours at 60°C, and
then reweighed to determine the air dry weight and percentage moisture for
each treatment. The resulting factor was used to convert wet forage weight to
air dry forage weight. All weights were then converted to a per acre basis.
Each plot was visited periodically after clipping to measure regrowth. Weight measurements were used to determine if any of the fertilizer rates were beneficial in extending the grazing season.

**Price determinations**


Three different methods were used to determine the price of the forage per pound. One method used the average price paid Utah farmers for all hay for the period 1958 to 1968 (Christensen and Richards 1969).

The second method involved the conversion of forage into animal unit months (AUM's). Given the value of an AUM, the number of pounds of forage equal to an AUM, and assuming a given percentage of measured forage as usable, the price per pound of forage was determined.

The third method used the value of Federal grazing fees and other costs of grazing on public land that are saved by increased forage production on private land. Implicit in this method is the assumption that all increases in forage production through fertilization will be utilized to feed cattle that would normally be grazing on Federal land; thereby, saving money by not paying Federal grazing fees and other grazing costs.

**Production functions**

Multiple regression analysis was used to determine the functional relationships between the forage yield and the two variable inputs, nitrogen and
phosphorus. These functions were then used to determine the optimum (least expensive) combination of nitrogen and phosphorus by using the price ratio of nitrogen and phosphorus. The optimum (most profitable) level of fertilization was then determined by using the price of the forage.
RESULTS AND DISCUSSION

Soil analyses

The results of the soil analyses are given in Table 2. Fertilizer recommendations of the Soils Laboratory are given in Table 3.

The pH of the soils range from moderately alkaline on the Theurer, Jensen, Curlew and Junction sites to slightly alkaline on the Swan site to slightly acid on the White site. The Junction and Curlew plots were the only sites which show a problem of salinity. The total soluble salts, as measured by electrical conductivity, is greater than 4 mmho/cm only at soil depths greater than 12 inches at Curlew and 6 inches at Junction.

The measured amount of available phosphorus decreased with increasing depth on all sites (Table 2). The Soils Laboratory recommended that phosphorus be supplemented only on the Jensen and Theurer plots, both of which are irrigated pastures (Table 3). The measured amount of available potassium indicated that there is abundant amounts of this element present in all soils. The Theurer site is marginal in amounts of potassium at depths below 6 inches.

The soil texture of all surface soils was silt loam. The only variations from silt loam occurred at the 12 inch depth on the Jensen and Junction sites where deviations were silty clay and silty clay loam respectively.

Additional soil information is given in Appendix A.
<table>
<thead>
<tr>
<th>Plot</th>
<th>Sample Depth (in.)</th>
<th>Soluble Salts (ECe)</th>
<th>Available Phosphorus (ppm)</th>
<th>Available Potassium (ppm)</th>
<th>Texture (Estimated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curlew</td>
<td>0-6</td>
<td>8.2</td>
<td>11.0</td>
<td>780+</td>
<td>Silt Loam</td>
</tr>
<tr>
<td></td>
<td>6-12</td>
<td>8.7</td>
<td>2.4</td>
<td>780+</td>
<td>Silt Loam</td>
</tr>
<tr>
<td></td>
<td>12-18</td>
<td>8.6</td>
<td>2.8</td>
<td>780+</td>
<td>Silt Loam</td>
</tr>
<tr>
<td>Jensen</td>
<td>0-6</td>
<td>8.0</td>
<td>9.0</td>
<td>764</td>
<td>Silt Loam</td>
</tr>
<tr>
<td></td>
<td>6-12</td>
<td>8.1</td>
<td>3.0</td>
<td>679</td>
<td>Silt Loam</td>
</tr>
<tr>
<td></td>
<td>12-18</td>
<td>8.1</td>
<td>2.0</td>
<td>679</td>
<td>Silt Loam</td>
</tr>
<tr>
<td>Junction</td>
<td>0-6</td>
<td>8.3</td>
<td>10.0</td>
<td>780+</td>
<td>Silt Loam</td>
</tr>
<tr>
<td></td>
<td>6-12</td>
<td>8.1</td>
<td>8.2</td>
<td>780+</td>
<td>Silt Loam</td>
</tr>
<tr>
<td></td>
<td>12-18</td>
<td>8.3</td>
<td>4.0</td>
<td>780+</td>
<td>Silt Loam</td>
</tr>
<tr>
<td>Swan</td>
<td>0-6</td>
<td>7.2</td>
<td>31.0</td>
<td>460</td>
<td>Silt Loam</td>
</tr>
<tr>
<td></td>
<td>6-12</td>
<td>7.6</td>
<td>7.8</td>
<td>289</td>
<td>Silt Loam</td>
</tr>
<tr>
<td></td>
<td>12-18</td>
<td>7.8</td>
<td>6.1</td>
<td>234</td>
<td>Silt Loam</td>
</tr>
<tr>
<td>Theurer</td>
<td>0-6</td>
<td>8.4</td>
<td>13.0</td>
<td>117</td>
<td>Silt Loam</td>
</tr>
<tr>
<td></td>
<td>6-12</td>
<td>8.3</td>
<td>7.0</td>
<td>101</td>
<td>Silt Loam</td>
</tr>
<tr>
<td></td>
<td>12-18</td>
<td>8.2</td>
<td>6.4</td>
<td>101</td>
<td>Silt Loam</td>
</tr>
<tr>
<td>White</td>
<td>0-6</td>
<td>6.9</td>
<td>52.0</td>
<td>1170</td>
<td>Silt Loam</td>
</tr>
<tr>
<td></td>
<td>6-12</td>
<td>6.9</td>
<td>45.0</td>
<td>655</td>
<td>Silt Loam</td>
</tr>
<tr>
<td></td>
<td>12-18</td>
<td>6.8</td>
<td>36.0</td>
<td>585</td>
<td>Silt Loam</td>
</tr>
</tbody>
</table>

Table 3. Soils Laboratory fertilizer recommendations

<table>
<thead>
<tr>
<th>Plot</th>
<th>Nitrogen (N) (lbs./ac)</th>
<th>Phosphorus (P) (lbs./ac)</th>
<th>Potassium (K) (lbs./ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curlew</td>
<td>30 to 40</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Jensen</td>
<td>100 to 150</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>Junction</td>
<td>30 to 40</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Swan</td>
<td>100 to 150</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Theurer</td>
<td>100 to 150</td>
<td>22 to 35</td>
<td>0</td>
</tr>
<tr>
<td>White</td>
<td>100 to 150</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Precipitation

Rangeland grass production is highly dependent upon precipitation. In years of drought ranges produce far below potential regardless of management. When working with fertilization it is important to know whether or not the year the data was collected was below or above average. On pastures with adequate irrigation the amount of precipitation is not as important.

The sites included in this analysis that fall under the second category are the Jensen and Theurer sites. These two irrigated sites receive similar rainfall (Appendix B). The Theurer site received more than adequate amounts of irrigation during the study period. The rising waters of the Logan River flooded the site for about 3 weeks. Although substantial growth was obtained from this plot, no fertilizer effects were noticable. In contrast, the tall wheatgrass on the Jensen plot showed significant differences in production due to fertilization. This irrigated site was supplied with adequate water throughout the entire growing season.

The Curlew site supported crested wheatgrass and was much more dependent upon precipitation than either the Jensen or Theurer sites. The 1970 precipitation exceeded the 1960–71 average by 0.43 inches and the 1931–60 average by 1.45 inches. The 1971 precipitation exceeded the 1960–71 average by 4.37 inches and the 1931–60 average by 5.39 inches.

The Junction site also supports crested wheatgrass and depends upon precipitation for growth. The precipitation on this site in 1970–71 was also above the 1960–71 average and the 1931–60 average (Appendix B). Precipitation amounts above the average on this site were much less than on the
Curlew site. The 1970 value was 0.84 inches above the 1960-71 average and 1.11 inches above the 1931-60 average. The 1971 value was 0.39 inches above the 12 year average and 0.66 inches above the 30 year average (Appendix B). Thus growth from this plot might be only slightly higher than in an average year.

Precipitation on the Swan site was also above average. The 1970 precipitation exceeded the 12 year average by 6.10 inches and the 30 year average by 7.29 inches. The 1971 precipitation exceeded the 12 year average by 4.39 inches and the 30 year average by 5.58 inches (Appendix B). Thus production might be less in an average year than reported in this study.

Precipitation on the White site was also above average during the study. The 1970 precipitation was greater than the 12 year average by 2.84 inches and the 30 year average by 4.28 inches. The 1971 precipitation exceeded the 12 year average by 4.29 inches and the 30 year average by 5.73 inches (Appendix B). Thus the production functions estimated in this study may predict slightly higher values than would occur in an average year.

Early growth initiation

In the early spring of 1971 measurements of plant height were taken at each site. Continued measurements were taken up to the time of clipping. The results of these measurements indicated that some fertilization rates were beneficial in initiating earlier growth. A summary of those rates which caused plant height to obtain 6 inches before the unfertilized area and the days involved in early green-up are given in Table 4.
Nitrogen fertilization was beneficial in causing early growth on 4 of the 6 sites but phosphorus fertilization showed no earlier growth benefits, on those sites where early green-up occurred, fertilized plants reached 6 inches of height an estimated 8 to 15 days before unfertilized plants (Table 4).

<table>
<thead>
<tr>
<th>Plot</th>
<th>Nitrogen rates pounds per acre</th>
<th>Extended green period - days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curlew</td>
<td>100 and 200</td>
<td>10 - 14</td>
</tr>
<tr>
<td>Jensen</td>
<td>200 and 400</td>
<td>8 - 12</td>
</tr>
<tr>
<td>Junction</td>
<td>NONE</td>
<td>0</td>
</tr>
<tr>
<td>Swan</td>
<td>NONE</td>
<td>0</td>
</tr>
<tr>
<td>Theurer</td>
<td>400 and 800</td>
<td>10 - 15</td>
</tr>
<tr>
<td>White</td>
<td>200 and 400</td>
<td>8 - 12</td>
</tr>
</tbody>
</table>

These results indicate that nitrogen fertilization of some Utah rangeland is one possibility of extending the grazing season earlier into the spring. The extension of the grazing season would enable ranchers to take their cattle off supplemental feeds earlier. This would result in a savings to the rancher equal to the difference between variable grazing costs and feeding costs for as much as two weeks.

Because of the soil moisture conditions present in the early spring on the Swan plot, the extension of the grazing season earlier into the spring would be impractical. The melting snow in the spring causes the soil to remain at
near saturation until plant height is about 7 to 10 inches. Therefore, earlier growth on this site is not as important as it might be on a foothill site.

As will be explained below, the lack of earlier growth on the Junction plot can be explained by the overall lack of response to fertilizer on this relatively dry site.

**Prices and costs**

Important in the determination of optima are the prices of inputs and outputs. Since fertilizer application is priced on a per acre basis, the cost of application is the same regardless of the application rate (except the 0 rate). This implies that the application cost becomes a fixed cost after the decision has been made to fertilize. This cost, and all fixed costs, are important in determining whether to fertilize or not, but it is not important in the determination of the optimum rate of fertilizer. The cost of fertilizer application used in this analysis for dry bulk fertilizer was $1.50 per acre which is the cross sectional average for the Western United States (Lewis, 1972).

The swathing of the hay is another fixed cost which applies to the analysis in the same fashion as the cost of application. Regardless of the pounds of forage produced per acre, the swathing cost remains constant. The average cost for swathing used in the analysis was $3.50 per acre, the cross sectional average for the Western United States (Lewis, 1972).

Variable costs are those costs which vary with changes in output. The variable costs in this analysis were fertilizer costs, baling costs, and hauling costs. The fertilizer costs involve the price of ammonium nitrate (source of N)
times the amount of ammonium nitrate applied. The average price paid by Utah farmers for ammonium nitrate from 1963 to 1968 was $82.08 per ton ($0.1207/lb. of N) (Christensen and Richards 1969). The price trend over that period for ammonium nitrate has been one of continual decline. The price per ton in 1963 was $86.00 and in 1968 was $76.50. The analysis of changes in the price of nitrogen will be discussed in the section entitled "Sensitivity Analysis."

The final production functions estimated through regression analysis did not involve phosphorus as a relevant independent variable. Thus the price of treble super phosphate (source of P) was of no consequence in the analysis.

Baling and hauling costs were taken from a cross sectional average of custom baling and hauling costs in the Western United States. The custom rate for baling was $0.13/bale ($0.0020/lb., assuming 33 bales/ton) and $0.10/bale ($0.0017/lb.) for hauling (Lewis, 1972).

Three prices were determined for the price of the forage. The first price was the average price paid to Utah farmers for all hay for the period 1958 to 1968. This price was $22.28/ton ($0.0111/lb.) (Christensen and Richards 1969). This price is relevant when the forage is cut and baled as hay. It also applies to grazing situations where the only alternative to grazing is buying and feeding hay.

The second price is relevant when the forage is grazed as part of the usual management scheme. Assuming 400 pounds of total digestible nutrients (T.D.N.) per animal unit month (A.U.M.) (Shultis et al. 1970) and the percentage of forage dry matter that is T.D.N. for tall, intermediate, and crested wheatgrass as 50% (National Academy of Sciences, 1971) the pounds of dry
forage per A.U.M. is 800. Due to sustained yield management considerations, animals cannot utilize 100% of the forage available. It was assumed that only 70% of the dry forage measured can be utilized. Thus 1333 pounds of dry forage are required per A.U.M. Assuming a value of $4.99/A.U.M. (Hooper et al. 1969) the price of the forage is $0.0030/lb.

The third method involved the amount of grazing fees and other non-fee costs avoided by using the additional forage produced through fertilization to feed cattle normally grazed on federal land. Implicit in this technique is the selling of the permits that are no longer needed because of increased production. The costs of grazing on federal land and private land and the difference (savings) are given in Table 5.

The difference column of Table 5 indicates savings or costs avoided by not grazing federal land. The veterinary costs are higher on private land than on federal land mainly because the cattle are more accessible for treatment on the private land and thus receive more intensive care. This is also reflected in a lower cost due to lost animals. Moving livestock and traveling to and from the allotments, interest on investment in permits, federal grazing fees, and association fees are costs not involved when grazing private land. Fence maintenance, water maintenance, and development depreciation are costs which must be met by private land owners regardless of increased grazing through fertilization.

The $1.14/A.U.M. interest on investment in permits was calculated by allowing the permit owner a 4.5% return on his investment, using $25.35 A.U.M. as the average value of the grazing permit. Thus, ($25.35/A.U.M.) (0.045) = $1.14/A.U.M. return on investment. This amount per A.U.M. can be saved
<table>
<thead>
<tr>
<th>Itemized costs</th>
<th>Federal Costs</th>
<th>Private Costs</th>
<th>Difference (Savings)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Federal grazing fee</td>
<td>0.78</td>
<td>----</td>
<td>0.78</td>
</tr>
<tr>
<td>Lost animals</td>
<td>0.60</td>
<td>0.37</td>
<td>0.23</td>
</tr>
<tr>
<td>Association fee</td>
<td>0.08</td>
<td>----</td>
<td>0.08</td>
</tr>
<tr>
<td>Veterinary</td>
<td>0.11</td>
<td>0.13</td>
<td>-0.02</td>
</tr>
<tr>
<td>Moving livestock to and from allotments</td>
<td>0.24</td>
<td>----</td>
<td>0.24</td>
</tr>
<tr>
<td>Herding</td>
<td>0.46</td>
<td>0.19</td>
<td>0.27</td>
</tr>
<tr>
<td>Salting and feeding</td>
<td>0.56</td>
<td>0.56⁸</td>
<td>0.00</td>
</tr>
<tr>
<td>Travel to and from allotments</td>
<td>0.32</td>
<td>----</td>
<td>0.32</td>
</tr>
<tr>
<td>Water (variable costs)</td>
<td>0.08</td>
<td>0.06</td>
<td>0.02</td>
</tr>
<tr>
<td>Fence maintenance</td>
<td>0.24</td>
<td>----</td>
<td>0.24</td>
</tr>
<tr>
<td>Horse</td>
<td>0.16</td>
<td>0.10</td>
<td>0.06</td>
</tr>
<tr>
<td>Water maintenance</td>
<td>0.19</td>
<td>----</td>
<td>0.19</td>
</tr>
<tr>
<td>Development depreciation</td>
<td>0.11</td>
<td>----</td>
<td>0.11</td>
</tr>
<tr>
<td>Other costs</td>
<td>0.13</td>
<td>0.14</td>
<td>-0.01</td>
</tr>
<tr>
<td>Interest on investment in permits</td>
<td>1.14</td>
<td>----</td>
<td>1.14</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$5.20</td>
<td>$1.55</td>
<td><strong>$3.65</strong></td>
</tr>
</tbody>
</table>

⁸Salting and feeding costs for private land was originally reported as $0.83, however this is prior to fertilization and it is assumed that with fertilization supplemental feeding could be reduced to at least the level of federal land.
each year by the land owner if he sells his permits and grazes on his now more productive land.

The value (price) of the forage per pound was determined by the third technique as follows:

\[
\frac{\$3.65/\text{A.U.M.}}{1333 \text{ lbs.}/\text{A.U.M.}} = 0.0027/\text{lb.}
\]

Table 6 contains a summary of prices and costs. It will be noted that techniques 2 and 3 give similar forage prices.

**Production functions**

A production function is defined as the functional relationship between one or more inputs \((x_1, x_2, \ldots, x_n)\) and the product produced \((Y)\). Algebraically this relationship can be expressed as

\[
Y = f(x_1, x_2, \ldots, x_n).
\]

The production function (which in geometric terms is also called the total physical product curve, TPP) is an important tool to both the economist and the biologist. It enables the biologist to better understand the complete picture of production, rather than merely a few isolated points representing the relationship between inputs and outputs. It enables the economist to analyze the production process and determine economic optima, otherwise unattainable.

The productions functions used in this analysis were of the form

\[
Y = a + bN - cN^2 + dP - eP^2 + fNP
\]

where \(Y\) is the pounds of air dry forage per acre, \(N\) is the pounds of nitrogen fertilizer applied per acre, \(P\) is the pounds of phosphorus fertilizer applied
Table 6. Summary of prices and costs.

<table>
<thead>
<tr>
<th>Fixed costs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer application</td>
<td>$1.50/ac</td>
</tr>
<tr>
<td>Swathing</td>
<td>$3.50/ac</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable costs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen fertilizer ($P_N$)</td>
<td>$0.1207/lb.</td>
</tr>
<tr>
<td>Baling hay ($P_h$)</td>
<td>$0.0021/lb.</td>
</tr>
<tr>
<td>Hauling hay ($P_h$)</td>
<td>$0.0017/lb.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prices</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Forage (baled hay) ($P_{Y1}$)</td>
<td>$0.011/lb.</td>
</tr>
<tr>
<td>Forage (grazed) ($P_{Y2}$)</td>
<td>$0.0030/lb.</td>
</tr>
<tr>
<td>Forage (federal fees avoided) ($P_{Y3}$)</td>
<td>$0.0027/lb.</td>
</tr>
</tbody>
</table>

per acre, and $a$, $b$, $c$, $d$, $e$, and $f$ are coefficients. In this analysis $Y$ is the output, $N$ and $P$ are the variable inputs.

Stepwise multiple regression analysis was used to estimate the production function and the resulting total physical product curve (TPP). This analysis was accomplished by a computer program which computed the coefficients ($a$, $b$, $c$, $d$, $e$, and $f$), performed an analysis of variance for all variables ($N$, $N^2$, $P$, $P^2$, $NP$), deleted the variable which contributed least to the model sum of squares, and then recomputed the analysis of variance for the new model. Two total physical product functions were estimated for each site (one for spring application and one for fall application) except for the Junction and Curlew plots, where only the spring functions were estimated.
The results of the initial regression analysis are given in Table 7.

Table 7. Results of initial regression analysis on each site.

<table>
<thead>
<tr>
<th>Plot</th>
<th>Application</th>
<th>$R^2$</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curlew</td>
<td>Spring</td>
<td>.59</td>
<td>1190</td>
<td>18.30*</td>
<td>-.0623*</td>
<td>5.29</td>
<td>-.0420</td>
<td>-.0275</td>
</tr>
<tr>
<td>Jensen</td>
<td>Spring</td>
<td>.66</td>
<td>5258</td>
<td>28.38*</td>
<td>-.0278*</td>
<td>2.31</td>
<td>-.0018</td>
<td>-.0019</td>
</tr>
<tr>
<td></td>
<td>Fall</td>
<td>.68</td>
<td>6201</td>
<td>27.24*</td>
<td>-.0266*</td>
<td>6.95</td>
<td>.0246</td>
<td>.0112</td>
</tr>
<tr>
<td>Junction</td>
<td>Spring</td>
<td>.15</td>
<td>1308</td>
<td>7.36</td>
<td>-.0360</td>
<td>3.48</td>
<td>-.0139</td>
<td>.0094</td>
</tr>
<tr>
<td>Swan</td>
<td>Spring</td>
<td>.06</td>
<td>2055</td>
<td>2.54</td>
<td>-.0030</td>
<td>1.24</td>
<td>-.0021</td>
<td>.0015</td>
</tr>
<tr>
<td></td>
<td>Fall</td>
<td>.08</td>
<td>2737</td>
<td>2.28</td>
<td>-.0026</td>
<td>1.32</td>
<td>-.0046</td>
<td>.0083</td>
</tr>
<tr>
<td>Theurer</td>
<td>Spring</td>
<td>.05</td>
<td>8183</td>
<td>-3.60</td>
<td>.0059</td>
<td>14.25</td>
<td>-.0822</td>
<td>.0102</td>
</tr>
<tr>
<td></td>
<td>Fall</td>
<td>.15</td>
<td>8370</td>
<td>15.11</td>
<td>-.0159</td>
<td>.03</td>
<td>.0429</td>
<td>.0068</td>
</tr>
<tr>
<td>White</td>
<td>Spring</td>
<td>.81</td>
<td>1931</td>
<td>29.50*</td>
<td>-.0463*</td>
<td>-.28</td>
<td>-.0018</td>
<td>.0058</td>
</tr>
<tr>
<td></td>
<td>Fall</td>
<td>.74</td>
<td>2536</td>
<td>25.63*</td>
<td>-.0392*</td>
<td>1.19</td>
<td>-.0110</td>
<td>.0128</td>
</tr>
</tbody>
</table>

*Significant at the .10 probability level.

The final models chosen for the analysis were those which showed significance of all included variables at the .10 level and had an $R^2$ greater than .50. The models meeting these criteria involved only the variables N and $N^2$ and P, $P^2$, and NP were deleted. These models are given in Table 8. The graphical representation of these production functions appear as figures 3, 4, 5, 6, and 7.
Table 8. Estimated production functions where significance of variables and model was at least at the .10 probability level.

<table>
<thead>
<tr>
<th>Plot</th>
<th>Application</th>
<th>Model Production Function</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curlew</td>
<td>Spring</td>
<td>$y = 1268 + 17.42N - .0623N^2$</td>
<td>.56</td>
</tr>
<tr>
<td>Jensen</td>
<td>Spring</td>
<td>$y = 5392 + 28.26N - .0278N^2$</td>
<td>.66</td>
</tr>
<tr>
<td></td>
<td>Fall</td>
<td>$y = 6070 + 27.96N - .0266N^2$</td>
<td>.67</td>
</tr>
<tr>
<td>White</td>
<td>Spring</td>
<td>$y = 1897 + 29.88N - .0463N^2$</td>
<td>.81</td>
</tr>
<tr>
<td></td>
<td>Fall</td>
<td>$y = 2515 + 26.46N - .0392N^2$</td>
<td>.73</td>
</tr>
</tbody>
</table>

The analysis of the Junction, Swan, and Theruer plots resulted in statistically insignificant production functions. The $R^2$ values for these sites were .14, .08, and .15 respectively and none of the beta coefficients were significant at the .10 probability level. The failure of these plots to produce significant production functions can be partially explained. The Junction plot did not have adequate moisture to utilize the nitrogen applied. Thus variations in production at this site were random. The Theruer plot was flooded by high water from spring runoff. The entire plot was under about one foot of water for approximately 3 weeks. It is therefore probable that the fertilizer was lost. The Swan plot results are somewhat more difficult to explain. One possible explanation is that the soil is not deficient in the nutrients applied. As Table 2 indicates the soil on the Swan plot had sufficient phosphorus. Because the summer precipitation on the area is mainly thunderstorms, it is possible that sufficient nitrates are supplied to the soil by rainwater. Another possible
Figure 3. Production function for Curlew spring application.

\[ Y = 1268 + 17.42N - 0.0623N^2 \]
Figure 4. Production for Jensen fall application.

\[ Y = 5392 + 28.26 N - 0.0278 N^2 \]
Figure 5. Production function for Jensen spring application.

\[ Y = 6070 + 27.96 N - 0.0266 N^2 \]
Figure 6. Production function for White clover application.

\[ Y = 1897 + 29.88 \times N - 0.0463 \times N^2 \]
Figure 7. Production function for White clover application.
explanation is supplied by a combination of factors. The fall application was applied on one foot of snow. This might have caused the loss of the ammonia \((\text{NH}_4)\) portion of the fertilizer to the atmosphere and the nitrate \((\text{NO}_3)\) portion to downslope or lateral movement. If so, fertilizer application would have been random and statistically insignificant results would have been obtained.

The spring application was applied on May 19, 1971. The precipitation occurring on the site from May 19 to July 13 was 1.54 inches. The important consideration in determining the effectiveness of the fertilizer was whether or not the applied nutrients reached the root zone. It is possible that the 1.54 inches of rainfall came in small thunderstorms, in which event the net soil moisture movement for the period would have been upward. Thus, the nitrates would accumulate in the surface inches of the soil and remain out of the root zone for most species. This is supported, somewhat, by the burning of leaves which occurred on the Idaho fescue plants growing on subplots where high nitrogen rates were applied. Idaho fescue, being a shallow rooted species, was the only grass to respond in such a way to the fertilizer. Even if the precipitation occurred in such a manner to cause the nitrates to enter the root zone, it is likely that the net movement was upward. Thus, the nitrogen probably accumulated in the surface inches and the root zones of most species remained deficient in nitrogen (James, 1972). Additional research will be required in order to determine the exact cause of the lack of response.

**Determination of optima**

The profit maximizing level of fertilization is the most important information that ranchers can have concerning range fertilization. If they are
limited in the amount of money they can spend to fertilize, the optimum level of fertilization will generally vary from the unlimited capital case.

The first step in determining the optimum level of fertilization is to determine the total physical product functions. From the total physical product functions the marginal physical product functions are calculated. For example, if the total physical product function were

\[ Y = a + bN - cN^2 + dP - eP^2 + fNP \]

the marginal physical product functions would be found by taking the first partial derivatives with respect to \( N \) and with respect to \( P \). This would yield

\[ MPP_N = \frac{\partial Y}{\partial N} = b - 2cN + fP \]

\[ MPP_P = \frac{\partial Y}{\partial P} = d - 2eP + fN. \]

where \( MPP_N \) is the marginal physical product of nitrogen and \( MPP_P \) is the marginal physical product of phosphorus.

Using the prices of nitrogen (\( P_N \)) and phosphorus (\( P_P \)) as marginal factor costs, the optimum (least expensive) combination of nitrogen and phosphorus can be determined. For example, to determine the least expensive combination of nitrogen and phosphorus the ratio of the marginal physical products to the marginal factor costs must be equal. Shown algebraically as

\[ \frac{MPP_N}{P_N} = \frac{MPP_P}{P_P}, \]

Using the price of the forage (\( P_Y \)) as marginal revenue, the optimum (most profitable) rate of nutrient application can be determined. The mathematical approach to this is accomplished through the use of marginal value
product \( \text{MVP}_N \) and \( \text{MVP}_p \) and marginal factor cost \( \text{MFC}_N \) and \( \text{MFC}_p \). The marginal value product of nitrogen and phosphorus are defined as the marginal revenue \( P_Y \), assuming perfect competition) multiplied by the marginal physical product of nitrogen and phosphorus:

\[
\text{MVP}_N = P_Y \cdot \text{MPP}_N \quad \text{and} \quad \text{MVP}_p = P_Y \cdot \text{MPP}_p
\]

The marginal factor costs are equal to the price of the inputs, nitrogen \( P_N \) and phosphorus \( P_p \), assuming perfect competition. The profit maximizing level of inputs is found by setting the marginal factor costs equal to the marginal value products for all inputs. Thus,

\[
\text{MVP}_N = \text{MFC}_N \quad \text{and} \quad \text{MVP}_p = \text{MFC}_p
\]

is the expression for maximum profit. This can also be written:

\[
P_Y \cdot \text{MPP}_N = P_N \quad \text{and} \quad P_Y \cdot \text{MPP}_p = P_p.
\]

The simultaneous solutions of the above equations yield the optimum (maximum profit) level of fertilization.

By comparing the amount of profit for the spring and fall applications, the most effective time of year for fertilization can be determined.

In the current analysis all production functions showing statistical reliability involved only the variable \( N \). The optimization of these functions is similar to that just discussed. The same definition holds for optimization,

\[
\text{MVP}_N = \text{MFC}_N. \text{ Therefore, } P_Y \cdot \text{MPP}_N = P_N \text{ solved for the unknown } N \text{ is the optimum, profit maximizing, level of nitrogen.}
\]

As an illustration of this technique the optimum level of nitrogen is determined using the fall application production function for the Jensen plot. Given the \( \text{TPP}, P_Y, P_N, \text{ price of baling } (P_b), \text{ and price of hauling } (P_h) \) the
profit maximizing level of N can be determined. In the case where the hay is baled, the determination of optima is found by using a net price of forage \( P_{Yn} \) which is equal to the price of the forage \( P_Y \) minus the cost of baling \( P_b \) and the cost of hauling \( P_h \). Since all three are expressed in terms of dollars per pound the resultant figure is the net price of the forage in dollars per pound.

The necessary information is as follows:

\[
Y = TPP = 6070 - 27.96N - .0266N^2
\]

\[
P_Y = \$ .0111/lb.
\]

\[
P_b = \$ .0021/lb.
\]

\[
P_h = \$ .0017/lb.
\]

\[
P_{Yn} = \$ .0073/lb.
\]

\[
P_N = \$ .1207/lb.
\]

The determination of the optimum level of N applied is shown in the following calculations.

\[
\frac{\partial Y}{\partial N} = \text{MPP}_N = 27.96 - .0532N
\]

\[
\text{MFC}_N = \text{MVP}_N \quad \text{or} \quad P_N = P_{Yn} \cdot \text{MPP}_N
\]

\[
\$ .1207/lb. = (\$ .0073/lb.) (27.96 - .0532N)
\]

solving for N yields

\[
N = 215 \text{ lbs./acre}
\]

Therefore, the profit maximizing level of nitrogen fertilization for the Jensen plot, fall application is 215 lbs./acre and 10,852 lbs. of forage/acre.
The optimization of production functions can also be accomplished graphically. Figure 8 shows the optimum levels of N and Y found graphically for the Jensen plot, fall application. The first step is drawing the TPP curve. Then a new origin is formed on the Y-axis above the maximum value on the TPP curve. The new N-axis has increasing values of N to the right and is of the same scale as the original N-axis. The new Y-axis has the same scale as before, but increases in a downward direction. Next the slope of the price line is determined by finding the amount of N that can be purchased with a given outlay ($20.00), thus \( \frac{\$20}{P_Y} = 166 \text{ lbs.} \) The amount of Y that can be sold for $20.00 is \( \frac{\$20}{P_Y} = 2740 \text{ lbs.} \) These two points determine the intercepts of the price ratio line. A straight line connecting these two points gives all the possible combinations of Y which can be sold and N which can be bought for $20.00.

The slope of this price ratio line is

\[
\frac{\$20}{P_Y} = \frac{P_N}{P_Y} - \frac{\$20}{P_Y}
\]

The slope of the TPP curve is given by the \( \frac{\partial Y}{\partial N} \) or \( MPP_N \). By definition the profit maximizing level of N is where \( MPP_N \cdot P_Y = P_N \) or \( MPP_N = \frac{P_N}{P_Y} \).

Therefore, at the point where a price ratio line just comes tangent to the TPP curve defines the profit maximizing point. As shown in Figure 8 this point is approximately 10,850 pounds of forage per acre and 215 pounds of N per acre, the same solution obtained algebraically.
Figure 8. Graphical optimization for Jensen fall application.
The determination of profit ($\pi$) per acre is accomplished by subtracting total costs (TC) per acre from total revenue (TR) per acre. TC includes fertilizer costs ($0.120$/lb.), application costs ($1.50$/ac), swathing costs ($3.50$/ac), baling costs ($0.0021$/lb.), and hauling costs ($0.0017$/lb.). TR is the market value of the hay. Therefore,

\[
TC = P_n \cdot N + \text{application} + \text{swathing} + P_b \cdot Y + P_h \cdot Y
\]

\[
TC = (0.120$/lb.) \cdot (215 \text{ lbs./ac}) + (1.50$/ac) + (3.50$/ac)
\]

\[
+ (0.0021$/lb.) \cdot (10,852 \text{ lbs./ac}) + (0.0017$/lb.)
\]

\[
(10,852 \text{ lbs./ac})
\]

\[
TC = 72.19/ac
\]

\[
TR = P_Y \cdot Y (0.0111$/lb.) \cdot (10,852 \text{ lbs./ac}) = 120.46/ac
\]

\[
\pi = TR - TC = 120.46 - 72.19 = 48.27/ac
\]

Thus the profit per acre is 48.27.

The same analysis was completed on all plots which yielded statistically significant production functions. These results are given in Table 9. The results indicate that fertilization of these range sites would be profitable if the hay were cut and baled. On the White and Jensen plots both spring and fall fertilizer applications were profitable. However, in both cases, the most efficient time of year to apply fertilizer was the fall. Profit was greater by nearly $5.00 per acre on the Jensen plot and over $2.00 per acre on the White plot when fertilizer was applied in the fall rather than spring.

Only the data from the spring application was available on the Curlew site. If the hay were cut and baled the Curlew site would yield over $4.00 per
acre. One of the two following approaches would be more applicable to this site since it is more likely that it would be grazed rather than cut and baled.

The optimum level of nitrogen application changes with changes in forage price. Since the price of the forage is a function of the method of harvest, optimum application rate also depends upon how the forage is harvested. When the forage is grazed the price is $.003/lb. (Table 6).

Table 9. Maximum profit rate of fertilizer application, pounds of forage produced, and profit per acre when forage is cut and baled.

<table>
<thead>
<tr>
<th>Plot</th>
<th>Application</th>
<th>Optimum levels of N lbs/ac</th>
<th>Forage produced lbs/ac</th>
<th>Profit $/ac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curlew</td>
<td>Spring</td>
<td>7</td>
<td>1386</td>
<td>4.27</td>
</tr>
<tr>
<td>Jensen</td>
<td>Fall</td>
<td>215</td>
<td>10852</td>
<td>48.27</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>211</td>
<td>10117</td>
<td>43.39</td>
</tr>
<tr>
<td>White</td>
<td>Fall</td>
<td>127</td>
<td>5243</td>
<td>17.95</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>144</td>
<td>5240</td>
<td>15.87</td>
</tr>
</tbody>
</table>

The Jensen plot, fall application will serve as an example of the determination of optima using \( P_Y = $.003/lb \) and \( P_N = $.1207/lb \).

\[
TPP = Y = 6070 + 27.96N - .0266N^2
\]

\[
MPP = \frac{\delta Y}{\delta N} = 27.96 - .0532N
\]

\[
MFC_N = MVP_N
\]

\[
P_N = P_Y \cdot MPP_N
\]
The fertilization level of N is negative, the implication to this site. Graphically, this can be in-ratio line and the TPP curve occurring rice of the forage is too low or the price nically feasible fertilization. Since it is he origin the relevant point on the curve is

\[
N = (\text{price} \times \text{forage produced}) = (0.003/\text{lb.}) \times 6070 \text{ lbs./ac.} = 18.21/
\]
each site are given in Table 10. It may be forage is only $0.003/lb. fertilization of the study sites becomes uneconomical. The values for spring and fall profit vary, even though no fertilizer should be applied in either fall or spring, because the spring and fall production functions have different intercepts. A more reasonable measure of profit may be the average of these two values.

If the forage is valued by the avoidance of federal grazing fees the relevant price of the forage is $0.0027/lb. The calculations of optima is accomplished by the procedure previously outlined. Because the value of federal fees avoided is even less than the price of $0.003/lb. employed above, the slope of the price ratio line will become even steeper and the optimum will again be zero rate of nitrogen application. Optimum forage per acre will remain unchanged and profit per acre is as follows: Curlew plot, spring...
Table 10. The optimum rate of nitrogen fertilization, forage produced, and profit per acre when forage is used for grazing.

<table>
<thead>
<tr>
<th>Plot</th>
<th>Application</th>
<th>Optimizing level of N lbs./ac</th>
<th>Forage Produced lbs./ac</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curlew</td>
<td>Spring</td>
<td>0</td>
<td>1268</td>
<td>3.80</td>
</tr>
<tr>
<td>Jensen</td>
<td>Fall</td>
<td>0</td>
<td>6070</td>
<td>18.21</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>0</td>
<td>5392</td>
<td>16.18</td>
</tr>
<tr>
<td>White</td>
<td>Fall</td>
<td>0</td>
<td>2515</td>
<td>7.55</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>0</td>
<td>1897</td>
<td>5.69</td>
</tr>
</tbody>
</table>

Many ranchers find themselves unable to fertilize at the profit maximizing rate because of limited budgets. This imposes an additional constraint on the optimization problem. An example will be used to demonstrate optimization with a budget constraint. Using the Jensen plot fall application production function, assume Mr. Jensen has 1,000 acres of land to which this production function applies and only $12,000 to spend on fertilizer. Thus the budget constraint becomes

\[ P_N \cdot N \cdot (1,000) = 12,000 \]

This information is necessary to determine the amount of N he should apply per acre. By solving for N the optimal level of N/ac is found. The solution becomes

\[ N = \frac{12,000}{(1,000 \text{ ac}) \cdot ($0.1207/\text{lb.})} = 99 \text{ lbs./ac} \]
and the pounds of forage produced is 8577 lbs./ac. The profit now becomes

\[
\pi = TR - TC = P_Y \cdot Y - (\text{application costs} + \text{cutting costs} + P_N \cdot Y + P_b \cdot Y + P_h \cdot Y) = $45.66/\text{ac}
\]

Thus profit has decreased by approximately $3.00/\text{ac} due to the budget constraint.

It should be noted that the budget constraint is the only equation necessary for the determination of the rate of N, if the solution is less than or equal to the unconstrained optimum. If the rate of N given by the budget constraint solution is greater than the unconstrained optimum, the budget is not limiting. Thus, simultaneous solution of two equations is sufficient to insure optimization with a budget constraint. The two equations are

\[
P_N \cdot N \cdot (\text{acres}) \leq \text{Budget}
\]

\[
\text{MPP}_N \cdot P_{YN} \geq P_N.
\]

The most profitable management on the Curlew site would be to fertilize with 7 pounds of nitrogen per acre and cut and bale the hay. If sold on the open market at $22.28/ton and transportation costs are zero, the profit would be $4.27/\text{ac} (Table 9). However, as pointed out by Nielsen (1965) the value of grazing changes from month to month. If the value of grazing is high in the months when fertilization causes increased growth, it may be economically feasible to fertilize even though the average grazing value used in the above analysis makes fertilization unprofitable.

The most profitable management on the Jensen site would be to fertilize with 215 lbs./ac of N in the fall and cut and bale the hay. This would yield a profit of $48.27/ac (Table 9).
The most profitable management on the White site would also be to fertilize in the fall and cut and bale the hay. Nitrogen should be applied at 122 lbs./ac and $17.95/ac profit would be realized (Table 9).

As with the Curlew site, these sites are also used as grazing areas. It is possible, as already mentioned, that the value of early spring and late fall grazing is higher than the average value used in this analysis. In the next section prices of forage and nitrogen will be allowed to vary and thresholds of economic feasibility will be determined. Thus a rancher can determine for his own operation whether cutting and baling hay or grazing is the more profitable according to the value he places on forage.

It is difficult to place values on all the benefits that accrue through fertilization. The increase in forage quality could best be valued in terms of changes in livestock production. Change in species composition towards more palatable and nutritious forage plants could be valued by a long term study on weight gains of various grazing animals.

Fertilization of land may be associated with costs as well as benefits. The increased growth of algae and the higher amounts of phosphates and nitrates in the rivers has been attributed, in part, to fertilization. The true picture of range fertilization must include an interdisciplinary analysis of all benefits and all costs. Future research into the economics of range fertilization may well be along these lines.

**Sensitivity analysis**

Sensitivity analysis is concerned with shifts in optima as the values of various independent variables change. In this analysis it is the comparison of
optimum rates of N as the prices of N and Y change. Given the production function

$$TPP = Y = a + bN - cN^2$$

and the necessary and sufficient condition for profit maximization

$$P_Y \cdot MPP_N = P_N$$

the optimum rate of N can be found. Thus

$$P_Y (b - 2cN) = P_N$$

$$N = \frac{P_N - bP_Y}{-2cP_Y}$$

yields the profit maximizing rate of N. By determining the sign of $\frac{\partial N}{\partial P_Y}$ and $\frac{\partial N}{\partial P_N}$, the direction which N changes with changes in $P_Y$ and $P_N$ can be found. The partial derivatives are

$$\frac{\partial N}{\partial P_Y} = \frac{P_N}{2cP_Y^2} > 0$$

$$\frac{\partial N}{\partial P_N} = \frac{1}{-2cP_Y} < 0$$

Since $\frac{\partial N}{\partial P_Y} > 0$ the optimum value of N and changes in the price of Y move in the same direction. Thus if $P_Y$ increases, the optimum N increases.

Graphically, as $P_Y$ increases the slope of the price ratio line $\frac{P_N}{P_Y}$ decreases and the tangency on the TPP curve moves to the right.

$$\frac{\partial N}{\partial P_N} < 0$$

which implies that the optimum value of N moves in the opposite direction from changes in $P_N$. Thus if $P_N$ increases, the optimum N decreases.

Graphically, as $P_N$ increases the slope of the price ratio line $\frac{P_N}{P_Y}$ increases and the tangency with the TPP curve moves to the left.
Tables 11, 12 and 13 give the optimum rates of N for the Curlew spring application, the Jensen fall application, and the White fall application for various values of $P_N$ and $P_Y$. If the forage is being cut and baled the price of the forage must be a net price $(P_{YN} = P_Y - P_b - P_h)$ where $P_b$ = price of baling and $P_h$ = price of hauling.

All three tables of optimum rates of nitrogen demonstrate that with increased forage prices, the optimum rate of N increases and vice versa and with increased nitrogen prices, the optimum rate of N decreases.

The usefulness of this type of analysis is apparent when one considers the annual changes in market prices of both forage and nitrogen. In any one year prices may change enough to cause the economic optimum to vary as much as 100 pounds of nitrogen per acre. The importance to the rancher of the production functions generated and the sensitivity analysis presented is obvious.

Using $P_N = $ .1207/lb. as the current price of nitrogen and the general equation for determining the optimum level of $N$, the price of the forage necessary to justify fertilization can be found. The equation for the optimum value of $N$ is

$$MPP_N \cdot P_Y = P_N.$$

Thus solving

$$(b - 2cN) P_Y = P_N$$

for $N$ yields

$$N = \frac{bP_Y - P}{2cP_Y}$$

which is the general equation for the optimum value of $N$. The calculation of $P_Y$ which would allow $N$ to equal zero would yield the minimum $P_Y$ which economically justifies fertilization. The condition sufficient for the above
equation to equal zero is for the numerator to equal zero. Thus, \( bP_Y \) must equal \( P_N \).

Therefore, for the Curlew spring application

\[
(17.42) \quad P_Y = \$ \cdot 1207/\text{lb.}
\]

\[
P_Y = \$ \cdot 0069/\text{lb.}
\]

and the \( P_Y \) must equal \$ .0069 in order to justify \( N \) application. For the Jensen fall application

\[
(27.96) \quad P_Y + \$ \cdot 1207/\text{lb.}
\]

\[
P_Y = \$ \cdot 0043/\text{lb.}
\]

For the White fall application

\[
(26.46) \quad P_Y = \$ \cdot 1207/\text{lb}
\]

\[
P_Y = \$ \cdot 0046/\text{lb.}
\]

Therefore, if \( P_N = \$ \cdot 1207/\text{lb.} \) and \( P_Y = \$ \cdot 0043/\text{lb.} \) and \( P_Y \) began rising slowly, fertilization would become feasible on the Jensen site first, then the White, and then the Curlew site.

Using \( P_Y = \$ \cdot 0073/\text{lb.} \) as the current net price of forage the values of \( P_N \) which would cause fertilization to become unprofitable were calculated. The \( P_N \) would have to be at least \$ \cdot 1272/\text{lb.}, \$ \cdot 2041/\text{lb.}, and \$ \cdot 1932/\text{lb.} \) to cause fertilization to be unprofitable on the Curlew spring, Jensen fall, and White fall sites respectively.

Using discrete and arbitrary changes in prices, the thresholds of economic feasibility are apparent in Tables 11, 12, and 13. Fertilization becomes profitable on the Curlew site when the price of the forage is equal to or greater than \$ \cdot 007/\text{lb.} \) and the price of nitrogen is equal to or less than \$ \cdot 10/\text{lb.} \).
Fertilization is justified at higher prices of nitrogen only when the price of the forage increases.

Fertilization is profitable on the Jensen site when $P_N \leq \$0.06/lb$ and $P_Y \geq \$0.003/lb$. As $P_Y$ increases, fertilization is profitable at even higher nitrogen prices. Fertilization is unprofitable when $P_Y = \$0.007/lb$ and $P_N = \$0.20/lb$.

Fertilization is profitable on the White site when $P_N \leq \$0.06/lb$ and $P_Y \geq \$0.003/lb$. When $P_Y = \$0.007/lb$, fertilization is profitable at $P_N \leq \$0.18/lb$. Fertilization is also profitable at all $P_Y \geq \$0.011/lb$ and $P_N \leq \$0.20/lb$. 
Table 11. Optimum rates of N/ac at various prices of forage ($P_Y$) and nitrogen ($P_N$) for the Curlew spring application.

| Price of | $P_Y$($$/AUM) | 4.00 | 9.33 | 14.66 | 20.00 | 26.66 | 39.99 |
| ammonium | $P_Y$($$/ton) | 6.00 | 14.00 | 22.00 | 30.00 | 40.00 | 60.00 |
| nitrate  | $P_Y$($$/lb.) | .003 | .007 | .011 | .015 | .020 | .030 |
| ($$/ton) | ($$/lb.)      |      |      |      |      |      |      |
| 40.80    | .06           | 0    | 71   | 96   | 108  | 116  | 124  |
| 68.00    | .10           | 0    | 25   | 67   | 86   | 100  | 113  |
| 95.20    | .14           | 0    | 0    | 38   | 65   | 84   | 102  |
| 122.40   | .18           | 0    | 0    | 8    | 44   | 68   | 92   |
| 136.00   | .20           | 0    | 0    | 0    | 33   | 60   | 86   |

Table 12. Optimum rates of N/ac at various prices of forage ($P_Y$) and nitrogen ($P_N$) for the Jensen fall application.

| Price of | $P_Y$($$/AUM) | 4.00 | 9.33 | 14.66 | 20.00 | 26.66 | 39.99 |
| ammonium | $P_Y$($$/ton) | 6.00 | 14.00 | 22.00 | 30.00 | 40.00 | 60.00 |
| nitrate  | $P_Y$($$/lb.) | .003 | .007 | .011 | .015 | .020 | .030 |
| ($$/ton) | ($$/lb.)      |      |      |      |      |      |      |
| 40.80    | .06           | 150  | 364  | 423  | 450  | 469  | 488  |
| 68.00    | .10           | 0    | 257  | 355  | 400  | 432  | 463  |
| 95.20    | .14           | 0    | 150  | 268  | 350  | 394  | 438  |
| 122.40   | .18           | 0    | 42   | 218  | 300  | 356  | 413  |
| 136.00   | .20           | 0    | 0    | 184  | 275  | 338  | 400  |
Table 13. Optimum rates of N/ac at various prices of forage ($F_Y$) and nitrogen ($P_N$) for the White fall Application

<table>
<thead>
<tr>
<th>Price of ammonium nitrate ($/ton$)</th>
<th>$P_Y$ ($$/AUM$)</th>
<th>4.00</th>
<th>9.33</th>
<th>14.66</th>
<th>20.00</th>
<th>26.66</th>
<th>39.99</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$P_Y$ ($$/ton$$/lb.$)</td>
<td>.003</td>
<td>.007</td>
<td>.011</td>
<td>.015</td>
<td>.020</td>
<td>.030</td>
</tr>
<tr>
<td>40.80</td>
<td>.06</td>
<td>82</td>
<td>228</td>
<td>268</td>
<td>286</td>
<td>299</td>
<td>312</td>
</tr>
<tr>
<td>68.00</td>
<td>.10</td>
<td>0</td>
<td>155</td>
<td>222</td>
<td>252</td>
<td>274</td>
<td>295</td>
</tr>
<tr>
<td>95.20</td>
<td>.14</td>
<td>0</td>
<td>82</td>
<td>175</td>
<td>218</td>
<td>248</td>
<td>278</td>
</tr>
<tr>
<td>122.40</td>
<td>.18</td>
<td>0</td>
<td>10</td>
<td>129</td>
<td>184</td>
<td>223</td>
<td>261</td>
</tr>
<tr>
<td>136.00</td>
<td>.20</td>
<td>0</td>
<td>0</td>
<td>106</td>
<td>167</td>
<td>210</td>
<td>252</td>
</tr>
</tbody>
</table>
SUMMARY AND CONCLUSIONS

Range researchers have studied the effects of fertilization on species composition, forage quality, and forage production for many years. It has become accepted that certain areas are capable of increased quality and quantity of forage through fertilization. Because researchers have shown that rangeland production can be increased through fertilization, a study was conducted to discover if fertilization of various Utah range sites was economically feasible.

Six range sites were selected for analysis, two dryland crested wheatgrass (*Agropyron cristatum*), one of which receives 9 to 10 inches of precipitation and the other 11 to 12 inches; one intermediate wheatgrass (*Agropyron intermedium*) site which receives 16 to 17 inches precipitation; one irrigated, tall wheatgrass (*Agropyron elongatum*) site; one irrigated, mixed meadow grass site; and one mountain meadow site. Precipitation during 1971 was above the 30 year average on all sites. Six rates of nitrogen and six rates of phosphorus were applied to each area in a factorial design (36 treatments) with both fall and spring application dates. Forage was harvested and production functions estimated for each application. The optimum rate of fertilizer was determined for each site and by comparing profit per acre, the most profitable application date was determined.
Only three of the six sites tested (the tall, intermediate, and 11 to 12 inch precipitation crested wheatgrass) showed significant responses to fertilization. Phosphorus was not beneficial in increasing forage production and the only variables which proved to be significant at the .10 level were N and N². Thus, the statistically reliable production functions were of the form:

\[ Y = a + bN - cN^2 \]

where Y is the pounds of forage produced per acre and N is the amount of nitrogen applied per acre.

Using the estimated production functions and the prices of the forage (P_Y) and nitrogen (P_N) the optimum rates of N were calculated. As the use of the forage changes, so does its value. It was determined that if the forage is cut and baled as hay the net value of the forage is $0.0073/lb. If the forage is valued as a substitute for private lease grazing, the price is $0.0030/lb. If the forage is valued in terms of avoiding federal grazing fees, the price is $0.0027/lb. Setting the net P_Y at $0.0073/lb. and P_N at $0.1207/lb. and accounting for baling and hauling costs the optimum application rate of N was 7, 215, and 127 pounds of N per acre on the crested, tall, and intermediate wheatgrass sites respectively and the profit was $4.27, $48.27, and $17.95/ac. If the forage is valued in terms of either of the grazing values, fertilization is not profitable on any of the three sites.

On the tall and intermediate wheatgrass sites the fall application was the most profitable. Only the spring application was analyzed for the crested wheatgrass site.
The optimum values of N were determined for various fertilizer and forage prices. At the current nitrogen price of $0.1207/lb., the net prices of forage which would cause fertilization to become unprofitable would be $0.0069/lb., $0.0043/lb., and $0.0046/lb. on the crested, tall and intermediate wheatgrass sites respectively. At the current net forage price of $0.0073/lb., the prices of nitrogen which would cause fertilization to become unprofitable would be $0.1272/lb., $0.2041/lb., and $0.1932/lb. for the crested, tall, and intermediate wheatgrass.

Nitrogen fertilization appears to extend the grazing season by as much as two weeks through earlier spring growth initiation.
LITERATURE CITED


Cook, C. Wayne. 1965. Plant and livestock responses to fertilized rangelands. Agricultural Experiment Station Bulletin 455, Utah State University.


Dwyer, Don D. 1971. Nitrogen fertilization of Blue Grama Range in the foothills of South—Central New Mexico. New Mexico Agricultural Experiment Station Bulletin 585.


James, D. W. 1972. Associate professor of soils, Utah State University. Personal interview, Aug. 3.


------, and John P. Workman. 1971. The importance of renewable grazing resources on federal lands in the 11 western states. Utah Agricultural Experiment Station Circular 155.


and Glenn P. Roehrkassee. 1971. Effect of heavy nitrogen rates upon yield, protein content, and nitrate accumulation in mountain meadow hay. Wyoming Agricultural Experiment Station, Bulletin 545.


Appendix A

Range Condition Guides for

Jensen, Swan, Theurer, and White Sites

Additional soil information is available from the Soil Conservation Service,
Logan, Utah.
**UNITED STATES DEPARTMENT OF AGRICULTURE**

**SOIL CONSERVATION SERVICE**

**RANGE CONDITION GUIDE FOR** Semi-Wet Meadows (Jensen) **RANGE SITE**

### DECREASEUR PLANTS
Plants that decrease when range is improperly grazed. Figures in ( ) indicate the approximate amount found in climax for the site.

<table>
<thead>
<tr>
<th>Plant Name</th>
<th>Approximate Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkali bluegrass</td>
<td>(2)</td>
</tr>
<tr>
<td>Alpine timothy</td>
<td>1</td>
</tr>
<tr>
<td>Bearded wheatgrass</td>
<td>(1)</td>
</tr>
<tr>
<td>Blue wildrye</td>
<td>1</td>
</tr>
<tr>
<td>Great Basin wildrye</td>
<td>(10)</td>
</tr>
<tr>
<td>Idaho fescue</td>
<td>5</td>
</tr>
<tr>
<td>Mountain brome</td>
<td>(1)</td>
</tr>
<tr>
<td>Nodding brome</td>
<td>1</td>
</tr>
<tr>
<td>Prairie Junegrass</td>
<td>(1)</td>
</tr>
<tr>
<td>Redtop</td>
<td>5</td>
</tr>
<tr>
<td>Slender wheatgrass</td>
<td>(30)</td>
</tr>
<tr>
<td>Tall native bluegrass</td>
<td>5</td>
</tr>
<tr>
<td>Trisetum</td>
<td>(1)</td>
</tr>
<tr>
<td>Tufted hairgrass</td>
<td>(10)</td>
</tr>
<tr>
<td>Beaked wheatgrass</td>
<td>1</td>
</tr>
<tr>
<td>Field Horsetail</td>
<td>1</td>
</tr>
<tr>
<td>Field horsetail</td>
<td>1</td>
</tr>
<tr>
<td>Little barley</td>
<td>1</td>
</tr>
<tr>
<td>Rushes</td>
<td>1</td>
</tr>
<tr>
<td>Sedge</td>
<td>5</td>
</tr>
<tr>
<td>Squirreltail</td>
<td>1</td>
</tr>
<tr>
<td>Western wheatgrass</td>
<td>5</td>
</tr>
<tr>
<td>Wiregrass</td>
<td>1</td>
</tr>
</tbody>
</table>

### INCREASER PLANTS:
Plants that increase when range is improperly grazed. Count no more than the amount shown as climax for the site in rating range condition.

<table>
<thead>
<tr>
<th>Plant Name</th>
<th>Approximate Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkali sacaton</td>
<td>5</td>
</tr>
<tr>
<td>Field Horsetail</td>
<td>1</td>
</tr>
<tr>
<td>Lettermann needlegrass</td>
<td>1</td>
</tr>
<tr>
<td>Little barley</td>
<td>1</td>
</tr>
<tr>
<td>Rushes</td>
<td>1</td>
</tr>
<tr>
<td>Sedge</td>
<td>5</td>
</tr>
<tr>
<td>Squirreltail</td>
<td>1</td>
</tr>
<tr>
<td>Western wheatgrass</td>
<td>5</td>
</tr>
<tr>
<td>Wiregrass</td>
<td>1</td>
</tr>
</tbody>
</table>

### INVADER PLANTS:
Plants that invade when range is improperly grazed. None of these are counted as climax in rating range condition.

<table>
<thead>
<tr>
<th>Plant Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheatgrass</td>
</tr>
<tr>
<td>Foxtail</td>
</tr>
<tr>
<td>Annual woods</td>
</tr>
<tr>
<td>Curlycup gumweed</td>
</tr>
<tr>
<td>Dandelion</td>
</tr>
<tr>
<td>Houndstongue</td>
</tr>
<tr>
<td>Poverty weed</td>
</tr>
<tr>
<td>Tarweed</td>
</tr>
</tbody>
</table>

### ESTIMATED YIELDS AND POTENTIAL IMPROVEMENT BY CONDITION CLASSES

<table>
<thead>
<tr>
<th>Condition Class</th>
<th>Excellent (100% - 76%)</th>
<th>Good (75% - 51%)</th>
<th>Fair (50% - 26%)</th>
<th>Poor (25% - 0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lbs of Acre Air Dry</td>
<td>Favorable Yrs</td>
<td>4200 - 1750</td>
<td>4200 - 1700</td>
<td>4000 - 1700</td>
</tr>
<tr>
<td>Total Annual Yield</td>
<td>Unfavorable Yrs</td>
<td>1700 - 500</td>
<td>1700 - 500</td>
<td>750 - 400</td>
</tr>
</tbody>
</table>

*Regrowth not considered - above based on one harvest per year*
UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

RANGE CONDITION GUIDE FOR

Mountain Loam (Swan and White)

RANGE SITES

<table>
<thead>
<tr>
<th>DECREASER PLANTS:</th>
<th>INCREASER PLANTS:</th>
<th>INVADER PLANTS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plants that decrease when range is improperly grazed. Figures in ( ) indicate the approximate amount found in climax for the site.</td>
<td>Plants that increase when range is improperly grazed. Count no more than the amount shown as climax for the site in rating range condition.</td>
<td>Plants that invade when range is improperly grazed. None of these are counted as climax in rating range condition.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bearded wheatgrass (1)</th>
<th>Bluebunch wheatgrass (80)</th>
<th>Incl. cheatgrass 86</th>
</tr>
</thead>
<tbody>
<tr>
<td>(cattle)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Great Basin wildry (3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(sheep)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Idaho fescue (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>King's fescue (sheep)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mt. Brome (cattle)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nodding brome (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oniongrass (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(sheep)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandberg bluegrass (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slender wheatgrass (1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tall native bluegrass</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>% Climax</th>
<th>Cheatgrass</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ESTIMATED YIELDS AND POTENTIAL IMPROVEMENT BY CONDITION CLASSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXCELLENT</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>100% - 76%</td>
</tr>
<tr>
<td>Lbs. per acre Air Dry</td>
</tr>
<tr>
<td>Favorable Yrs.</td>
</tr>
<tr>
<td>Unfavorable Yrs.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Estimated Yields and Potential Improvement by Condition Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXCELLENT</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>100% - 76%</td>
</tr>
<tr>
<td>Lbs. per acre Air Dry</td>
</tr>
<tr>
<td>Favorable Yrs.</td>
</tr>
<tr>
<td>Unfavorable Yrs.</td>
</tr>
</tbody>
</table>

| Percent of Potential |
|----------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 100% - 76% | 75% - 51% | 50% - 26% | 25% - 0% |
| Lbs. per acre Air Dry |
| Favorable Yrs. | 2750-1750 | 3000-2000 | 2000-1500 | 2500-1700 |
| Unfavorable Yrs. | 1750-1050 | 1750-900 | 1200-500 | 1000-500 |

<p>| Big sagebrush 2 |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Estimated Yields and Potential Improvement by Condition Classes |</p>
<table>
<thead>
<tr>
<th>EXCELLENT</th>
<th>GOOD</th>
<th>FAIR</th>
<th>POOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% - 76%</td>
<td>75% - 51%</td>
<td>50% - 26%</td>
<td>25% - 0%</td>
</tr>
<tr>
<td>Lbs. per acre Air Dry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Favorable Yrs.</td>
<td>2750-1750</td>
<td>3000-2000</td>
<td>2000-1500</td>
</tr>
<tr>
<td>Unfavorable Yrs.</td>
<td>1750-1050</td>
<td>1750-900</td>
<td>1200-500</td>
</tr>
</tbody>
</table>

<p>| Big sagebrush 2 |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Estimated Yields and Potential Improvement by Condition Classes |</p>
<table>
<thead>
<tr>
<th>EXCELLENT</th>
<th>GOOD</th>
<th>FAIR</th>
<th>POOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% - 76%</td>
<td>75% - 51%</td>
<td>50% - 26%</td>
<td>25% - 0%</td>
</tr>
<tr>
<td>Lbs. per acre Air Dry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Favorable Yrs.</td>
<td>2750-1750</td>
<td>3000-2000</td>
<td>2000-1500</td>
</tr>
<tr>
<td>Unfavorable Yrs.</td>
<td>1750-1050</td>
<td>1750-900</td>
<td>1200-500</td>
</tr>
</tbody>
</table>
UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
RANGE CONDITION GUIDE FOR
Wet Meadows (Theurer) RANGE SITE

<table>
<thead>
<tr>
<th>DECREASED PLANTS: Plants that decrease when range is improperly grazed. Figures in ( ) indicate the approximate amount found in climax for the site.</th>
<th>INCREASED PLANTS: Plants that increase when range is improperly grazed. Count no more than the amount shown as climax for the site in rating range condition.</th>
<th>INVADER PLANTS: Plants that invade when range is improperly grazed. None of these are counted as climax in rating range condition.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpine timothy ( 1)</td>
<td>Climax</td>
<td>Hindu gourd</td>
</tr>
<tr>
<td>Bearded wheatgrass ( T)</td>
<td>Columbia needlegrass ( T)</td>
<td>Cheatgrass</td>
</tr>
<tr>
<td>Blue wildrye ( T)</td>
<td>Great Basin Wildrye ( T)</td>
<td>Foxtail</td>
</tr>
<tr>
<td>Creeping wildrye ( 5)</td>
<td>Field horsetail ( T)</td>
<td>Kentucky bluegrass ( T)</td>
</tr>
<tr>
<td>Dodger brome ( T)</td>
<td>Little barley ( T)</td>
<td>Muhly grass ( T)</td>
</tr>
<tr>
<td>Redtop ( 5)</td>
<td>Rushes ( T)</td>
<td>Sedges (broadleaf) ( T)</td>
</tr>
<tr>
<td>Slinker wheatgrass ( 1)</td>
<td>Western wheatgrass ( T)</td>
<td>Annual weeds</td>
</tr>
<tr>
<td>Trisetum ( T)</td>
<td>Wiregrass ( T)</td>
<td>Cocklebur</td>
</tr>
<tr>
<td>Timothy ( 1)</td>
<td>Arrow grass ( T)</td>
<td>Curlycup gumweed</td>
</tr>
<tr>
<td>Tufted hairgrass ( 30)</td>
<td>Astar ( T)</td>
<td>Poverty weed</td>
</tr>
<tr>
<td>( )</td>
<td>Cinquefoil ( T)</td>
<td>Teasel</td>
</tr>
<tr>
<td>( )</td>
<td>Dandelion ( T)</td>
<td></td>
</tr>
<tr>
<td>( )</td>
<td>Goldenrod ( T)</td>
<td></td>
</tr>
<tr>
<td>( )</td>
<td>Shooting star ( T)</td>
<td></td>
</tr>
<tr>
<td>Cow parsnip ( 1)</td>
<td>Senecio ( T)</td>
<td></td>
</tr>
<tr>
<td>Native clover ( 5)</td>
<td>Rose ( T)</td>
<td>Big rabbitbrush</td>
</tr>
<tr>
<td>White Dutch Clover ( 1)</td>
<td>Shrubby cinquefoil ( T)</td>
<td></td>
</tr>
<tr>
<td>( )</td>
<td>Silver (water) sagebrush ( T)</td>
<td></td>
</tr>
<tr>
<td>( )</td>
<td>Willow ( T)</td>
<td>Rubber rabbitbrush</td>
</tr>
</tbody>
</table>

ESTIMATED YIELDS AND POTENTIAL IMPROVEMENT BY CONDITION CLASSES

<table>
<thead>
<tr>
<th>EXCELLENT</th>
<th>GOOD</th>
<th>FAIR</th>
<th>POOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% - 76%</td>
<td>75% - 51%</td>
<td>50% - 26%</td>
<td>25% - 0</td>
</tr>
<tr>
<td>Lbs. per Acre Air Dry Favorable Yrs.</td>
<td>6500-4000</td>
<td>6500-4000</td>
<td>7500-5000</td>
</tr>
<tr>
<td>Total Annual Yield Unfavorable Yrs.</td>
<td>3500-3000</td>
<td>4250-3500</td>
<td>3500-2000</td>
</tr>
</tbody>
</table>
Appendix B

Yearly and Average Precipitation on Sites

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Junction³</td>
<td>7.45</td>
<td>8.00</td>
<td>6.95</td>
<td>12.42</td>
<td>11.68</td>
<td>12.60</td>
<td>4.93</td>
<td>11.65</td>
<td>12.47</td>
<td>8.28</td>
<td>10.61</td>
<td>10.16</td>
<td>9.77</td>
<td>9.50</td>
</tr>
<tr>
<td>Swan⁴</td>
<td>16.03</td>
<td>25.99</td>
<td>18.29</td>
<td>22.82</td>
<td>30.18</td>
<td>24.09</td>
<td>18.37</td>
<td>23.70</td>
<td>30.19</td>
<td>16.71</td>
<td>29.79</td>
<td>28.08</td>
<td>23.69</td>
<td>22.50</td>
</tr>
</tbody>
</table>

¹Estimated by the Environmental Data Service, U.S. Department of Commerce
²Date obtained from Climatological Data for Utah, Environmental Data Service, Dept. of Comm. (Snowville weather station)
³Same source as 1 (KVNU weather station, Logan)
⁴Data obtained from precipitation gages on the site
⁵Same source as 1 (conversion of Monte Cristo Storage gage to precipitation on the site)
⁶Same source as 1 (USU weather station, Logan)
**VITA**

**Thomas Milton Quigley**

Candidate for the Degree of

Master of Science

**Thesis:** An Economic Analysis of Nitrogen and Phosphorus Fertilization on Six Utah Range and Meadow Sites

**Major Field:** Range Resource Economics

**Biographical Information:**


*Education:* Attended elementary schools in Salt Lake City and Kanosh, Utah; graduated from Millard High School in 1967; received the Bachelor of Science degree from Utah State University in 1971, with a major in watershed science; completed requirements for the Master of Science degree, specializing in range resource economics, at Utah State University in 1972.

*Professional Experience:* Research assistant for the Forest Science Department, Utah State University, 1969-71; research assistant for the Range Science Department, Utah State University, 1971-72.

*Professional Organizations:* Xi Sigma Pi and Phi Kappa Phi.