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# Economics of Carry-Over Production and Increased Grazing Season Length Due to Range Fertilization

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# ECONOMICS OF CARRY-OVER PRODUCTION AND INCREASED GRAZING SEASON LENGTH DUE TO RANGE FERTILIZATION

by

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A thesis submitted in partial fulfillment
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of

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in

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Paul W. McCormick

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# ABSTRACT

Economics of Carry-over Production and Increased

Grazing Season Length Due To Range Fertilization

by

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Utah State University, 1973

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This paper entails the economic and biological interpretation of the response of rangeland grasses to nitrogen fertilization. Six sites throughout Utah received graduated rates of fertilizer. The coefficients of the production function

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

were identified.

An initial production and a carry-over response were identified on sites receiving greater than ten inches of annual precipitation. Optimum fertilization rates may be identified by equating the marginal physical product to the ratio of the price of nitrogen to the price of the forage.

Forage response to nitrogen is reflected strongly in the early growth response in which fertilizer rates of 15 to 120 pounds of nitrogen per acre produce adequate forage for grazing 4 to 18 days prior to unfertilized range.

(80 pages)

# INTRODUCTION

The fertilization of rangelands has long been considered a marginal range improvement practice. For at least 25 years, researchers have studied the application of commercial fertilizer to rangeland. Most have concluded that while fertilizer increased forage yields, the costs were not justified.

Current economic changes add impetus to this study. The increased demand for meat will in turn cause an increased demand by the producer for forage resources. Fertilization provides a means to increase these resources.

The objectives of this study include the determination of (1) the most profitable rate of nutrient application; (2) the most profitable season of nutrient application; (3) the optimum fertilizer reapplication schedule and (4) the effect of fertilizer application on grazing season length.

Production functions are determined for each site and for both seasons of application. This allows the determination of the economic optima for forage production. The linear model prediction of range readiness will help determine the extent of differences in readiness between fertilized and unfertilized forage in a given year.

# REVIEW OF LITERATURE

Responses of rangeland to nitrogen fertilization has been well documented. Sampson (1952) summarized the results of early fertilization work as follows:

> Fertilization of range or meadow sites tends to increase nutrition and palatability of the forage or hay. The animal tends to graze the forage closely on areas where a needed fertilizer has been applied, where they crop unfertilized units supporting the same kind of plants only moderately or slightly. (Sampson, 1952, p.231)

In the northern Great Plains, Wight and Black (1972) reported a favorable response to nitrogen and phosphorus fertilization. In the same area Rogler (1972) reported the opportunities from range fertilization to be: (1) increased forage and livestock production and (2) increased palatability and the potential for better livestock distribution.

Woolfolk and Duncan (1962) and Jones (1972) each reported favorably on the response to nitrogen in forage production, utilization and livestock gains on California annual grasslands.

Problems in range fertilization have been discussed by Patterson and Youngman (1960) and Kay and Evans (1965). These problems include increased competition from early annuals such as cheatgrass (Bromus tectorum). These competitors utilized soil moisture earlier in the growing season, before perennial growth initiation, eventually depleting the stand. Kay and Evans (1965) indicated that grazing the fertilized grass further depleted the stand.

Crested wheatgrass response to fertilization has been studied in Utah, Oregon, Washington and Wyoming. Cook (1965) observed an increase of 65 percent in total digestable nutrients resulting from nitrogen fertilization on Utah ranges. At Benmore, Utah, phosphorus did not affect yield, however, an application of 60 pounds of nitrogen increased yield as much as 1125 pounds per acre in a favorable year, with a carry-over increase of 200 pounds per acre the second year (U.S. Department of Agriculture, 1964).

Extensive work with fertilization on crested wheatgrass in Wyoming (Lang and Landers, 1968; Seamands and Lang, 1960) indicate positive responses in production.

Oregon researchers (Sneva, Hyder and Cooper, 1958; Hyder and Sneva, 1959, 1961, 1963, 1965; Sneva, 1973b) are most complete in reporting forage responses to nitrogen application over a number of years and analyzing the morphological and physiological responses of crested wheatgrass.

### Early growth and carbohydrates

Forage response to fertilizer applications comes primarily during the early growth periods. Sneva (1973b) indicated that for each pound of nitrogen applied to crested wheatgrass, approximately eight pounds of additional spring herbage per acre resulted.

The stimulation of early growth caused by fertilization is characterized by a more rapid depletion of soil moisture (Sneva and Hyder, 1965; Wight and Black, 1972) and a greater mobilization of carbohydrates (Hyder and Sneva, 1961). Lavin (1967) reported that the plant's dependence upon temperature and moisture conditions cause initiation of growth to occur at about the same time for fertilized and unfertilized intermediate wheatgrass. After the initiation of growth, however, production is usually greater in fertilized plants (Sneva, Hyder and Cooper, 1958).

Crested wheatgrass is noted for its ability to withstand early spring grazing. This is primarily due to its ability to accumulate relatively large carbohydrate reserves early in the year, and to its morphological characteristics of short basal internodes. The short basal internodes contribute to the early abundance of leafy herbage (Hyder and Sneva, 1959).

Fertilization speeds up the growth process, creating a more fragile plant, one which may be more susceptible to stress. Clipping studies of crested wheatgrass by Hyder and Sneva (1963), indicate a set-back in root growth in plants harvested in late April, while plants harvested two weeks later in early May, did not suffer the slowing of root growth. May 1 was identified as the "Critical period" of carbohydrate storage in crested wheatgrass. At this time leaves had reached a height of six inches in the Oregon study.

The greater mobilization of carbohydrates in fertilized plants has resulted in continued recommendations to <u>not</u> apply fertilizer to achieve earlier grazing, even though production is several times greater (Hyder and Sneva, 1961; Sneva, 1973b). One crop grazing, from the "heads-in-boot" stage until antethisis, (Mid-May thru July 1) has been recommended to take advantage of the increased herbage, nutrient yields and carbohydrate-storage concentrations in fertilized crested wheatgrass.

Sharp (1970) in discussing general crested wheatgrass management, indicated that "animal welfare generally has more importance than other considerations in determining the time to begin grazing on rangeland seeded to crested wheatgrass."

Hyder and Sneva (1961) reported that fertilization after late May, when crested wheatgrass has reached a maximum of photosynthetic surface, will not accelerate the growth rate of the plants. The physiological response of crested wheatgrass to nitrogen occurs before mid-May and any subsequent growth is proportional to the amount of leaf tissue present and active. The plant's demand for carbohydrates in respiration, growth and reproduction is met by carbohydrate storage and current photosynthetic production. If grazing takes place during the early period of growth when the plant is utilizing its root carbohydrate reserves, and before there is sufficient photosynthetic production to adequately sustain the plant, serious damage to the plant may occur.

Season of application

Lavin (1967) indicated that season of fertilizer application should depend upon (1) the time of fertilizer purchase, (2) storage costs, and (3) seasonal workload. Reported results on other fertilizer studies (Sneva, 1973a; and Hull, 1963) showed that fall applications of nutrients are no more effective than winter or spring. Seamonds (1971) using ammonium nitrate and liquid urea, suggested a ten per cent yield advantage in favor of spring application.

Carry-over

A carry-over response under rangeland conditions has been reported in several areas (Choriki, 1968; Mason, 1972; Sneva, 1958), particularly if dry years follow the year of application. When application preceeds unusually high moisture conditions, the operator may expect to receive full application benefits during the year immediately following application.

Seamonds (1960) reported no significant increases in hay production as the result of the carry-over effects of nitrogen application. However, after five years, heavy nitrogen applications could still be identified by the dark green color.

Moisture in the previous growing season may be an important factor in determining the response of fertilized plants. Fuller (1965) reported a slow build up of available nitrogen resulting from continuous fertilizer applications. Forage response to nitrogen application is dependent upon (1) moisture of the current year, (2) moisture of the preceding year and (3) availability or carry-over of nitrogen in the soil (Sneva and Hyder, 1965).

Economics

The economic analysis of fertilizer response on rangelands is quite simple and straightforward. Heady and Pesek (1954) described the basic production function applicable to range fertilization. Hooper (1969) utilized the basic production function in an analysis of nutrient application on California annual grasslands. Quigley (1972) initiated the current study and analyzed the first year production.

Heady and Pesek (1954) identify the optimum rate of nutrient application as that rate at which the value of the marginal product (the dollar return from the last unit of input) equals the price per unit of nutrient.

Price range forage

Quigley (1972) considers three methods of pricing range forage: (1) using a hay price, excluding haying costs; (2) the market price of grazing land per animal unit month (AUM); and (3) 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.

Nielsen (1972) indicates that local supply and demand conditions for livestock forage are far more important in determining prices than the quality of forage produced.

# METHODS OF PROCEDURE

## Site descriptions

White . . . The White plot was established in an intermediate wheatgrass (Agropyron intermedium) pasture west of Paradise, Utah. The site is on a north facing slope, receiving an average of 18 inches of rainfall during the last 10 years. The stand is very healthy, supporting a dense stand of intermediate wheatgrass with northern sweet broom (Hedysarum boreale) mixed in.

Curlew . . . The Curlew plot was located in the Curlew National Grassland, approximately eight miles north of Snowville, Utah. The stand consists totally of crested wheatgrass (Agropyron cristatum). The stand is vigorous with large, healthy bunches and approximately 40 percent interspace. The site is on the bottom of the Curlew Valley. Deep creek is approximately one quarter of a mile east of the plot. The site receives an average of 12.5 inches of precipitation annually.

Junction . . . The Junction plot was located twenty miles west of Snowville, Utah. The site receives between 9 and 10 inches of precipitation annually. The vegetation in this plot is made up primarily of crested wheatgrass, with an encroachment of halogeton (Halogeton glomeratus) wherever disturbed. The stand is made up of 50-60 percent interspace and small bunches. Low precipitation limits the management opportunities on the site.

Benmore . . . Two plots were established at the Benmore Experimental Range approximately four miles south of Vernon, Utah. The area is generally level, broken by shallow, intermittent stream channels. Plots were established in pastures No. 11 and No. 22. Pasture No. 11 is seeded to fairway wheatgrass (Agropyron cristatum), and pasture No. 22 is composed of standard wheatgrass (Agropyron desertorum). Both pastures have been heavily invaded by big sagebrush (Artemesia tridentata). The stand in pasture No. 22 contains a large percentage of bulbous bluegrass (Poa bulbosa), which blooms early, then drys up. The site receives approximately 13 inches of precipitation annually.

Eureka . . . The Eureka plot was on a crested wheatgrass seeding some ten miles SW of Eureka, Utah. The area was chained free of Juniper and Pinyon Pine and seeded. The grass appears to be in good health, with small vigorous bunches. Where disturbed, russian thistle (Salsola kali) has invaded. The annual moisture on this site is approximately 12 inches.

Wah-Wah . . . The Wah-Wah plot was located in the foothills near the southern end of the Wah-Wah valley, forty miles west of Milford, Utah. The area has been chained free of Juniper and seeded to crested wheatgrass. The site is slightly rolling, with a vigorous stand of grass. Annual precipitation is 12 inches.

Plot descriptions

Three different plot designs were used in this study (Figures 1, 2, 3). The White, Curlew and Junction plots were established in 1970 to study the effects and interrelationships of nitrogen and phosphorus as added nutrients. These

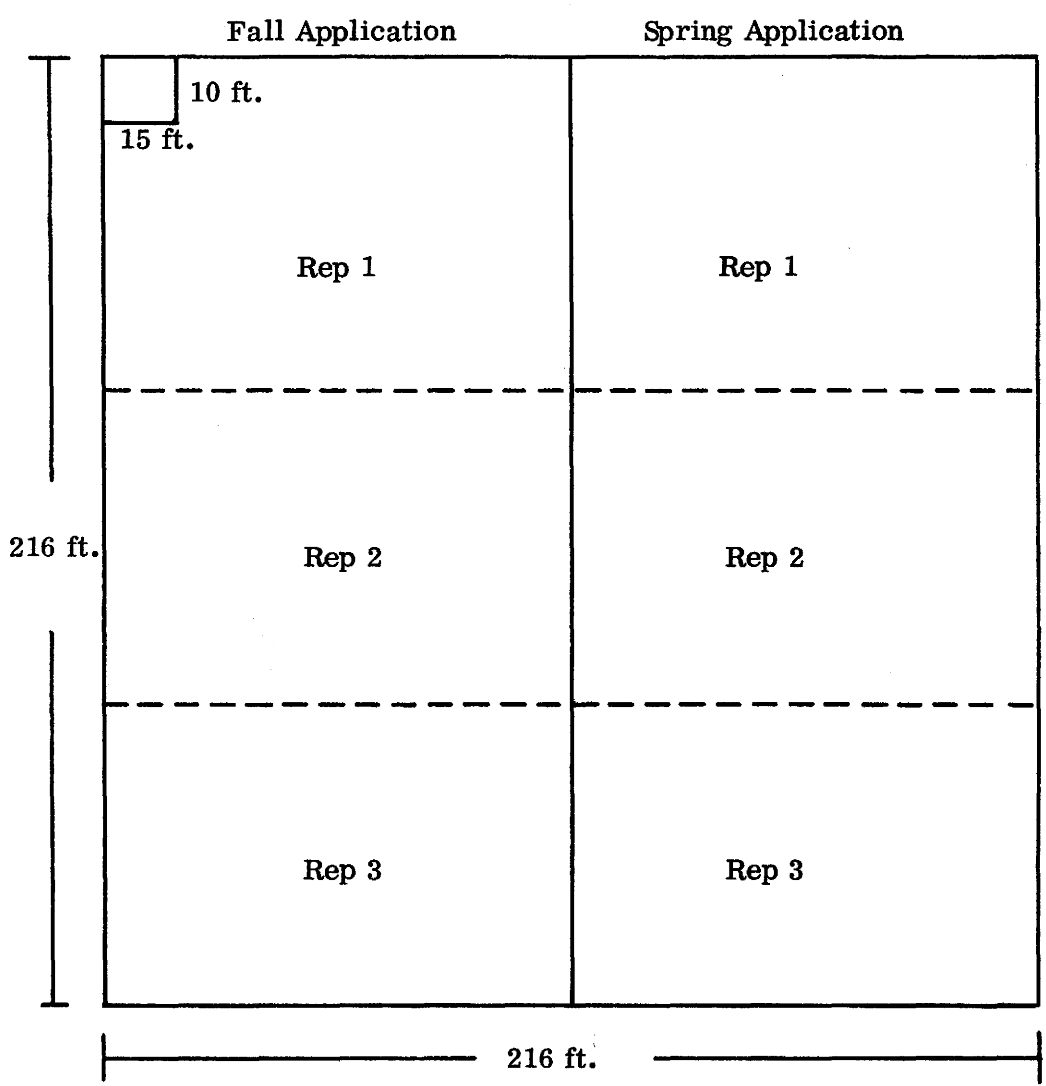



Figure 1. Experimental design of White, Junction and Curlew plots.

plots constitute a randomized block factorial experimental design with three replications of 36 different treatments (six levels of nitrogen, and six levels of phosphorus) for each season (Fall and Spring) (Table 2). Ammonium nitrate (34 percent nitrogen) and treble super phosphate (45 percent $P_2 0_5$) were the fertilizers used.

The Eureka and Wah-Wah plots were established in 1971 to analyze the possible increased utilization by livestock of fertilized grasses. Five rates of nitrogen and two levels of phosphorus were applied during the spring and fall seasons on fenced and open areas (Table 2 and Figure 2).

The Benmore plots were established in 1972 as a preliminary fertilizer study on the Benmore Experimental Range. Six levels of nitrogen were applied in a randomized block design which included three replications of six treatments in each season (Table 2 and Figure 3).

The application of fertilizer occurred during a four year period beginning in the fall of 1970 and ending in the spring of 1973.

Table 1. Schedule of range fertilization

| Plot | Season | Year | Plot | Season | Year |
|---|---|---|---|---|---|
| White | Spring | 1971 | Benmore | Spring | 1973 |
| | Fall | 1970 | | Fall | 1972 |
| Curlew | Spring | 1971 | Eureka | Spring | 1972 |
| | Fall | 1972 | | Fall | 1971 |
| Junction | Spring | 1971 | Wah-Wah | Spring | 1972 |
| | Fall | 1972 | | Fall | 1971 |

Harvesting

The plots were mowed during mid-June at the early flowering stage of development. A three foot buffer strip was removed from the plot borders and around each treatment. The plants were moved, weighed and sub-samples collected from one replication per treatment for each season. The sub-samples were air dried at 60 degrees C. for 24 hours to determine the moisture content and all weights were adjusted to dry weight per acre.

The final production models chosen for the analysis were those which showed significance of all included variables at the .10 level and had a coefficient of multiple determination ($R^2$) greater than .50. The resultant predictive function for all sites took the following form:

$$Y = a + bN - cN^2 \quad (1)$$

where Y is the total production of forage on the site, and N is the pounds of nitrogen per acre applied. On all plots, in each year, no significant response was identified from the application of phosphorus.

Optimization of carry-over production

Utilizing the initial production function (1), analysis of carry-over production may be executed by discounting each year's residual response (Baum, Heady, and Blackmore, 1956). This will result in the accumulated production function:

$$Y = a_1 + b_1N - c_1N^2 + (a_2 + b_2N - c_2N^2)\ (1 + i)^{-(n-1)} + \ldots$$
$$\ldots (a_n + b_nN - c_nN^2)\ (1 + i)^{-(n-1)}$$

Table 2. Treatment numbers assigned to rates of nitrogen and phosphorus

| Pounds of P per acre | Pounds of N per acre | | | | | |
|---|---|---|---|---|---|---|
| | **White Plot** | | | | | |
| | 0 | 25 | 50 | 100 | 200 | 400 |
| 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| 12.5 | 12 | 11 | 10 | 9 | 8 | 7 |
| 25 | 13 | 14 | 15 | 16 | 17 | 18 |
| 50 | 24 | 23 | 22 | 21 | 20 | 19 |
| 100 | 25 | 26 | 27 | 28 | 29 | 30 |
| 200 | 36 | 35 | 34 | 33 | 32 | 31 |
| | **Junction, Curlew Plots** | | | | | |
| | 0 | 12.5 | 25 | 50 | 100 | 200 |
| 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| 6.25 | 12 | 11 | 10 | 9 | 8 | 7 |
| 12.5 | 13 | 14 | 15 | 16 | 17 | 18 |
| 25 | 24 | 23 | 22 | 21 | 20 | 19 |
| 50 | 25 | 26 | 27 | 28 | 29 | 30 |
| 100 | 36 | 35 | 34 | 33 | 32 | 31 |
| | **Eureka and Wah-Wah Plots** | | | | | |
| | 0 | 20 | 40 | 60 | 80 | |
| 0 | 1 | 3 | 5 | 7 | 9 | |
| 40 | 2 | 4 | 6 | 8 | 10 | |
| | **Benmore Plot** | | | | | |
| | 0 | 15 | 30 | 60 | 90 | 120 |
| | 1 | 2 | 3 | 4 | 5 | 6 |

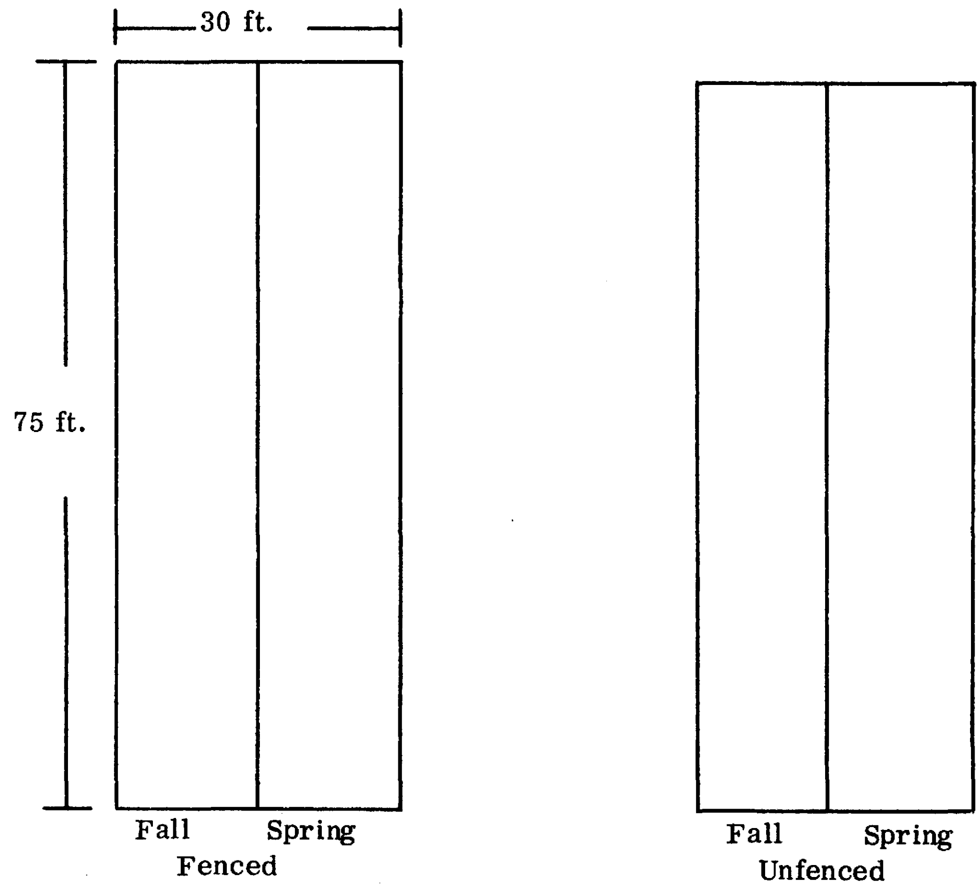



Figure 2. Experimental design of Eureka and Wah-Wah plots.

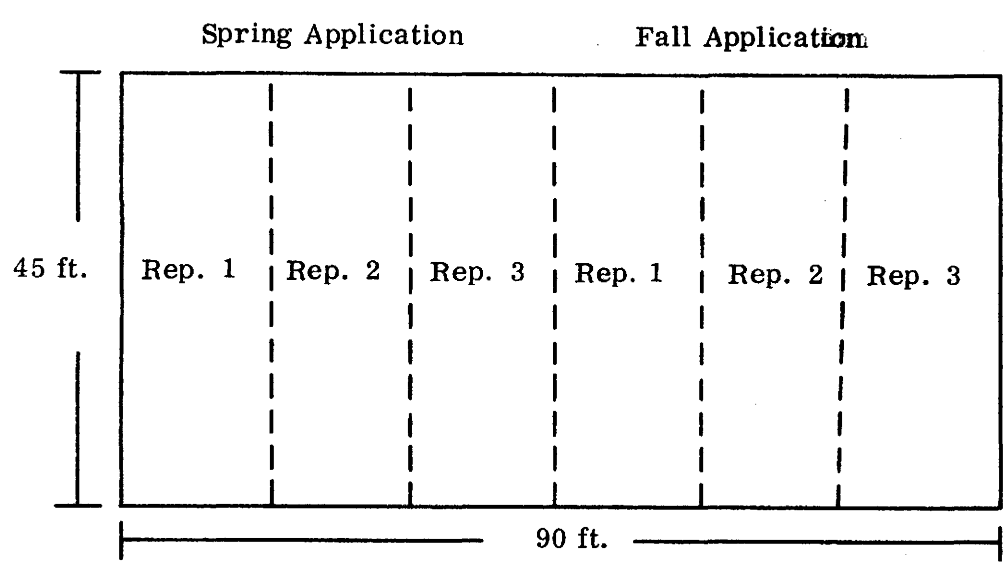



Figure 3. Experimental design of Benmore plot.

The optimum (most profitable) level of fertilization may be determined by equating the sum of the discounted marginal products to the ratio of the price of nitrogen to the price of forage. The formula used to determine the optimum level is:

$$MPP_1 + (MPP_2)(1 + i)^{-1} + (MPP_3)(1 + i)^{-2} + \ldots$$
$$(MPP_n)(1 + i)^{-(n-1)} = P_N/P_Y$$

where _i_ is the interest rate selected for use in the discounting process, $P_N$ is equal to the price of nitrogen per pound and $P_Y$ is equal to the price of forage per pound.

Early growth response

To evaluate the response of grasses to nitrogen application during the early growth period, weekly recordings of plant height of initial production were taken during the spring of 1973. Recordings began when forage became apparent. Measurements began on the Junction and Curlew plots on April 1, and at Benmore, April 12, 1973. Recordings continued through mid-May, with a final measurement in June. Previous to clipping. Recordings ceased on Junction, Eureka and Curlew-spring following three weeks of growth with no significant stimulation of plant height due to fertilization.

Six inches of height and leaf stage four was defined as "range readiness" to evaluate the early growth response to nitrogen fertilizer (Sharp, 1970; Quigley, 1972; Hyder and Sneva, 1961).

Linear regression analysis was used to describe the growth function for each level of nitrogen over time. Inverse prediction of the linear regression was used to determine the mean and confidence interval for the dates associated with each level of nitrogen at six inches of height. The *t* test was used to determine the significance of the difference between the control and fertilized treatments. Days of advanced growth were predicted for those treatments with significant differences from the control at the .05 level.

# RESULTS AND DISCUSSION

The results of this study include three years of production, 1971, 1972 and 1973. Quigley (1972) analyzed the 1971 initial production response and determined the optimum fertilization levels. Discussion will include the 1971 production as the initial production of the carry-over responses on the White and Curlew, spring sites.

Three aspects of fertilization response will be covered: (1) initial production, (2) carry-over response and (3) early growth response. Season of application and determination of optimum levels of fertilizer application will be included in the total response of forage to fertilization.

## Fertilization decision

The decision making process for fertilization is made up of four steps: (1) the determination of a production function for a site or area; (2) the analysis of that function and the current price ratio of the price of nitrogen per pound to the price of forage per pound, to determine if fertilization is practical and if so, (3) the calculation of an optimum (most profitable) rate of application and (4) the determination of the most profitable season of application.

Interpretation of all results is based upon the following production function model which explains the performance of rangeland grasses fertilized with nitrogen:

$$Y = a + bN - cN^2 \qquad (1)$$

where Y is the pounds of air dry forage per acre and N is the pounds of available nitrogen per acre. The production function may be broken into three separate components. The first independent variable _a_ indicates the approximate average yield without fertilization. The second independent variable _b_ describes the vegetation's response to the addition of nitrogen to the site (pounds of forage per pound of nitrogen). The third variable _c_ describes the vegetation limits to respond to the nitrogen input. Understanding these descriptive aspects of the production function allows a rapid interpretation and understanding of the production response.

Before deciding how much fertilizer should be applied, the rancher must first determine if fertilization is practical. Marginal analysis is not applicable until the decision to fertilize has been made. The decision to fertilize involves determining if the ratio of the price of nitrogen to the price of forage ($P_N/P_Y$) is small enough to allow fertilization to be more profitable than no fertilization. The price of nitrogen must be low and the value of forage high for the fixed and variable costs of fertilization to be overcome by increased production due to the addition of nitrogen. Solving the problem requires the use of the current price of nitrogen to determine the necessary price of forage to break-even.

A break-even forage price is determined by calculating the forage price necessary for the net return to a site without fertilization to be matched by the net return to fertilization with a minimum rate of application of nitrogen per acre. A minimum rate of 20 pounds per acre will be used in the example as this will be considered a minimum practical application. This calculation is as follows:

$$VTP - P_N \cdot N - P_A = \text{net return without fertilization} \quad (2)$$

where the value of the totalproduct (VTP or $TPP.P_Y$) less the price of nitrogen ($P_N$) times pounds of nitrogen per acre (N) less the price of application ($P_A$), determines the net return with fertilization. The net return without fertilization is determined by multiplying the price of forage ($P_Y$) times the first independent variable a in the production function (1).

The White, fall application, production will be used to demonstrate the procedure necessary to calculate the break-even forage price:

$$y = 4802 + 31.95N - .0392N^2$$

where y is the expected production with fertilization of N pounds of nitrogen per acre.

Given: The price of nitrogen is \$.12 per pound, the price of fertilization is \$1.50 per acre and the application rate is 20 pounds of nitrogen per acre.

$$TPP_N \cdot P_Y - P_N \cdot N - P_A = \text{net return without fertilization}$$

$$[4802 + 31.95N - .0392N^2]\, P_Y - \$.12 \cdot N - \$1.50 = 4802 \cdot P_Y$$

where 4802 pounds of forage per acre is the average production without fertilization.

$$[4802 + 31.95(20) - .0392(20)^2]\,P_Y - \$.12(20) - \$1.50 = 4802 \cdot P_Y$$

$$639.P_Y - 15.68.P_Y = \$3.90$$

$$632.32.P_Y = \$3.90$$

$$P_Y = .0062 \text{ and } P_N/P_Y = 19$$

Therefore, before fertilization becomes profitable the price ratio must be 19 or less. If the price ratio is within this limit, marginal analysis may then be used to determine the optimum rate of fertilization.

Marginal analysis (equating marginal costs and marginal revenue) of the empirical function allows the determination of an optimum rate of nutrient application at each site. Once it has been determined that fertilization is profitable, the optimum rate of application is dependent only upon the price of forage and the cost of nutrients (variable costs) and is not influenced by the cost of application (fixed costs). The cost of application does, however, affect the profit in that it reduces the net return accruing to the nutrient application (Pesek and Heady, 1958).

The value assigned to fertilizer by the rancher will be the value of the marginal product of grazing. The value of the marginal product becomes the demand for fertilizer. Meeting this demand is the supply or the aggregate marginal cost curve of producing the fertilizer. The determination of an equilibrium position is then found by equating supply and demand (ie. where the marginal factor cost ($P_N$) is equal to the value of the marginal product ($P_Y \cdot MPP_N$).

The first derivative of the production function provides the equation for the marginal physical product of the function. The first derivative of the function (1) with respect to N yields:

$$MPP_N = b - 2cN$$

The profit-maximizing forage yield is determined from the optimum nutrient input which is identified by equating the marginal product (the amount added to total yield by one more unit of nutrient) to the net price ratio (the price of nutrients divided by the price of forage):

$$MPP_N = P_N/P_Y$$

where $P_N$ is equal to the price per pound of nitrogen fertilizer and $P_Y$ is equal to the price per pound of forage.

Three conditions restrict the application of optimum recommendations. First the lack of knowledge of the relevant yield relationships and cost structures, (2) the uncertainty of future prices and production and (3) the existence of severe captial limitations (Baum, Heady and Blackmore, 1956).

The determination of the most profitable season of application is made by evaluating the net profit from the total production response of each season. This may be accomplished by identifying the total production at the optimum rate and subtracting application costs and costs of fertilizer.

Marginal analysis of the empirical production functions estimated in this study will be made as if the initial test of fertilization feasibility had been met successfully.

Initial production

Initial or first year production responses were not significant in 1972. The Eureka and Wah-Wah sites were fertilized during the fall of 1971 and the spring of 1972. Both sites showed insignificant responses to fertilizer application. Both sites received below normal rainfall prior to the growing season.

Curlew, fall application; Junction, fall application and Benmore, fall and spring applications are plots that received fertilizer applications in the fall of 1972 or the spring of 1973. Normal or average moisture was received during the 1972-73 growing season on all sites. Initial responses to nitrogen fertilization, significant at the .10 probability level, were measured on Curlew, fall application; Benmore No. 11, fall application and spring application; and Benmore No. 22, spring application plots. The resulting significant production functions are shown in Table 3 and graphically exhibited in Figures 4-6.

Table 3. Estimated initial production functions. 1973

| Plot | Application | Model production function | $R^2$ |
|---|---|---|---|
| Curlew | Fall '72 | $y = 544 + 14.94N - .0399N^2$ | .83 |
| Benmore No. 11 | Spring '73 | $y = 472 + 17.71N - .1046N^2$ | .65 |
| | Fall '72 | $y = 285 + 13.72N - .0754N^2$ | .69 |
| Benmore No. 22 | Spring '73 | $y = 365 + 13.62N - .0690N^2$ | .66 |

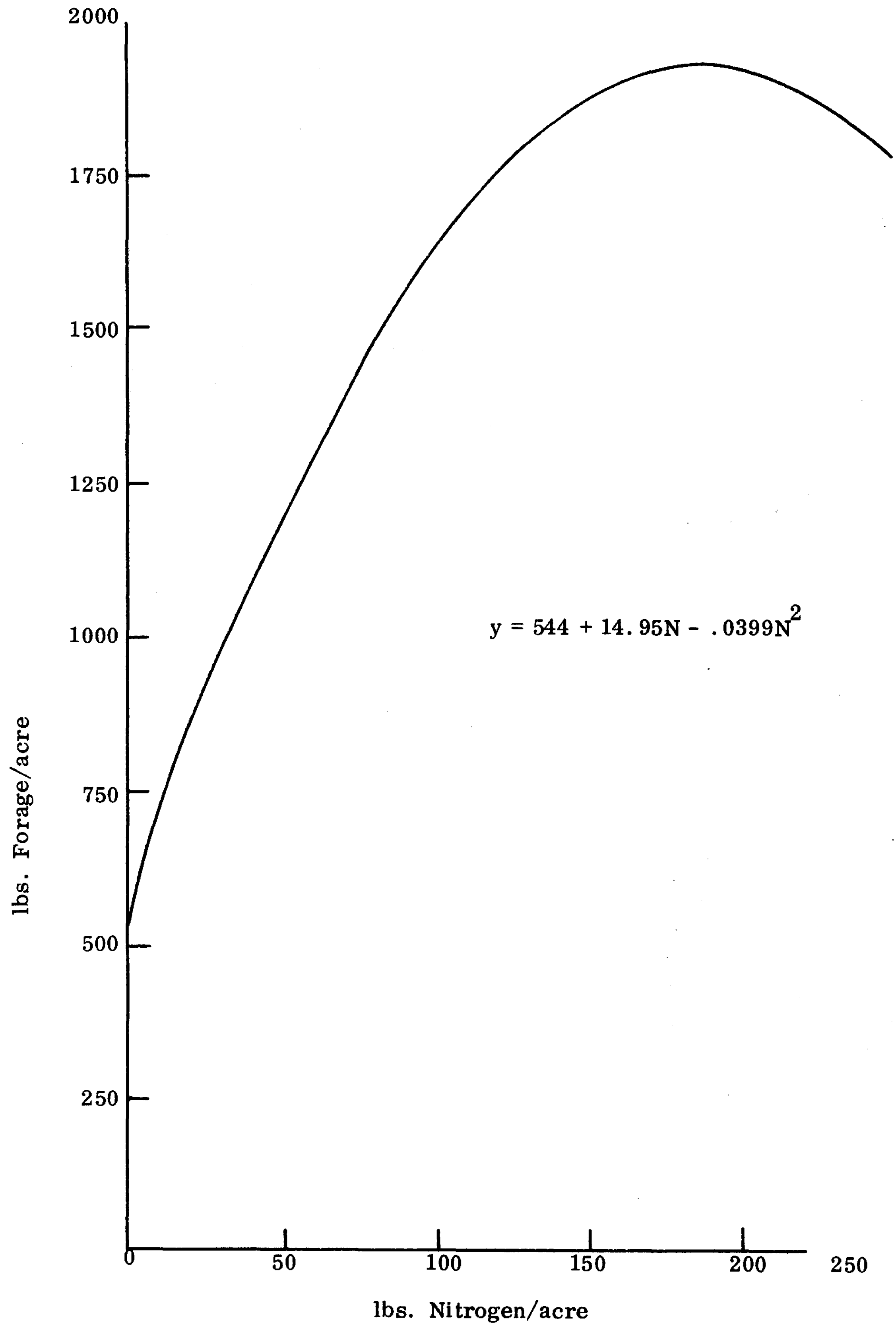



Figure 4. Production function showing the response of the Curlew, fall application to nitrogen fertilization in 1973.

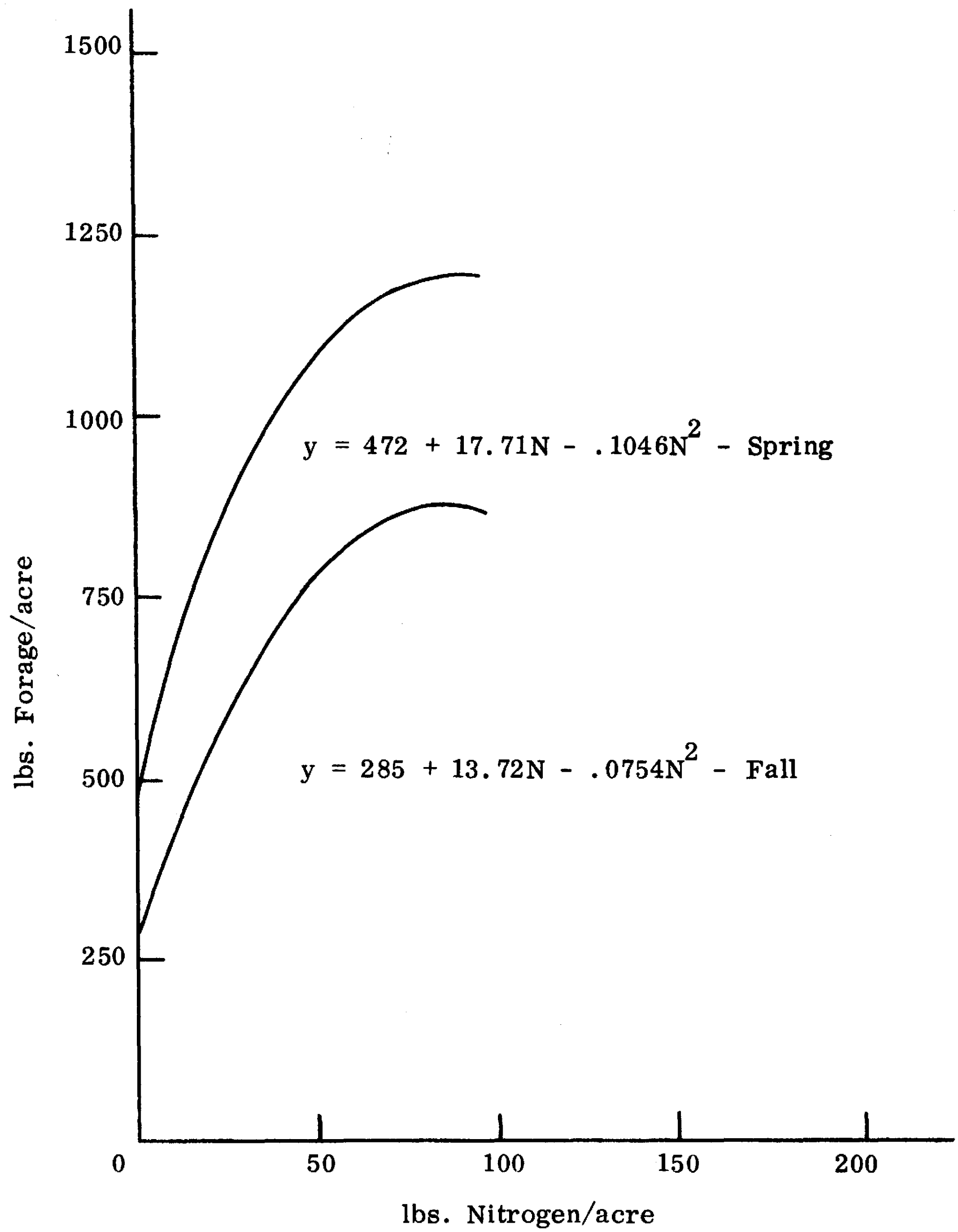



Figure 5. Production function showing the response of the Benmore #11 site, fall and spring applications to nitrogen fertilization in 1973.

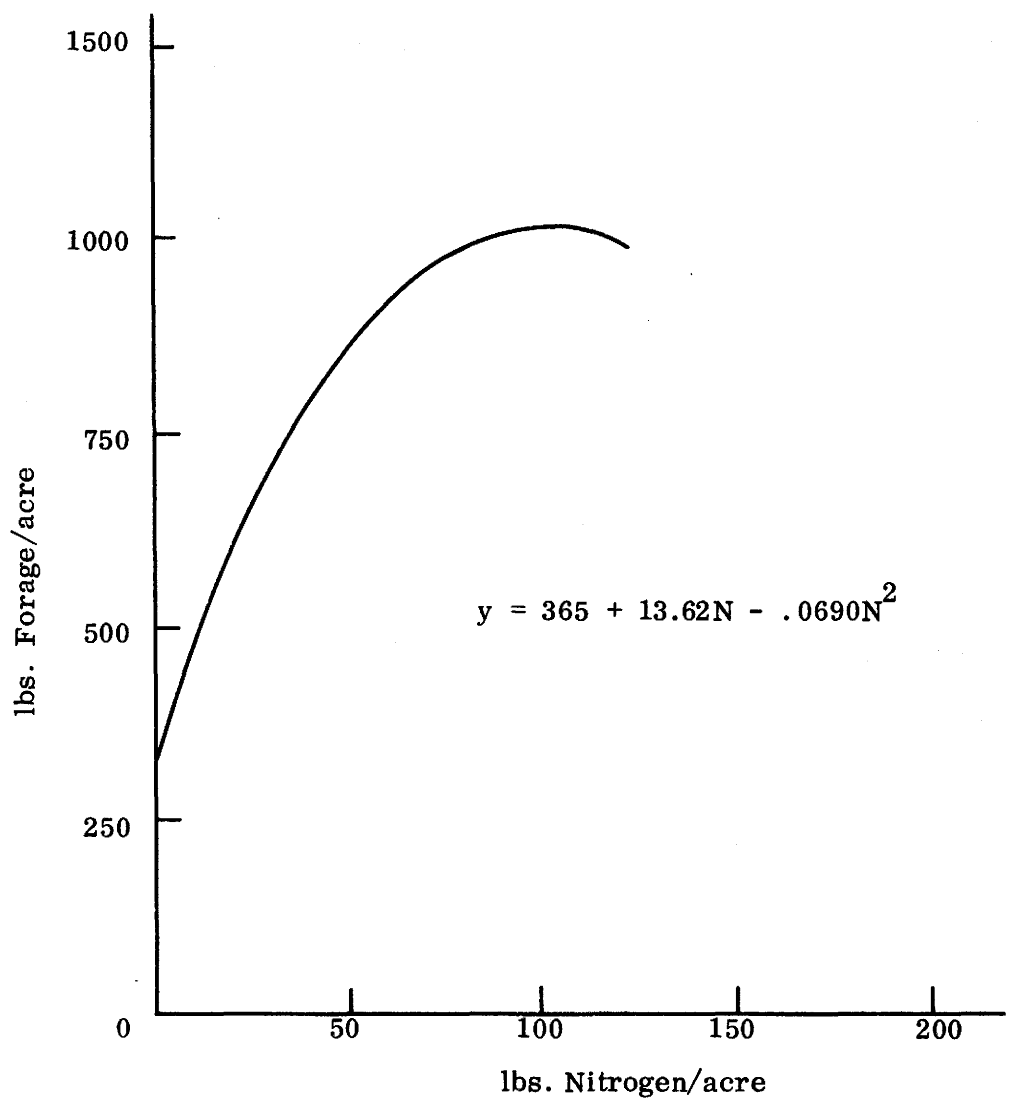



Figure 6. Production function showing the response of the Benmore #22 site, spring application to nitrogen fertilization in 1973.

The Junction plot receives marginal precipitation for crested wheatgrass growth. Even during normal years moisture is not adequate to provide a production response to the addition of nutrients. This site represents the response of crested wheatgrass to the addition of nutrients on sites of inadequate moisture. The same response was noted following the spring applications in 1972 (Quigley, 1972).

The Benmore No. 22, fall plot is in a depleted stand of crested wheatgrass. Early spring growth consisted of a high percentage of bulbous bluegrass, which responded favorably to nitrogen early in the growing season. Bulbous bluegrass matures early and was essentially gone from the stand by the late June harvest of this plot. The early response and production was not measured since the bulbous bluegrass reached dormancy prior to harvest and did not add to the total production weight.

The Curlew Grassland site received applications of both phosphorus and nitrogen. Multiple regression analysis indicated no response to the additional phosphorus and that 83 percent of the yield variation was explained by the added nitrogen. This is a similar response to that reported by Quigley (1972) on the spring application on both the Curlew site and on other sites analyzed.

The Benmore plots; No. 11, spring application and fall application and No. 22, spring application, each show significant response to fertilization. The forage response per pound of nutrients (slope of the production curve) was similar on the Curlew and Benmore sites. However, the Benmore plots reach maximum production at a lower level of fertilization than Curlew. The comparison of this phenomenon appears on Table 4.

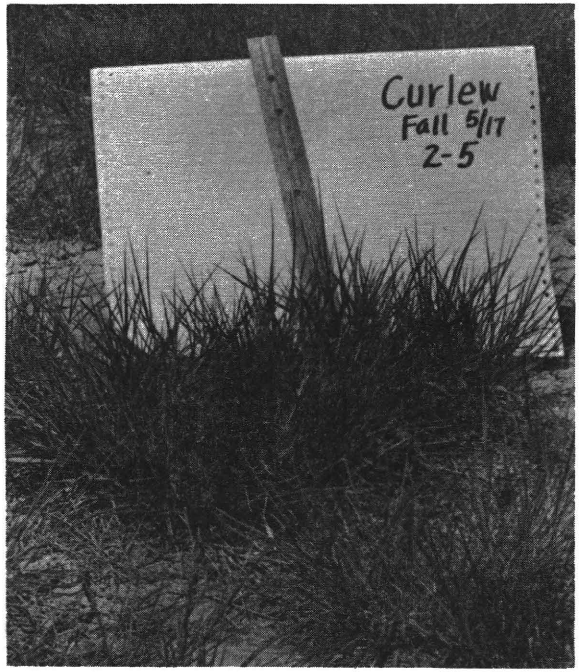
Table 4. Comparative forage responses and nitrogen application rate causing maximum production.

| Plot | Lb. Forage/lb. Nitrogen | Lb. Nitrogen/acre @ maximum production |
|---|---|---|
| Curlew, fall | 14.94 | 187 |
| Benmore No. 11, spring | 17.71 | 84 |
| Benmore No. 11, fall | 13.72 | 83 |
| Benmore No. 22, spring | 13.62 | 99 |

Ability of the site to respond to added nitrogen may depend upon two factors: (1) current growing season moisture and (2) the ability of the stand to produce to its potential. Curlew grassland is a relative young seeding, (seeded in 1962) free of invading species or competition. The bunches are vigorous and well developed. The Benmore site (seeded in 1939) is in a depleted condition, heavily invaded by sagebrush (Artemesia tridentata) and bluegrass (Poa secunda and Poa bulbosa). A stand of crested wheatgrass plants in a depleted condition does not appear as able to compete or produce to the potential of the site as do the plants growing vigorously and free of competition. Figure 7 pictorially shows the differences in general appearance of the grass at the Benmore and Curlew sites.

## Carry-over response

Important in the consideration of fertilization as a range improvement practice is the total response of a site to the addition of nitrogen. This total




Curlew plot, fall application, photographed May 17, 1973.


Benmore #11 plot, spring application, photographed May 18, 1973.

Figure 7. Control plots of Curlew and Benmore showing differences in stand.

response includes the initial response plus any second or third year carry-over production from an initial nutrient application.

A definite carry-over response occurred on all plots having an initial response to nitrogen fertilizer. The predictive equations for each year appear in Table 5.

Table 5. Predictive equations of plots showing a carry-over response significant at the .10 level.

| Plot | Year | Predictive equation | $R^2$ |
|---|---|---|---|
| Curlew | 1971 | $y = 1268 + 17.42N - .0623N^2$ | .56 |
| spring | 1972 | $y = 433$ | .20 |
| | 1973 | $y = 489 + 3.72N$ | |
| White | 1971 | $y = 1897 + 2988N - .0463N^2$ | .81 |
| spring | 1972 | $y = 1822 + 7.33N$ | .70 |
| fall | 1971 | $y = 2515 + 26.46N - .0392N^2$ | .73 |
| | 1972 | $y = 2516 + 6.05N$ | .67 |
| Eureka | | | |
| spring | 1973 | $y = 744 + 10.66N$ | .74 |
| fall | 1973 | $y = 670 + 7.19N$ | .91 |
| Wah-Wah | | | |
| spring | 1973 | $y = 605 + 12.89N$ | .72 |
| fall | 1973 | $y = 630 + .1776N^2$ | .94 |

The Curlew plot, spring application, showed an initial curvilinear response to nitrogen with the realization of maximum production at approximately 145 pounds of additional nitrogen per acre (Figure 8). The 1972 year

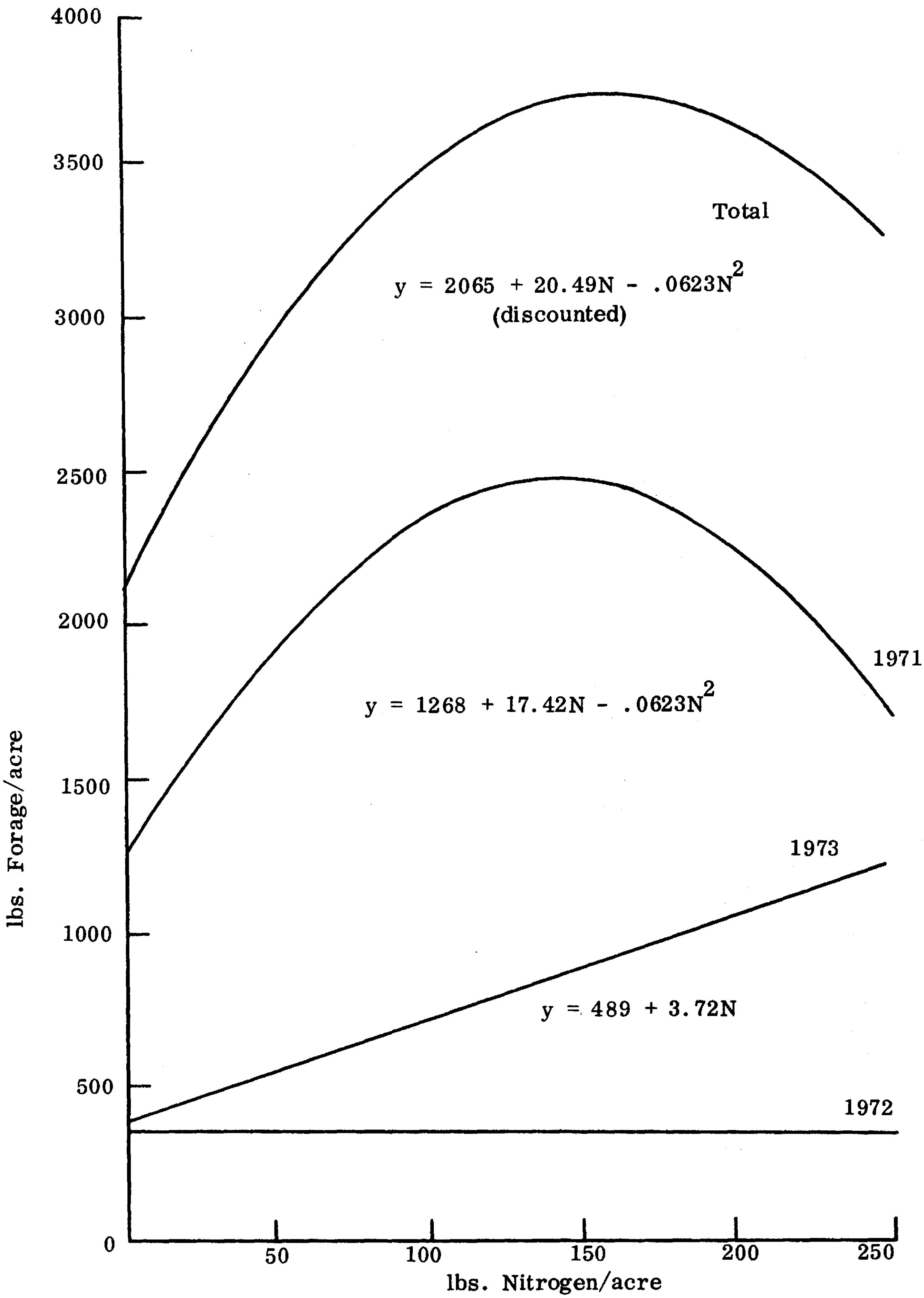



Figure 8. Production functions showing the response in 1971, 1972 and 1973 to nitrogen fertilizer applied in the fall of 1970 on the Curlew site.

was unusually dry (8.63 inches of precipitation, compared to an average of 12 inches) and significant responses of grass to nitrogen was not observed. The 1973 harvest indicated that much of the added nitrogen carried over for two years to create a significant response in 1973. The third year's (1973) response at Curlew was linear as was the second year's on the White plot. With two consecutive years of average or above average precipitation, the response on the Curlew site would be expected to be similar to that of the White plot. Had moisture conditions been favorable, the hypothesized second year's carry-over response would be expected to be linear, but somewhat greater than the actual third year response.

The White plot exhibited a curvilinear function in the initial production year (1971), with maximum production at approximately 330 pounds of nitrogen per acre (Figures 9 and 10). During the second year (1972) enough additional nitrogen and adequate moisture were present in the soil to create a linear response. The third year (1973) produced no additional fertilizer response.

The Eureka and Wah-Wah plots did not respond during their initial year (1972). Moisture on these plots was below normal for the 1972 growing season. The 1973 season, with normal precipitation, did show a linear response to nitrogen (Figures 11 and 12).

Knowledge of a carry-over or residual effect should influence the decision making process regarding fertilization. A carry-over response will reduce the risk or uncertainty of fertilization. An operator may be less hesitant to apply fertilizer if he is partially assured of regaining some of his investment even if a dry year follows the initial application.

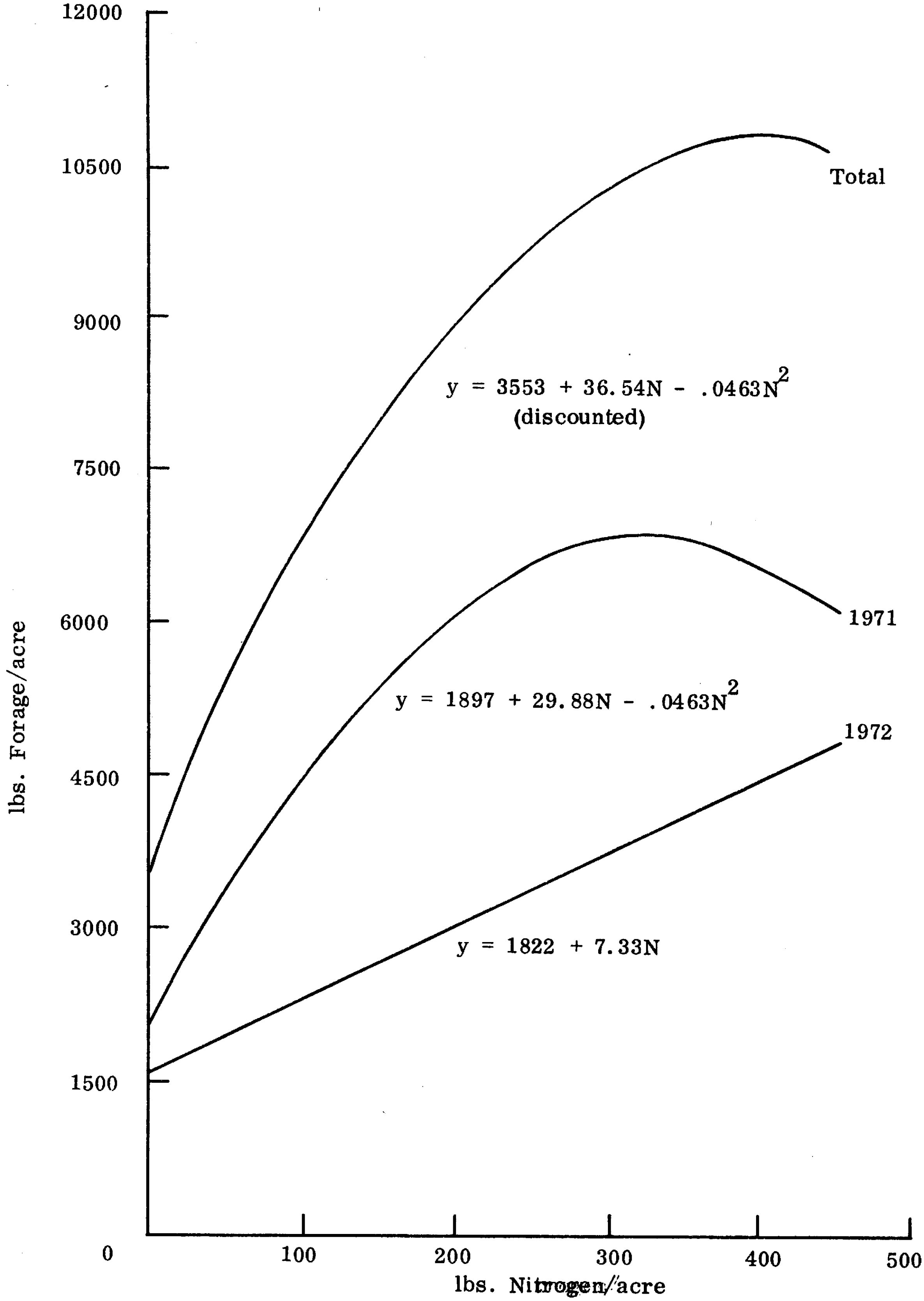



Figure 9. Production functions showing the response in 1971 and 1972 to nitrogen fertilizer applied in the spring of 1971 on the White site.

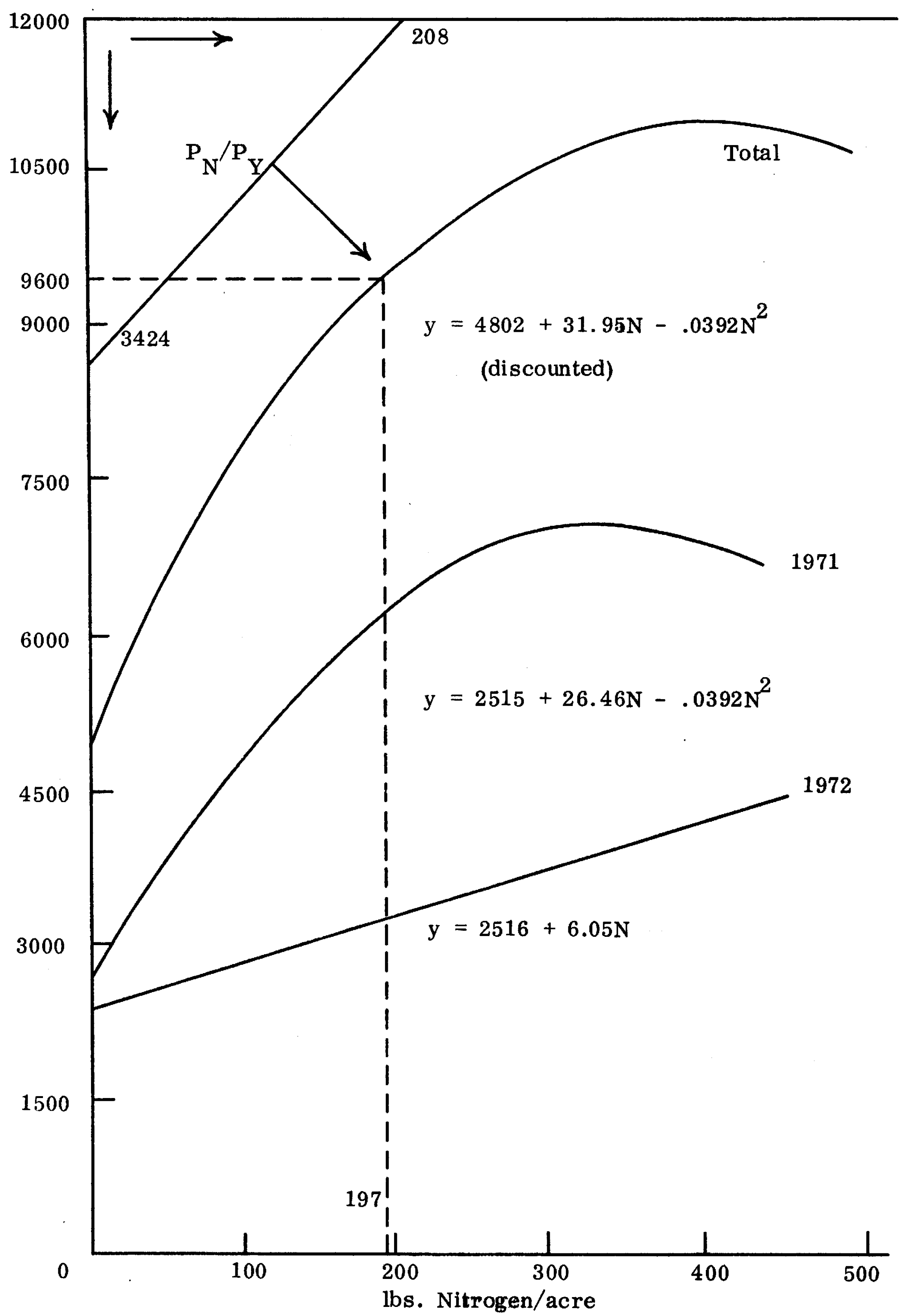



Figure 10. Production functions showing the response in 1971 and 1972 to nitrogen fertilizer applied in the fall of 1970 on the White site. Graphical optimization of the total production function is also shown.

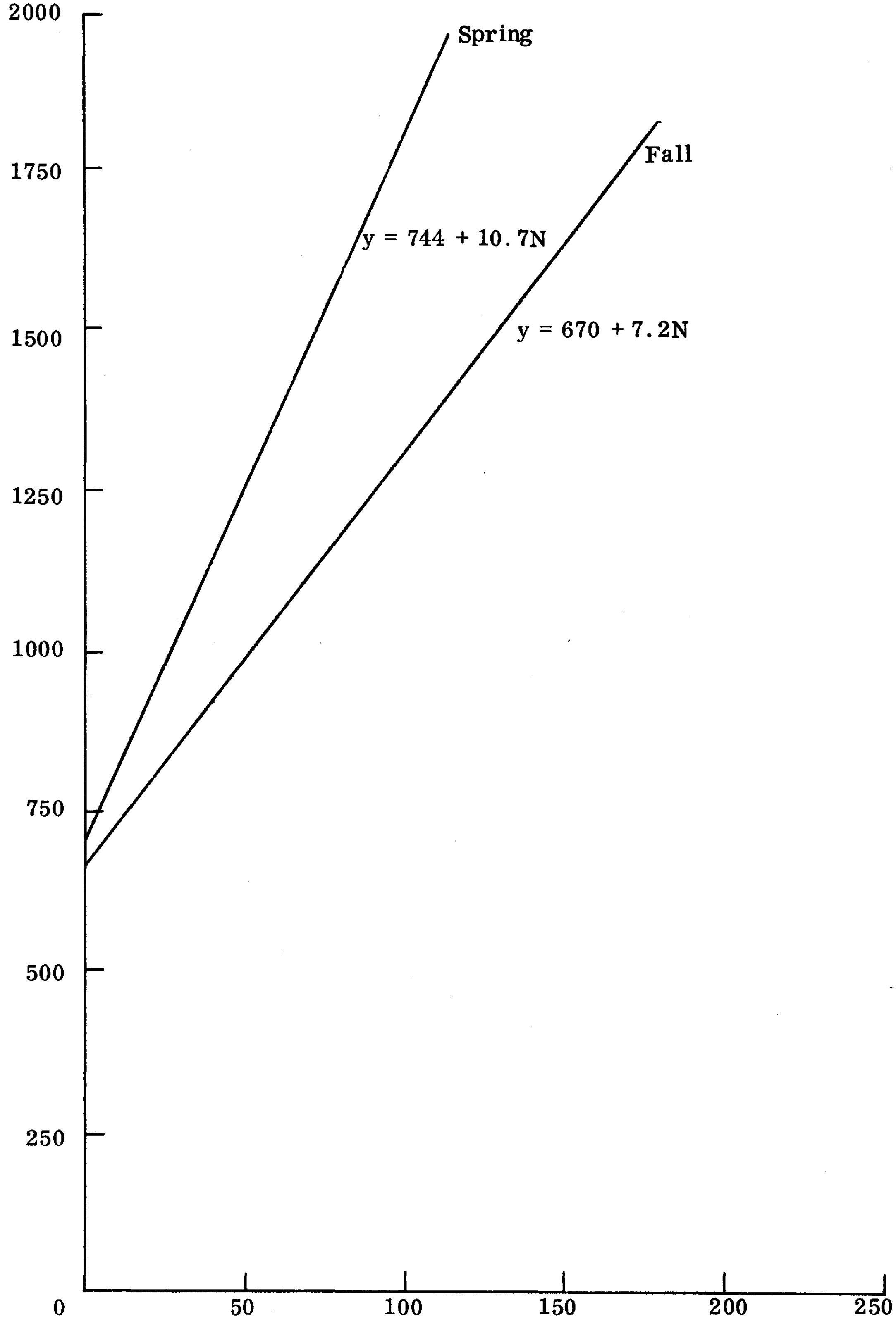



Figure 11. Production functions showing the response of crested wheatgrass in 1973 to a carry-over of nitrogen fertilizer applied in the spring of 1972 and the fall of 1971 on the Eureka site.

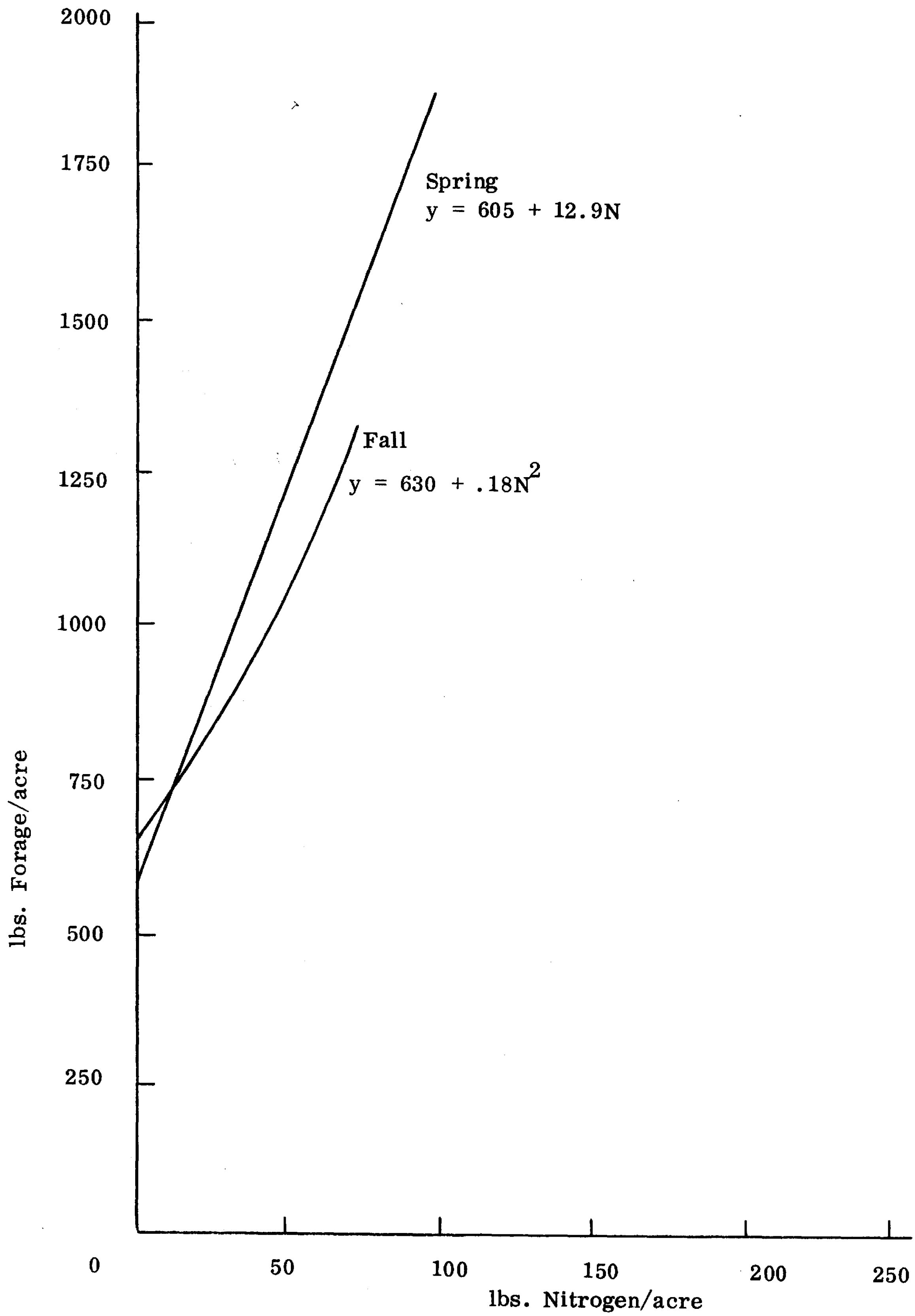



Figure 12. Production functions showing the response of crested wheatgrass in 1973 to a carry-over of nitrogen fertilizer applied in the spring of 1972 and the fall of 1971 on the Wah-Wah site.

Since the decision to fertilize must be made without full knowledge of the responses and future moisture conditions and since considerable time must pass prior to receiving some of the benefits, discounting the carryover response and adding it to the initial response to establish an aggregate production function provides the appropriate decision making tool. Discounted total functions appear in Table 6.

Table 6. Aggregate production functions, discounted at an interest rate of 10 percent.

| Plot | Application | Model production function |
|---|---|---|
| White | Spring '71 | $y = 3553 + 36.54N - .0463N^2$ |
| | Fall '70 | $y = 4802 + 31.95N - .0392N^2$ |
| Curlew | Spring '71 | $y = 2065 + 20.49N - .0623N^2$ |

The discount rate used is ten percent. Each operator can select and use the discount rate which will fit his own capital and uncertainty situations. The magnitude of the discount rate should differ with each rancher. On one hand, it will depend on alternative rates of return on capital in other parts of his business. Otherwise the magnitude of the discount rate will be a function of the subjective price and yield uncertainty in the operator's mind (Baum, Heady and Blackmore, 1956).

The yield responses determined in this project may be fitted to any set of prices and discount rates determined in the market place. The following analysis demonstrates the need for a long term series of production functions for each site, reflecting the initial and carry-over responses under the various climatic situations that may be expected. Only from these data can sound recommendations be made which can be expected to predict true responses over time.

The residual effect of fertilizer calls for a revision of the optimum level of fertilization from analysis of first year response. This optimum level of fertilization can be determined by equating the discounted value of the marginal responses with the marginal cost of fertilizer (Baum, Heady and Blackmore, 1956).

The initial production response of the fall White plot analyzed by Quigley (1972) resulted in an optimum rate of 127 pounds per acre. The initial production function is:

$$y = 2515 + 26.46N - .0392N^2$$

A carry-over response was measured in 1972 which resulted in the predictive equation:

$$y = 2516 + 6.05N$$

The aggregate production function (Table 7) was determined by discounting the carry-over response and adding to the initial production function.

The marginal analysis of the total response takes the following form:

$$MPP_1 + (MPP_2)(1 + i)^{-1} = P_N/P_Y$$

For the fall White plot the calculation of a new optimum rate is:

$$MPP_1 = 26.46 - .078N \qquad MPP_2 = 6.05$$

$$(26.46 - .0784N) + (6.05)(.9091) = 31.95 - .0784N = (\$.12)/(\$.0073)$$

$$N = 198 \text{ lbs./acre}$$

where the net price of hay is $.0073 per pound and the price of nitrogen is $.12 per pound (Quigley, 1972). The discount factor for an interest rate of 10 percent is .9091.

The revised optimum rate of fertilization will also provide an adjusted profit for each year. Utilizing Quigley's figures: Total cost (TC) includes fertilizer costs ($ .12/lb.), application costs ($1.50/a), swathing costs ($3.50 /a), baling costs ($ .0021/lb.), and hauling costs ($ .0017/lb.). Total revenue (TR) is the market value of hay (10 year average, $22.27/T or $ .0111/lb.).

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

1971:

From the initial production function:

$$y = 2515 + 26.46N - .0392N^2$$

and the optimum rate of 198 pounds of nitrogen, the total production for 1971 is calculated to be 6217 pounds of forage. The calculation of TC and TR is as follows:

$TC = (\$.12/lb.)(198\ lb/a) + (\$1.50/a) + (\$3.50/a) + (\$.0021/lb.)\cdot$

$(6217\ lbs.) + (\$.0017/lb.)(6217\ lbs.) = \$52.39$

$TR = P_Y \cdot Y\ (\$.0111/lb.)\ (6217\ lbs.) = \$69.01$

Profit = TR - TC = \$69.01 - \$52.39 = \$16.62/acre

(Quigley's 1971 profit @ 127 lb. N was \$17.95/acre

1972:

From the carry-over production function:

$$y = 2516 + 6.05N$$

and the optimum rate of 198 pounds of nitrogen, the total production for 1972 is calculated to be 3376 pounds of forage (discounted 10 percent). The calculation of TC and TR is as follows:

$TC = \$3.50 + (\$.0021/lb.)(3376\ lbs.) + (\$.0017/lb.)(3376\ lbs.) = \$16.33$

$TR = (\$.0111/lb.)(3376\ lbs.) = \$37.47$

Profit = \$37.47 - \$16.33 = \$21.14/acre for carry-over

Total profit over 2 years is \$37.76/acre.

This profit would only be realized if the production was harvested for hay. At this time, utilization of the forage for grazing (forage grazing value of \$5.00

per AUM or \$ .0044 per pound), would not permit a profitable fertilization program.

The White, spring application, is the only other plot that exhibits production capable of being utilized for hay. Calculation of a new optimum rate of application with the 1972 carry-over response yields an optimum rate of 218 pounds of nitrogen per acre and a profit of \$14.18 per acre for the first year of production (144 lb. N/a and \$15.87/a profit, Quigley, 1972). The total profit over the two years of production is \$35.65 per acre with the carry-over production being discounted 10 percent.

The determinization of the most profitable rate of application may be determined graphically (Figure 10). This may be done by: (1) plotting the total production curve, then (2) creating a second origin at the top of the Y axis, with units of nitrogen to the right in scale with the lower N rates and projecting units of forage downward, with the same scale as forage up, (3) a price line is determined by selecting a budget (\$25) and finding the intercepts by dividing the price of nitrogen ($P_N$) into the budget ($\$25/P_N = 208$ units of nitrogen) and dividing the price of forage ($P_Y$) into the budget ($\$25/P_Y = 3424$ units of forage), (4) joining these intercepts gives a price line $P_N/P_Y$. Projecting this line until tangent to the total production curve will give the rate of nitrogen (197 #) and total production (9600 pounds of forage per acre) where the last dollar invested in nitrogen fertilizer will yield one dollar in forage.

To identify when to refertilize, comparison must be made between the net value of the added yield (year 2) and the net value of forage resulting from refertilization. If the net return in year two is greater, refertilization would be delayed. Where production figures from refertilized forage are not available, carry-over must be compared to the initial production. However, it must be recognized that refertilization when carry-over response is still present would provide less response than the initial application.

### Stand invasion by annuals

Two sites, Junction and Eureka, indicated that invasion by annuals was influenced by fertilizer. The Junction plot responded with heavy infestation of halogeton on the more heavily fertilized plots. The moisture limitation, clipping, and the fertilizer stimulation seemed to put a great deal of stress on the stand resulting in many crested wheatgrass bunches dying.

The Eureka site showed a heavy invasion of Russian thistle on grazed plots fertilized at 60 and 80 pounds per acre. There was little invasion on the fenced plots.

Invasion by annuals on fertilized rangeland seems to occur when a stand is put under a stress situation (Patterson and Youngman, 1960; Kay and Evans, 1965). Fertilization first stimulates the forage plants, making them more vulnerable to grazing during their early growth cycle. Grazing or clipping the plants at critical times (periods of low carbohydrate reserves or unusual drought conditions) may deteriorate the stand allowing the invasion of annuals. The additional nutrients in the soil seem to encourage a more rapid and vigorous annual establishment.

Season of application

Previous research (Hull, 1963; Sneva, 1973a; and Lavin, 1967), indicates no differences between seasons of fertilizer application. However, on mountain meadows, Seamonds (1971) identifies an advantage of ten percent in yield from spring fertilizer application. Quigley (1972) indicated that the most profitable time of the year to apply nitrogen fertilizer is fall. Profit was greater on both the Jensen and White plots when fertilizer was applied in the fall rather than spring.

In 1973, the Benmore No. 11 plot showed a greater total response from the spring application of fertilizer than fall application. This was the only plot which had a significant response on both spring and fall applications. The variations in season of application response indicate that the climatic conditions of each growing season will dictate the vegetational response to season of application.

The decision of when to fertilize will depend upon economic factors related to costs of fertilizer, storage and labor demands for each operator.

Utilization

An unplanned utilization study took place on the Benmore No. 11, fall application plot. Between June 8 and June 25, 1973, rabbits entered the plot and totally grazed the forage on the 90 and 120 pound applications on two of the three replications. The grazing was unusual in that only the heavily fertilized plots were completely grazed. This may be an indication of the possibility of increasing palatability through heavy fertilization.

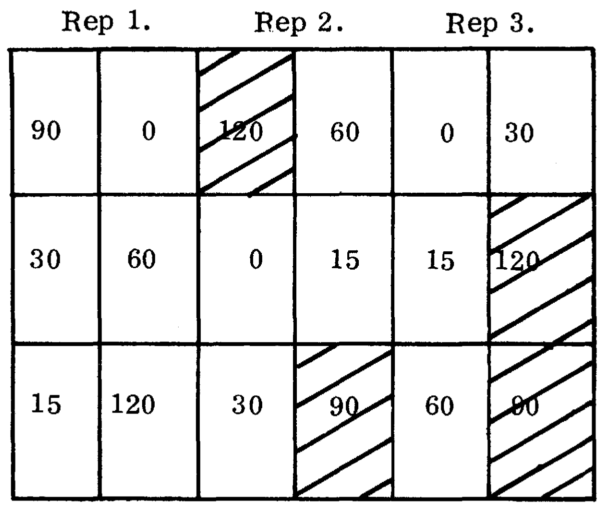



Figure 13. Plots exhibiting 100 percent utilization by rabbits on the Benmore #11, fall application.

Early growth

Early growth of crested wheatgrass is strongly stimulated by fertilization. Inverse prediction of the growth curves shows that fertilized crested wheatgrass reached six inches of height from 4 to 18 days earlier than that on u unfertilized plots.

Inverse prediction was used to determine the number of days each fertilizer rate would reach range readiness. Inverse prediction of the linear regression:

$$y = a + bX$$

where $\underline{y}$ is the plant height achieved $\underline{X}$ days after the initial measuring date and where $\underline{a}$ is the height at the initial measurement date.

The inverse prediction of the linear regression allows the determination of the days of growth from the initial measurement date, for the plants to reach a predetermined plant height (a height of 6 inches was defined as range readiness) (Appendix A).

Table 7 shows the linear regression equation for growth response and the prediction of the number of days in 1973 at which each rate would reach range readiness. Figures 15 through 18 graphically demonstrate the growth pattern for each plot.

The Benmore No. 11, spring application results show negative days to reach range readiness at the 30 to 120 pound application rates. This results from the initial measurement day (May 5, 1973) occurring after six inches of height had been reached.

Table 8 shows the number of days that each of five rates of fertilization advanced the attainment of 6 inches of growth in comparison to unfertilized forage. Fertilization at 25 to 30 pounds of nitrogen per acre caused the Curlew and Benmore sites to reach range readiness 11 to 13 days prior to the unfertilized plots.

The early growth response of crested wheatgrass presents the opportunity to consider range fertilization as a method of reducing hay feeding costs during the late spring. To evaluate this opportunity, it is necessary to compare hay costs with the cost of fertilization. Hay feeding costs will not be considered in this discussion as they vary with each operation and only create a larger

Table 7. Results of linear regression of early growth with Y set at six inches.

| Initial measurement date | Plot | Rate | $R^2$ | Regression equation | Days to reach 6" |
|---|---|---|---|---|---|
| April 7, 1973 | Benmore | 0 | .88 | y = 1.78 + .10X | 40 ± 10 |
| | No. 11 | 15 | .83 | y = 2.16 + .12X | 36 ± 13 |
| | Fall | 30 | .88 | y = 2.60 + .13X | 27 ± 10 |
| | | 60 | .85 | y = 2.40 + .15X | 24 ± 12 |
| | | 90 | .93 | y = 2.64 + .15X | 23 ± 8 |
| | | 120 | .87 | y = 2.25 + .16X | 24 ± 11 |
| May 5, 1973 | Benmore | 0 | .92 | y = 4.03 + .17X | 11 ± 11 |
| | No. 11 | 15 | .86 | y = 5.6 + .18X | 2 ± 15 |
| | Spring | 30 | .81 | y = 6.01 + .15X | -.5 ± 17 |
| | | 60 | .82 | y = 6.13 + .15X | -1.3 ± 17 |
| | | 90 | .84 | y = 7.14 + .15X | -7.8 ± 16 |
| | | 120 | .68 | y = 6.89 + .15X | -7 ± 26 |
| April 14, 1973 | Benmore | 0 | .81 | y = 2.42 + .12X | 29 ± 12 |
| | No. 22 | 15 | .86 | y = 2.50 + .15X | 23 ± 10 |
| | Fall | 30 | .87 | y = 2.8 + .18X | 18 ± 9 |
| | | 60 | .86 | y = 2.60 + .17X | 20 ± 10 |
| | | 90 | .83 | y = 2.60 + .19X | 18 ± 11 |
| | | 120 | .85 | y = 2.60 + .19X | 18 ± 10 |
| April 12, 1973 | Curlew | 0 | .68 | y = 3.3 + .10X | 27 ± 13 |
| | Fall | 12.5 | .65 | y = 3.5 + .12X | 20 ± 14 |
| | | 25 | .76 | y = 3.5 + .16X | 16 ± 11 |
| | | 50 | .80 | y = 3.3 + .14X | 19 ± 10 |
| | | 100 | .75 | y = 3.7 + .15X | 15 ± 12 |
| | | 200 | .84 | y = 3.6 + .18X | 11 ± 9 |

Table 8. Days of advanced range readiness with range fertilization

| Plot | Nitrogen level per acre 12.5 | 15 | 25 | 30 | 50 | 60 | 90 | 100 | 120 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|
| Benmore No. 11 fall application | | 4 | | 13 | | 16 | 17 | | 16 | |
| Benmore No. 11 spring application | | 9 | | 12 | | 12 | 19 | | 18 | |
| Benmore No. 22 fall application | | 6 | | 11 | | 9 | 11 | | 11 | |
| Curlew, fall application | 7 | | 11 | | 8 | | | 12 | | 16 |

margin in favor of fertilization for early growth. All fertilization costs will be attributed to the advancement of early growth, although increased forage production resulting after range readiness is achieved also benefits the livestock operator.

The cost of fertilized forage per day of advanced grazing is estimated by use of the formula:

$$\frac{a + bN}{d} = \text{cost/day/acre}$$

where $\underline{a}$ is the per acre fixed cost of fertilizer application, $\underline{b}$ is the price per pound of nitrogen, $\underline{N}$ is the pounds of nitrogen applied per acre and $\underline{d}$ is the number of days advanced readiness. From the cost per day figure, a break-even or comparable hay cost may be calculated.

A 1000 pound cow, nursing a calf has a nutrient requirement of 23.1 pounds of dry matter or .0115 tons of hay per day (National Research Council, 1970). Quigley (1972) indicated that a grazing animal requires 800 pounds of air dry forage per AUM to meet daily requirements. Managing for only 70 percent utilization, 1143 pounds of air dry forage must be produced per acre or 38 pounds per day (.0190 T/day). Assessments of early growth produced on seedings in Oregon (Hyder and Sneva, 1961) indicates that during the early growth period, crested wheatgrass is capable of producing approximately 500 pounds per acre in 10 to 14 days or 36 to 50 pounds of forage per acre per day. This closely approximates the animal's daily range requirement (38 lb./day). Therefore, the range is capable of producing enough feed to support approximately one cow per acre or the carrying capacity is one acre per AUM.

Dividing the cost per day for fertilized forage by the tons per day hay requirement, a break-even price between hay and fertilized forage may be calculated. If the price of hay is more than the calculated cost, consideration should be given to range fertilization.

In regions of long hay feeding periods, late April and early May often become a time when the rancher runs short of hay. At this time of year, hay is usually quite expensive. By early April the rancher can usually forsee the need for extra feed and consideration of range fertilization as an alternative to purchasing hay may be made at this time. In 1973, the decision to fertilize could have been made as late as April 7, when spring fertilization occurred. Spring fertilization took place as soon after snow melt as soil conditions would allow.

Calculation of the break-even price required for consideration of range fertilization may be made using the 1973 figures. At the 30 pounds per acre rate, range readiness (six inches of growth) was reached 12 days before the unfertilized plots. A break-even price for this rate is calculated as follows:

$$\frac{\$1.50 + \$.12/\text{lb. N}(30\#/\text{a})}{12 \text{ days}} = \$.43/\text{day}$$

$$\frac{\$.43/\text{day}}{\$.0115\text{T}/\text{day}} = \$37.39/\text{Ton}$$

Had the range operator run short of hay during late April, the decision to fertilize would have been a profitable one, considering hay prices at $45 per ton ($ .52/lb.). For a breeding herd of 500 head, fertilization would have resulted in a savings of $.09 per head per day or $540 over the twelve day period.

Costs used in the above calculation ($1.50/acre application cost, $.12/lb. of nitrogen) would need to be adjusted for each individual operation. Table 9, provides an immediate reference for comparable costs of hay. Table 10, gives the costs of days of advanced grazing, given the costs of application and nitrogen.

Table 9. Costs of hay per animal unit day (AUD), based upon a daily requirement of .0115 T/day.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Price of hay/Ton | $ 50 | $ 45 | $ 40 | $ 35 | $ 30 | $ 25 | $ 20 |
| Price per AUD | .575 | .5175 | .46 | .4025 | .345 | .2875 | .23 |

Table 10. Fertilization costs per day for advanced grazing.

| Lbs. N | Days of advanced grazing | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| 75 | | | | | | | | | $.59 |
| 60 | | | | | | | $.55 | .51 | .49 |
| 50 | $.75 | .69 | .63 | .58 | .54 | .50 | .47 | .44 | .42 |
| 30 | .51 | .47 | .43 | .39 | .37 | .34 | .32 | .30 | .28 |
| 25 | .45 | .41 | .38 | .32 | .32 | .30 | .28 | .27 | .25 |

$$\text{Costs per day} = \frac{\$1.50 + .1207N}{\text{days}}$$

The decision making process must also include the knowledge of the risk of stand depletion due to possible grazing during the period of low carbohydrate reserves (Hyder and Sneva, 1961). Views of the Benmore and Curlew plots (Figure 14) give an indication of the amount of photosynthetic tissue available in mid-May. The height measurements upon which this analysis has been based do not fully reflect the production of fertilized forage.

## Moisture utilization

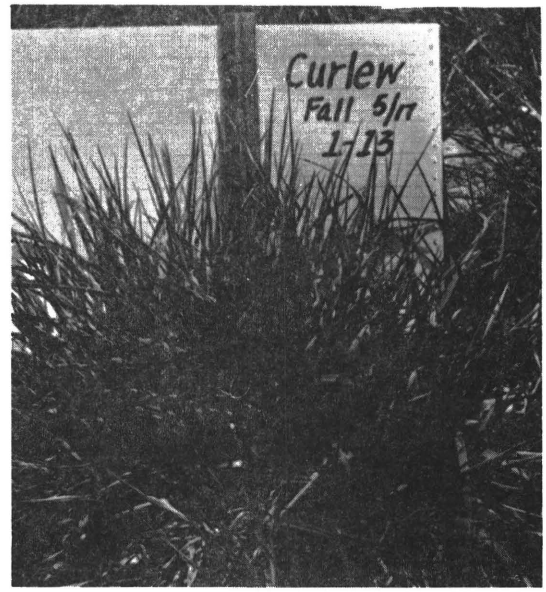
Moisture stress became readily apparent as plant height leveled off during early June on Benmore No. 11, spring plot (Figure 17) at fertilizer levels of 30 pounds per acre and greater. This indicates the ability of fertilized plants to use moisture more rapidly, and to mature earlier in the year. The

Benmore No. 11, fall application (Figure 16) exhibited the early maturing in mid-May at 60, 90, and 120 pounds of nitrogen per acre.

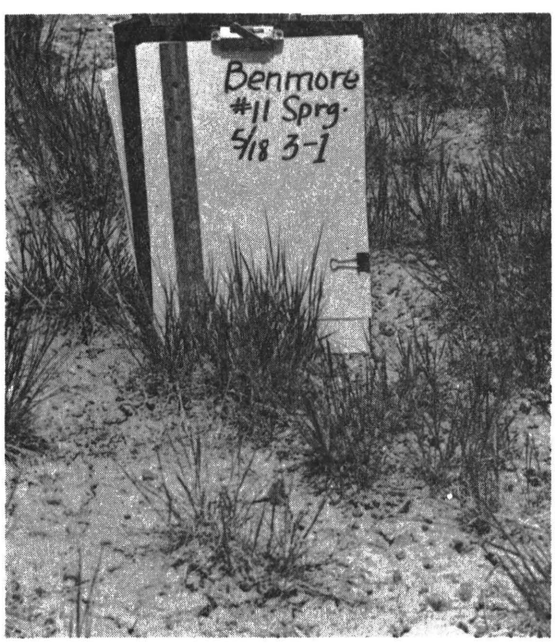
The Curlew plots did not exhibit the early maturation in height measurements, although this was apparent visibly. The heavier fertilized plants began browning at the base in mid-May. The Curlew site received considerable moisture during late May and early June, which probably extended the growing season for all levels of fertilization.

The observed moisture stress is substantiated by other research (Hyder and Sneva, 1965; Sneva, Hyder, and Cooper, 1958; Wight and Black, 1972) where earlier and more rapid depletion of soil moisture is associated with rapid early growth.


Range readiness with 0 pounds of nitrogen per acre on Curlew, fall application, May 17, 1973.




Range readiness with 100 pounds of nitrogen per acre on Curlew, fall application, May 17, 1973.




Range readiness with 0 pounds of nitrogen per acre on Benmore #11, spring application, May 18, 1973.


Range readiness with 120 pounds of nitrogen per acre on Benmore #11, fall application, May 18, 1973.

Figure 14. Pictures showing plant growth at "range readiness."

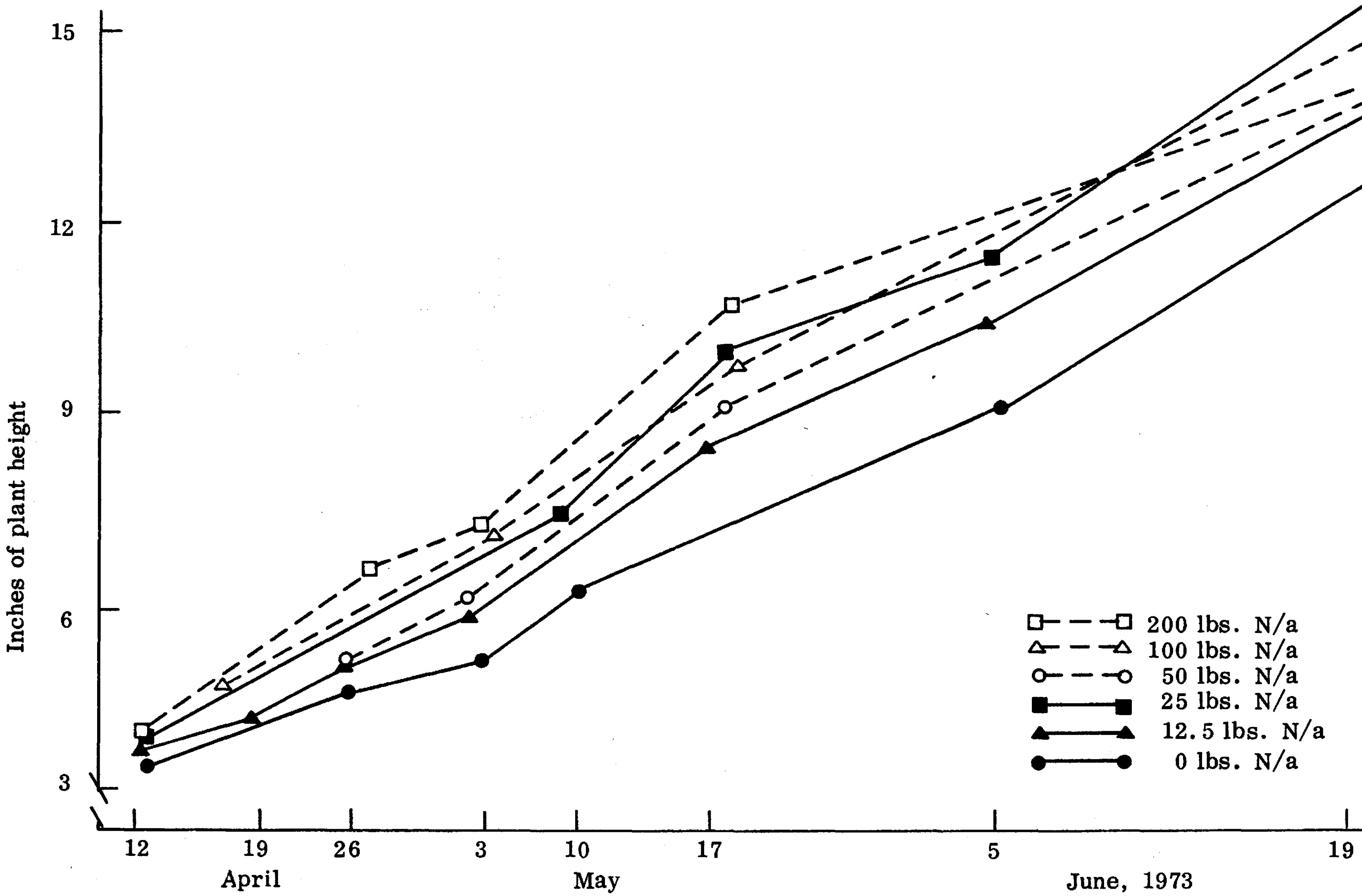



Figure 15. Early growth response, Curlew 1972 fall application.

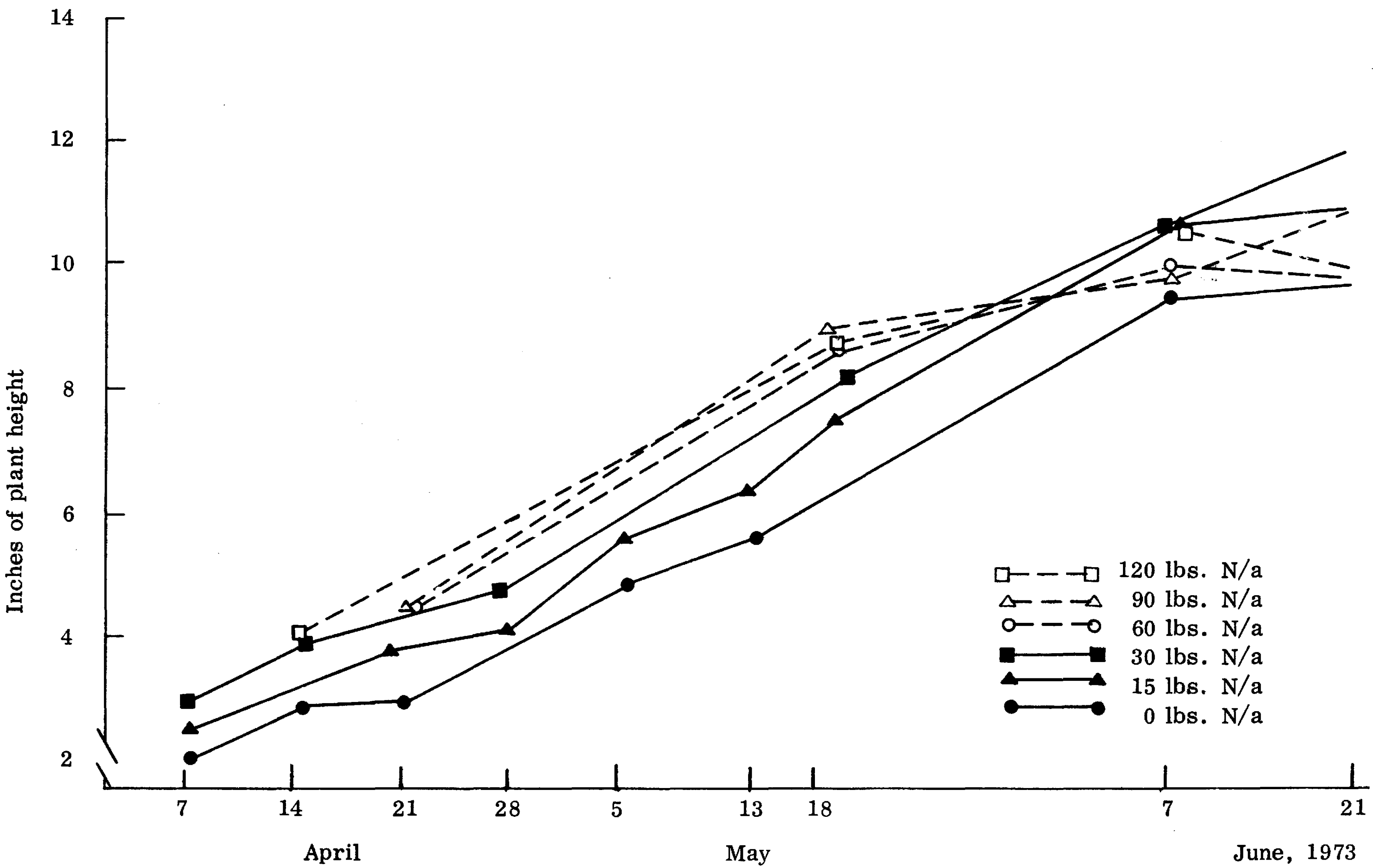



Figure 16. Early growth response, Benmore #11, 1972 fall application.

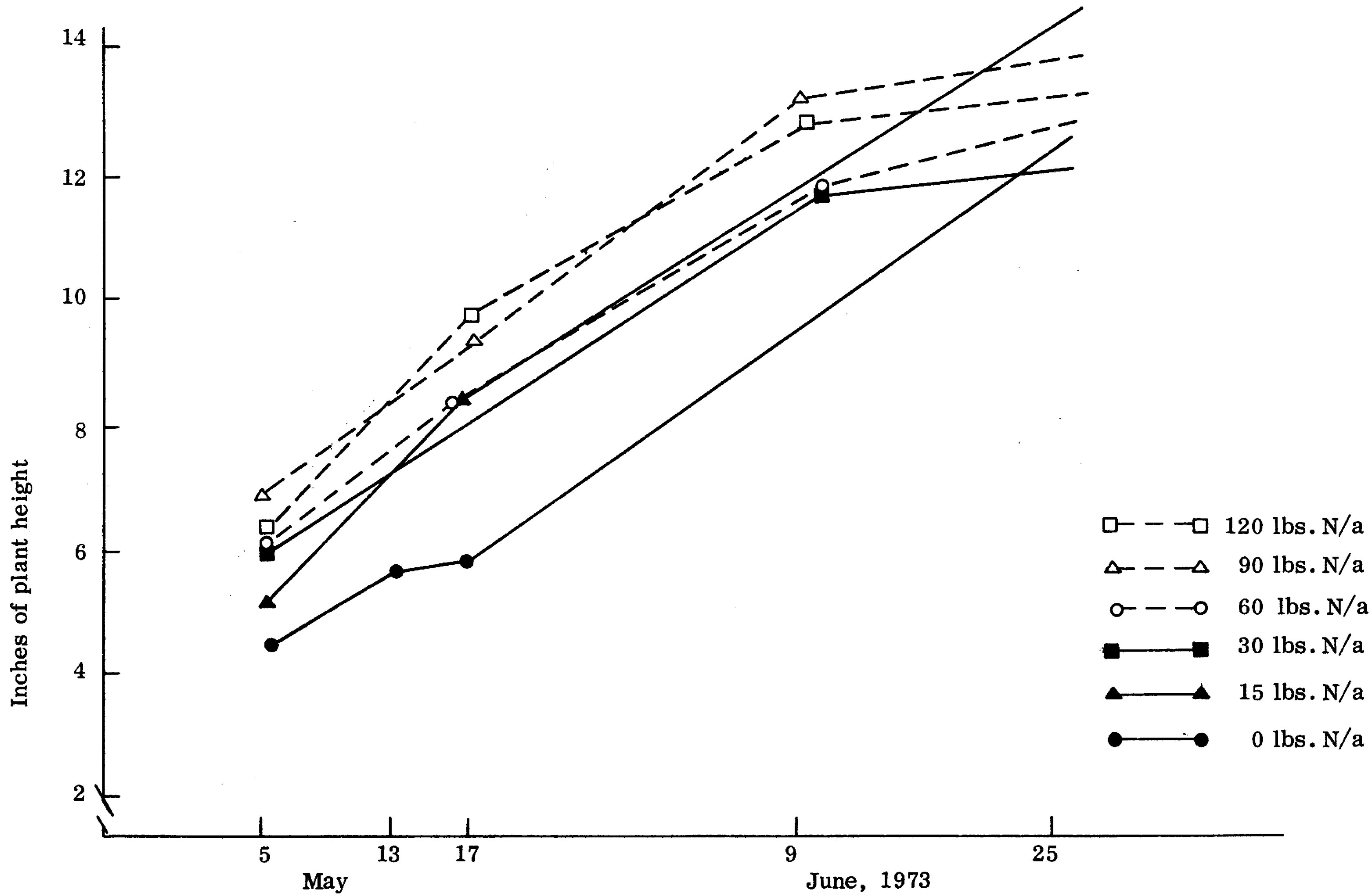



Figure 17. Early growth response, Benmore #11, 1973 spring application

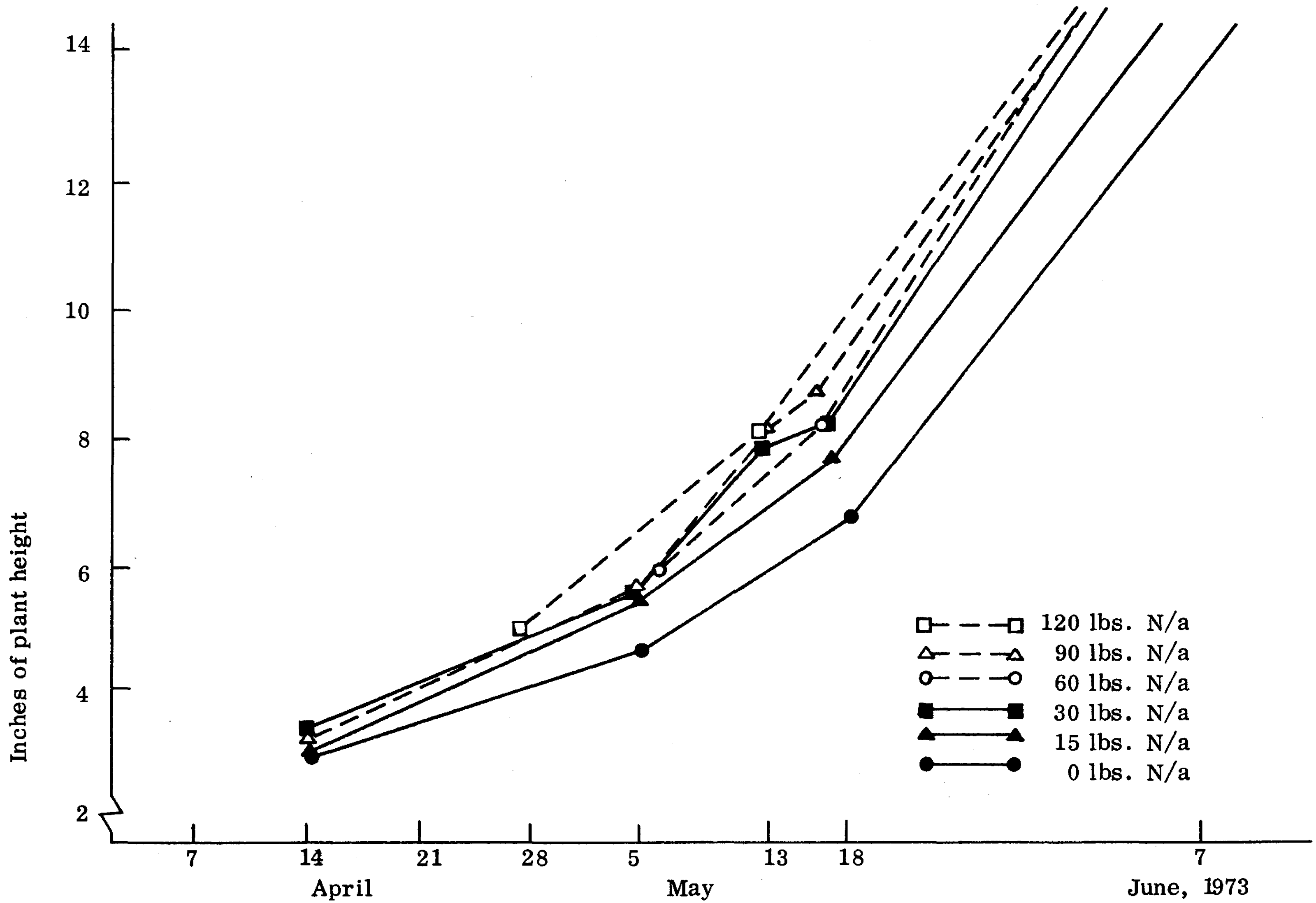



Figure 18. Early growth response, Benmore #22, 1972, fall application

# SUMMARY AND CONCLUSIONS

Knowledge that range fertilization results in increased forage production in regions of adequate moisture has been available for many years. Economic analysis may be used to evaluate when, where and how much fertilizer can be used most profitably.

Five crested wheatgrass sites and one intermediate wheatgrass site received graduated rates of nitrogen fertilizer. Phosphorus was also applied to three of the sites. Each site was evaluated for initial and carry-over production and the early growth response to nitrogen.

The predictive equation:

$$y = a + bN - cN^2$$

was found in all cases to estimate the response of range grasses to the application of nitrogen.

Moisture is the critical ingredient in range fertilization. The response of an area depends directly upon the timing and quantity of moisture received. The application of nitrogen to the Utah rangelands studied resulted in significant production responses where rainfall was in excess of ten inches annually. On most range areas, there does not appear to be enough moisture to leach the nutrients downward through the soil to the point of elminating the carry-over response.

Initial responses were measured on all sites where moisture was adequate and where other environmental factors such as flooding did not affect the site. Increases of 26-30 pounds of forage for each pound of nitrogen applied were observed on intermediate wheatgrass stands while responses of 14-18 pounds of forage per pound of nitrogen were observed on crested wheatgrass seedings. No response to phosphorous was noted.

Initial response carried over into the second year of production on all sites receiving adequate moisture. Where below normal moisture occurred, a carry-over was not observed in the second year. However, with adequate moisture, a carry-over was observed in the third year following application. Carry-over responses resulted in from 6 to 13 pounds of forage per pound of nitrogen applied.

The total response from each site is evaluated by summing the discounted carry-over response and the initial response to calculate a total production function:

$$y = a_1 + b_1N - c_1N^2 + (a_2 + b_2N - c_2N^2)(1 + i)^{-1} + \ldots$$

$$\ldots (a_n - b_nN - c_nN^2)(1 - i)^{-(n-1)}$$

The key to the fertilization decision is the ratio of the price of nitrogen to the price of forage. This value must be smaller than the marginal response of forage (number of pounds of forage produced per pound of nitrogen applied).

Considering grazing as the only method of forage harvest, fertilization of rangelands to increase total forage production is not economical at current prices. The limited supply of beef and the resulting increase in prices will result in increases in forage value. Periodic checks of the price ratio should be made to correctly analyze the economic aspects of the fertilization opportunity.

Early growth response of seeded range grass to nitrogen fertilization was analyzed by making weekly height measurements of fertilized and control plots. Range readiness was estimated to occur when the site had 200-300 pounds of forage per acre with a height of six inches and leaf stage of four. In 1973, 15 to 120 pounds of nitrogen per acre advanced range readiness from 4 to 18 days ahead of control plots. The opportunity, in years of spring hay shortage, to compare costs of fertilization with those of purchasing additional hay. This decision may be made in the early spring. With adequate spring moisture, fertilizer may be applied and significant response seen prior to normal range readiness.

During years of spring hay shortage, the costs of fertilization should be compared with those of purchasing additional hay. This decision may be made in the early spring since with adequate spring moisture, fertilizer may be applied and significant response seen prior to normal range readiness. During 1973, fertilization to advance range readiness was less costly than purchasing hay.

Range fertilization has the potential of becoming an effective range management tool. Greater production, earlier production and increased palitability are all biological incentives for the consideration of fertilization. Economic considerations include an increasing demand for grazing resources and high hay costs during the late spring feeding period. Each of these create a need for further and more complete information regarding the response of different sites over a period of time in order to totally evaluate rangeland responses to fertilization.

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# APPENDIXES

# Appendix A

## Inverse Prediction in Simple Linear Regression

Inverse prediction may be used to estimate the confidence interval for X when given an identified Y, from the simple linear regression:

$$Y = b_0 + b_1 X \quad (1)$$

The procedure is as follows. Compute:

$$\hat{X} = (Y_0. - b_0)/b_1 \quad (2)$$

where $Y_0$ is the observed value of Y for which we desire to estimate the associated X value. A 100$\gamma$ percent confidence interval for the true but unknown X value is defined by:

$$\left.\begin{matrix} L \\ U \end{matrix}\right\} = \bar{X} + \frac{b_1(Y_0 - \bar{Y})}{D} - \frac{ts_E}{D} \sqrt{B(Y_0 - \bar{Y})^2 - D\frac{(n+1)}{n}} \quad (3)$$

where

$$B = 1/\Sigma x^2 \quad (4)$$

$$D = b_1^2 - t^2 s_E^2 B - b_1^2 - t^2 s_{b_1}^2 \quad (5)$$

and

$$t = t_{(1-\gamma)/2(n-2)}. \quad (6)$$

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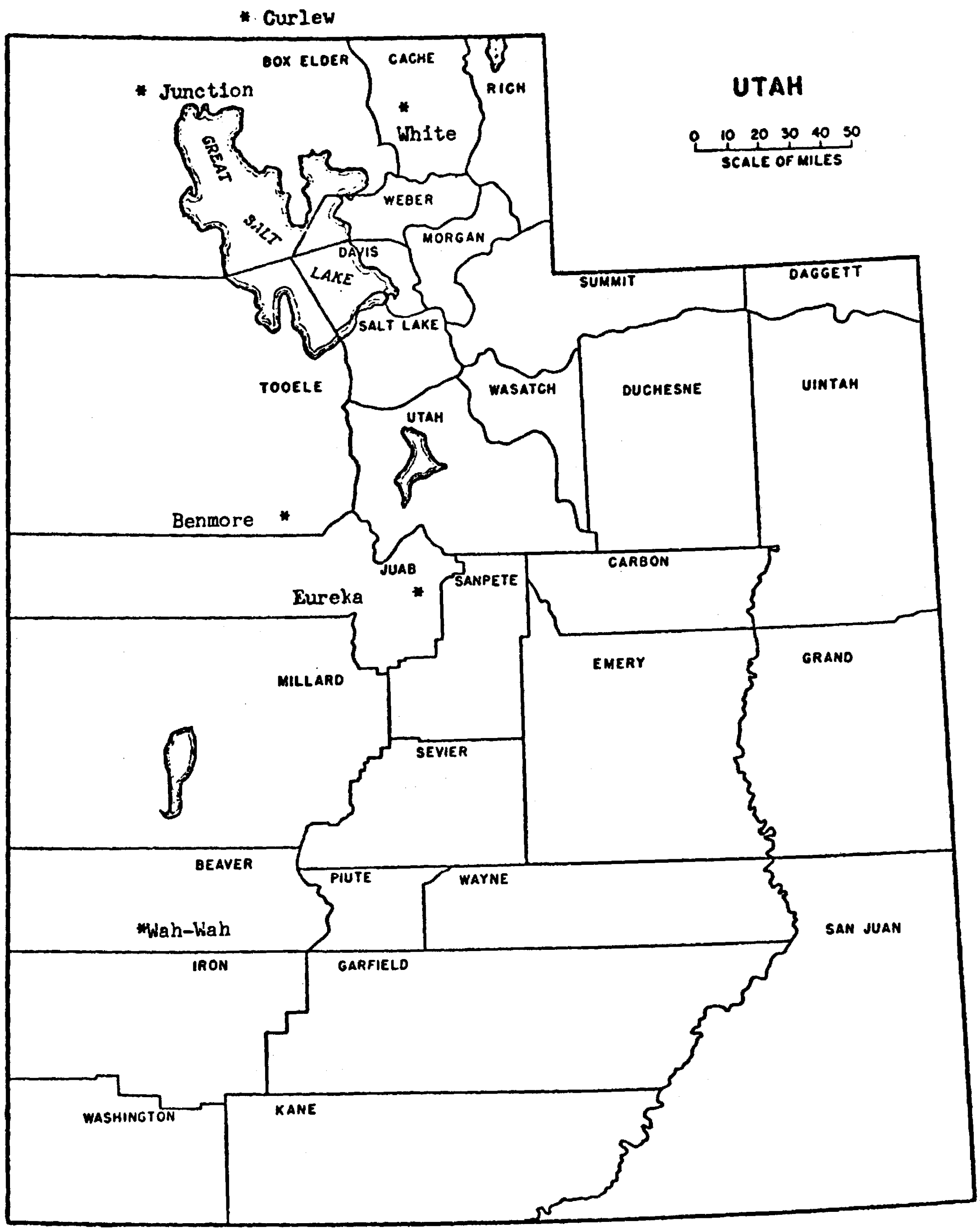
# Appendix B

## Map of the State of Utah

## Plot Locations




*Plot Locations

# Appendix C

## Yearly precipitation on Sites

Precipitation Utah State University - Logan, Utah

| Month | '64-65 | '65-66 | '66-67 | '67-68 | '68-69 | '69-70 | '70-71 | '71-72 | '72-73 |
|---|---|---|---|---|---|---|---|---|---|
| | Inches of precipitation by individual crop years | | | | | | | | |
| July | T | .64 | .02 | .37 | .11 | .54 | 1.02 | .18 | .04 |
| August | .21 | 1.47 | .47 | .11 | 3.44 | .63 | .38 | 1.20 | .34 |
| September | .19 | 2.87 | .93 | .12 | .32 | .60 | 1.32 | 1.22 | 1.56 |
| October | .60 | .05 | .43 | 1.90 | 2.03 | 1.46 | 2.61 | 4.39 | 2.52 |
| November | 1.76 | 4.45 | 1.31 | .62 | 1.88 | .32 | 3.53 | 1.30 | 1.53 |
| December | 3.68 | 1.56 | 1.71 | 2.36 | 1.32 | 1.25 | 2.78 | 2.00 | 1.62 |
| January | 1.79 | .43 | 1.63 | 1.34 | 3.31 | 1.92 | 1.94 | .83 | |
| February | 1.54 | 1.15 | .74 | 2.66 | 2.99 | .94 | 1.09 | .35 | 1.13 |
| March | .13 | 1.26 | 3.30 | 2.77 | .29 | 1.25 | 2.46 | .89 | 2.04 |
| April | 1.39 | 1.41 | 4.46 | 2.00 | 1.80 | 1.55 | 3.04 | 3.82 | 1.45 |
| May | 1.77 | 1.11 | 1.95 | 1.37 | .15 | 2.31 | 1.45 | .17 | .45 |
| June | 1.95 | .40 | 3.56 | 3.22 | 3.51 | 1.31 | 2.10 | 1.87 | |
| Total | 14.4 | 16.30 | 20.46 | 18.84 | 21.15 | 14.08 | 23.72 | 18.22 | |

Precipitation at Vernon, Utah

| | Inches of precipitation by individual crop years | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Month | '64-65 | '65-66 | '66-67 | '67-68 | '68-69 | '69-70 | '70-71 | '71-72 | '72-73 |
| July | 0.08 | 2.15 | 0.47 | 0.62 | 2.01 | - | 1.69 | 0.27 | 0.04 |
| August | 0.49 | 2.86 | - | 0.45 | 2.61 | - | - | 2.63 | 0.74 |
| September | 0.16 | 1.03 | - | 1.19 | 0.04 | - | - | 1.21 | 0.44 |
| October | 0.34 | 0.00 | - | 0.60 | 1.15 | - | 0.57 | 1.95 | 1.54 |
| November | 0.89 | 0.75 | 0.35 | 0.92 | 0.66 | - | 1.19 | 0.30 | 0.78 |
| December | 1.75 | 1.01 | 1.85 | 1.37 | 0.82 | - | 0.96 | 0.59 | 0.78 |
| January | 0.62 | 0.22 | 1.18 | 0.07 | - | 0.39 | 1.14 | 0.80 | |
| February | 0.11 | 0.73 | 0.01 | 0.54 | - | 0.43 | 0.33 | 0.07 | 0.14 |
| March | 0.53 | 0.30 | 1.22 | 0.98 | - | 0.25 | 0.95 | 0.07 | 1.21 |
| April | 0.76 | - | 0.89 | 1.06 | - | - | 0.66 | 0.56 | 0.62 |
| May | 1.54 | 0.18 | 2.54 | 0.88 | - | - | 0.51 | 0.04 | 0.51 |
| June | 0.49 | T | 1.88 | 1.15 | - | 1.62 | 0.27 | 1.27 | |
| Total | 7.76 | 9.23 | 10.39 | 9.83 | | | 8.27 | 9.76 | |

Precipitation at Snowville, Utah

| Month | Inches of precipitation by individual crop years | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | '64-65 | '65-66 | '66-67 | '67-68 | '68-69 | '69-70 | '70-71 | '71-72 | '72-73 |
| July | 0.13 | 1.38 | 0.40 | 1.42 | - | - | 1.48 | 0.05 | 0.09 |
| August | 0.42 | 1.27 | 0.72 | 0.32 | - | - | 0.21 | 0.58 | 0.17 |
| September | 0.80 | 0.61 | 0.38 | 2.60 | - | - | 1.42 | 1.33 | 1.32 |
| October | 0.09 | 0.06 | 0.01 | 0.22 | - | - | 1.08 | 0.94 | 2.25 |
| November | 1.38 | 4.03 | 1.12 | 0.52 | - | - | 1.83 | 1.60 | 1.02 |
| December | 0.56 | 0.77 | 1.38 | 0.83 | - | 0.96 | 1.04 | 1.30 | 0.62 |
| January | 1.06 | 0.32 | 1.07 | 1.41 | 2.08 | 2.04 | 1.49 | 0.44 | 1.74 |
| February | 0.56 | 0.27 | 0.20 | 1.56 | 1.25 | 0.43 | 0.38 | 0.23 | 0.50 |
| March | 0.10 | 0.45 | 1.10 | 0.64 | 0.04 | 0.44 | 0.75 | 0.58 | 1.47 |
| April | 2.29 | 0.14 | 0.41 | 0.77 | 0.04 | 0.64 | 3.91 | 0.91 | 0.87 |
| May | 0.62 | 1.59 | 0.55 | 1.20 | - | 0.90 | 2.11 | 0.12 | 0.82 |
| June | 3.23 | 0.20 | 2.43 | 0.66 | - | 1.44 | 2.45 | 0.55 | 1.92 |
| Total | 11.28 | 11.09 | 13.36 | 12.15 | | | 18.15 | 8.63 | 12.79* |

*Collected data

# VITA

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