Economics of Carry-over Response to Nitrogen Fertilization of Rangelands

JOHN P. WORKMAN AND PAUL W. McCORMICK

Highlight: Prior to the recent increases in nitrogen prices fertilization of a Utah mountain loam range site was found to be profitable when increased forage was harvested as grass hay. However, that evaluation was based only on forage response during the initial growing season. We have since observed significant carry-over response during the second and third years following fertilizer application. At the original nitrogen and hay prices studied, incorporation of carry-over into the economic analysis increased both optimum application rates and per acre profits from fertilization. Fertilization was found even more profitable at current nitrogen and grass hay prices. Insufficient data were available to determine optimum reapplication schedules, although intuitive indications favor reapplication every 2 years for sites showing profitable initial and second year carry-over response. Spring application proved superior to fall application on both sites.

Prior to the recent dramatic increases in ammonium nitrate prices, nitrogen fertilization was shown to be a profitable practice for a Utah mountain loam range site (Workman and Quigley 1974). When forage was harvested as hay, application of nitrogen at the optimum rates of 127 lb N per acre for fall application and 144 lb per acre for spring application yielded additional per-acre profits of \$3.09 and \$5.52, respectively. When increased yields were harvested directly by livestock as leased forage, nitrogen application was not profitable. In both cases, however, the analyses were based on forage response during only the initial growing season following application. From 1972 to 1974 the study was continued to determine carry-over forage production response during the second, third, and fourth growing seasons following application so that any significant carry-over response could be included in the economic analysis of range fertilization.

Site Description

Range sites studied included a mountain loam site and a semidesert loam site. The mountain loam site is situated at a 4,800-ft elevation about 0.5 mile west of Paradise, Utah. The soil is a silt loam and the vegetation is primarily seeded intermediate wheatgrass (*Agropyron intermedium*). Annual precipitation averages 16 inches, most of which

is received during the winter. The area is normally grazed by cattle in both spring and fall.

The semidesert loam site is located 11 miles north of Snowville, Utah at an elevation of 4,800 feet, and supports a pure stand of crested wheatgrass (*Agropyron cristatum*). The soil is a silt loam and average annual precipitation is 11 inches. The area is grazed by cattle on a rotational basis from April through December.

Methods

Six rates of ammonium nitrate were applied to each site during spring and fall on 10 ft × 15 ft-subplots. The statistical design consisted of three replications of each application rate and season arranged in a randomized block. Application rates were 0, 25, 50, 100, 200, and 400 lb N/acre on the mountain loam site and 0, 12.5, 25, 50, 100, and 200 lb N/acre on the semidesert loam site. Spring applications took place in 1971 on both sites. A fall application was made during 1970 on the mountain loam site and during 1972 on the semidesert loam site.

Beginning in 1971, each subplot was clipped at the end of the growing season and the harvested forage weighed to determine total air-dry forage production for the initial second, third, and fourth growing season following fertilizer application. Production equations for forage as a function of nitrogen application were estimated by stepwise regression analysis. Independent variables that showed *t*-test significance ≥ 90% were retained in the predictive equations.

Statistically significant carry-over production functions were discounted back to year of initial application at the current cost of borrowed operating capital (10%) and added to the original forage production functions to form aggregate production functions (Baum et al. 1956). Standard marginal analysis was employed to determine optimum fertilizer rates (Heady and Pezek 1954). Fertilizer application and forage harvest costs employed in the analysis of the initial growing season production function followed Doane's Agricultural Report (1972), while fertilizer and hay prices came from Christensen and Richards (1969).

Results and Discussion

Biological Response

The production function tested by stepwise multiple regression analysis for both forage production response during the initial growing season following application and carry-over response during subsequent growing seasons was:

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

where *Y* = pounds air dry forage per acre and *N* = pounds nitrogen applied per acre. Statistically significant production functions for initial and carry-over forage response to nitrogen

Authors are associate professor of range economics, Department of Range Science, Utah State University; Lake County Extension Agent, and assistant professor, Oregon State University.

The report is published with the approval of the Director, Utah Agricultural Experiment Station, as Journal Paper No. 2121.

Manuscript received September 20, 1976.

Table 1. Production functions with independent variables significant at $\geq 90\%$ probability.

Site	Season and year of application	No. of growing seasons after application	Production function	r ²
Semidesert loam	Spring, 1971	Initial (1971)	$Y = 1268 + 17.42N - .0623N^2$	.56
		Second (1972)	Insignificant	
		Third (1973)	$Y = 489 + 3.72N$	.69
		Fourth (1974)	Insignificant	
	Fall, 1972	Initial (1973)	$Y = 544 + 14.94N - .0399N^2$	.83
		Second (1974)	Insignificant	
Mountain loam	Spring, 1971	Initial (1971)	$Y = 1897 + 29.88N - .0462N^2$	.81
		Second (1972)	$Y = 1822 + 7.33N$	.70
		Third (1973)	Insignificant	
	Fall, 1970	Initial (1971)	$Y = 2515 + 26.46N - .0392N^2$	.73
		Second (1972)	$Y = 2516 + 6.05N$	.67
		Third (1973)	Insignificant	

fertilization appear in Table 1. Carry-over response on the mountain loam site was as might have been expected. Results on the semidesert loam site, however, are more difficult to explain. The absence of second-year carry-over response during 1972 followed by significant carry-over in 1973 can probably be attributed to 1972 being a dry year. Only 8.6 inches of precipitation were received as compared to the average of 11 inches.

Optimum Application Rates—

Initial Growing Season

Based on production functions for the initial growing season and prices employed in the original study (Workman and Quigley 1974), standard marginal analysis (Heady and Pezek 1954) was used to determine the most profitable nitrogen application rates. For the fall application on the mountain loam site, for example, the nitrogen application rate that would maximize per-acre profit was found by equating

$$\frac{dY}{dN} = 26.46 - .0784N$$

with the ratio of nitrogen price to the net price of forage

$$\frac{P_N}{P_Y} = \frac{.1207}{.0073}$$

Nitrogen price was based on the 1971 price of \$82.08 per ton for 34% ammonium nitrate. Forage price represents the 1971 net price of hay after subtracting the variable costs of baling and hauling. Solving for N , we obtain 127 lb N per acre. Optimum application rates for both sites and both application seasons are shown in Table 2, along with calculated per-acre profit at the optimum application rate as compared to per-acre profit without fertilizer. Profit at the optimum application rate was calculated by substituting 127 lb N into the initial production function, valuing the resulting 5,243 lb forage per acre at \$.0073 per pound and subtracting the fixed application cost of \$1.50 per acre, fixed hay swathing costs of \$3.50 per acre, and the

Table 2. Per acre profit at optimum nitrogen application rate when analysis is based only on forage response during initial growing season.

Site	Season of application	Optimum rate (lb N/acre)	Profit at optimum rate (\$/acre)	Profit without fertilizer (\$/acre)	Added profit due to fertilizer (\$/acre)
Semidesert loam	Spring	7	4.27	5.76	-1.49
	Fall	0	.47	.47	0
Mountain loam	Spring	144	15.87	10.35	5.52
	Fall	127	17.95	14.86	3.09

variable nitrogen costs of \$15.33 per acre ($.1207/\text{lb} \times 127 \text{ lb N}$). The result was an estimated per-acre profit of \$17.95. Per-acre profit without fertilizer amounted to 2,515 lb forage per acre valued at \$.0073 per pound minus fixed hay swathing costs of \$3.50 per acre, or \$14.86 per acre. Thus, the additional per-acre profit obtained from nitrogen fertilization was \$3.09.

Fertilization increased the calculated per acre profit on the mountain loam site but was not economically feasible on the semidesert loam site. Although 7 lb N per acre is the recommended rate of fertilization if nitrogen is to be applied, fertilization of the semidesert loam site proved impractical since the value of the added forage production would not pay the fixed application costs.

Spring application on the mountain loam site provided more added profit per acre than did fall fertilization (Table 2) due to higher forage response per pound of N applied (Table 1). Forage response per pound of N was also greater with spring than with fall application on the semidesert loam site. In both cases the smaller response to fall application was probably due to nitrogen losses by leaching or volatilization during the 5-month period between application and spring growth.

Forage Carry-Over Response

Both sites exhibited statistically significant carry-over responses during their second or third growth seasons following fertilization (Table 1). Accurate determinations, then, of optimum fertilization rates and of expected additional per-acre profit due to applying those rates, must include carry-over responses. Such inclusion involves discounting carry-over responses at the current cost of borrowed operating capital, 10%, back to the initial growing season following application and then summing the discounted carry-over function and the original forage response function to form an aggregate production function (Baum et al. 1956). Using the mountain loam site fall application response as an example, the second year carry-over response function is

$$Y = 2,516 + 6.05N.$$

Discounting the added forage production (6.05N only since the intercept term, 2,516, represents forage yield without fertilization) for 1 year at 10%, we obtained 5.50N, which, when added to the original response function

$$Y = 2,515 + 24.46N - .0392N^2$$

produced the aggregate production function

$$Y = 2,515 + 31.96N - .0392N^2.$$

Setting

$$\frac{dY}{dN} = 31.96 - .0784N$$

equal to

$$\frac{P_N}{P_Y} = \frac{.1207}{.0073}$$

and solving for N , we obtained a revised optimum application rate of 195 lb N per acre. Substituting the optimum application rate into the aggregate production function and using the prices and costs listed above for forage, ammonium nitrate, fertilizer application, and hay swathing indicated a \$24.44 per-acre profit at the revised optimum (Table 3), as compared to \$17.95 for the initial growing season optimum (Table 2). An even more important comparison is between the \$9.58 added profit per acre due to fertilizer (\$24.44-\$14.96) when carry-over response was included and the \$3.09 added profit per acre when the analysis was based on initial growing season response alone (Table 2). Revised optima and per-acre profitability are shown in Table 3.

Table 3. Revised per acre profit and revised optimum nitrogen application rates including carry-over response—original prices.

Site	Season of application	Aggregate production function	Optimum rate (lb N/acre)	Profit at optimum rate (\$/acre)	Profit without fertilizer (\$/acre)	Added profit due to fertilizer (\$/acre)
Semidesert loam	Spring	$Y = 1268 + 20.49N - .0623N^2$	32	4.71	5.76	-1.05
Mountain loam	Spring	$Y = 1896 + 36.54N - .0462N^2$	217	24.66	10.35	14.31
	Fall	$Y = 2515 + 31.96N - .0392N^2$	195	24.44	14.86	9.58

In all cases both optimum application rate and added profit per acre due to fertilization were increased by inclusion of carry-over response. Economic analyses of range fertilization that do not include forage response during growing seasons subsequent to initial fertilizer application underestimate application rate optima and also understate fertilization profitability.

With carry-over response included in the analysis, spring application on the mountain loam site showed an even more striking advantage by providing an increased per-acre profit of \$14.31 versus \$9.58 per acre increased profit with fall application (Table 3).

Our calculations showed nitrogen fertilization to remain unprofitable when increased production was valued at \$6 per AUM (U.S. Dep. Agr. 1976) as leased forage to be used directly by livestock.

Optimum application rates and per-acre profits at current prices (Table 4) were calculated using \$171 per ton of 34% N ammonium nitrate (\$.2525/lb N), \$31 per ton of hay or \$.0155 per lb (*net* price based on a market price of \$45 per ton of grass hay minus \$9 per ton for baling minus \$5 per ton for hauling), swathing costs of \$5 per acre and fertilizer application costs of \$2 per acre (Utah Agricultural Statistics 1976). When increased production was valued as harvested hay, fertilization of both sites studied was more profitable at current than at original prices studied (Table 4). This is due to the increased net price of grass hay which compensated for the recent sharp increase in ammonium nitrate prices.

Table 4. Optimum application rates and per acre profit including carry-over response—current prices.

Site	Season of application	Optimum rate (lb N/acre)	Profit at optimum rate (\$/acre)	Profit without fertilizer (\$/acre)	Added profit due to fertilizer (\$/acre)
Semidesert loam	Spring	34	13.79	14.65	-0.86
	Fall	0	3.43	3.43	0
Mountain loam	Spring	220	57.02	24.39	32.63
	Fall	201	56.45	33.98	22.47

Spring application again proved superior to fall application on both sites. Comparison of Tables 3 and 4 reveals that although calculated per acre profits from fertilization are much higher at current than at the original prices studied, optimum application rates are almost identical.

Optimum Reapplication Schedule

Determination of optimum reapplication schedules for sites showing profitable initial and second year carry-over responses to fertilization requires the following information: (1) initial and second year carry-over response to fertilizer application when the site has *not* been fertilized previously or when there is *no* carry-over response still present from previous applications, and (2) initial and second year carry-over response when second year carry-over response from application during the previous year *is* still present. Our study provides the necessary data for (1) but not for (2), which would have necessitated a

doubling in both number of sample plots and number of growing seasons studied. Key comparisons underlying fertilizer reapplication decisions when data for both (1) and (2) are available are shown in Table 5.

Table 5. Comparisons underlying fertilizer reapplication decisions for sites showing profitable initial and second year carry-over response.

Initial year (1971)	Second year (1972)	Third year (1973)
(a) Net return to 1971 response to 1971 application and discounted 1972 second year carry-over response	(a) Net return to 1972 second year carry-over response and discounted 1973 net return when not fertilized	If no fertilizer applied in 1972: (a) Net return to 1973 response to 1973 application and discounted 1974 second year carry-over
Versus	Versus	Versus
(b) Net return in 1971 when not fertilized	(b) Net return to 1972 <i>initial</i> response and discounted 1973 second year carry-over response from 1972 application <i>plus</i> net return to 1972 second year carry-over response from 1971 application	(b) Net return in 1973 when not fertilized

The 1971 decision represents the most simple case. The site in question has either not been fertilized previously or, if prior application has taken place, carry-over response is no longer present. The decision as to whether or not to apply fertilizer would be based simply on a comparison of net returns to initial and discounted 1972 carry-over response from the 1971 application versus 1971 net return in the absence of fertilizer application.

Provided that fertilization was found to be profitable and application was made in 1971, the 1972 reapplication decision would be more complex. In this case the net return of 1972 second year carry-over response from the 1971 application plus the discounted net return during 1973 (when not fertilized and with no significant third year carry-over) would be compared to net return to 1972 initial response from 1972 reapplication plus the discounted net return to 1973 second year carry-over from 1972 reapplication *plus* the net return to 1972 second year carry-over response from the 1971 application.

If no fertilizer were applied in 1972, the 1973 reapplication decision would be identical to that described for the original application decision of 1971. In the absence of significant carry-over from the 1971 application, the 1973 decision would be between the sum of net return to 1973 initial and discounted 1974 second year carry-over response to 1973 reapplication compared to net return in 1973 in the absence of fertilizer.

Our study did not provide sufficient data to make the

comparisons outlined in Table 5. Since forage production response to reapplication in the *presence* of carry-over from a previous application is an unknown, the optimum reapplication schedule could not be calculated. Due to the quadratic nature ("law of diminishing returns") of the production functions estimated for the initial growing season after application, reapplication would undoubtedly have provided less added forage production than resulted from our initial application. While the diminished response cannot be quantified with the data available, the near certainty that response to reapplication would have been less than response to our initial application leads to an intuitive comment concerning determination of an optimum reapplication schedule. It appears that on sites that show profitable response to fertilization for both the initial growing season and second year carry-over, the optimum reapplication schedule is every 2 years.

Summary and Conclusions

Two Utah range sites that responded significantly to nitrogen application during the initial 1971 growing season also exhibited significant second or third year carry-over responses. At the original hay and nitrogen prices studied, incorporation of carry-over into the analysis increased both optimum application rates and per-acre profitability from range fertilization. Economic studies that do not include carry-over response underestimate optimum fertilizer rates and also understate profitability.

Although ammonium nitrate recently increased from the \$82 per ton price tested originally to the current price of \$171 per ton, the net price of grass hay has gone from \$14.69 per ton to

\$31. As a result, nitrogen fertilization of the mountain loam site for the purpose of increasing grass hay production is even more profitable now than when originally evaluated. At the current Utah price of \$6 per AUM, however, fertilization of rangeland to be harvested as leased forage remains unprofitable.

Determination of optimum fertilizer reapplication schedules requires data concerning initial and carry-over responses to nitrogen in the *absence* of previous fertilizer application as well as a measure of initial and carry-over responses in the *presence* of carry-over from previous fertilization. Although our experiment did not provide the latter data, intuitive indications favor reapplication every 2 years for sites showing profitable initial and second year carry-over response.

Literature Cited

- Baum, E. L., E. O. Heady, and J. Blackmore (Ed.). 1956. Methodological procedures in the economic analysis of fertilizer use data. Iowa State Univ. Press, Ames.
- Christensen, R. A., and S. H. Richards. 1969. Price trends for decision making in agriculture—Utah 1969. Utah Agr. Exp. Sta. Resources Series 49.
- Doane's Agricultural Report. 1972. Machinery custom rates. Doane's Agr. Rep. 35(11-5):303-306.
- Heady, E. O., and J. T. Pesek. 1954. A fertilizer production surface with specification of economic optima for corn grown on calcareous silt loam. J. Farm Econ. 36:446-482.
- U.S. Department of Agriculture. 1976. Farm market real estate developments. Economic Res. Serv. CD-18, July. 37 p.
- U.S. Department of Agriculture and Utah Crop and Livestock Reporting Service. 1976. Utah Agricultural Statistics. Salt Lake City, Utah. 106 p.
- Workman, John P., and Thomas M. Quigley. 1974. Economics of fertilizer application on range and meadow sites in Utah. J. Range Manage. 27: 390-393.

Rangeland Plant Physiology

edited by Ronald A. Sosebee

- 290 pages
- illustrated
- soft cover perfect bound
- extensive bibliographies
- \$12.00 postpaid

In nine chapters, RANGELAND PLANT PHYSIOLOGY discusses the characteristic life processes, activities, and functions of the rangeland plant.

Of particular interest to all who study, manage, or simply admire plant life, the book is a valuable college text supplement and a reference source for range managers and technicians. Each chapter, authored by one or more authorities in the field, examines in considerable depth one aspect of plant physiology. Chapters include:

I. Gas Exchange in Photosynthetic Pathways in Range Plants; II. Carbohydrate Translocation in Range Plants; III. Distribution and Utilization of Carbohydrate Reserves in Range Plants; IV. Water Relations of Range Plants; V. Salinity Effects on Range Plants; VI. Seed Physiology; VII. Plant Growth Regulators; VIII. Mineral Cycling in Rangeland Ecosystems; IX. Developmental Morphology and Management Implications.

Society for Range Management
2760 West Fifth Ave.
Denver, Colorado 80204

WHEN YOU'RE THINKING OF
NATIVE GRASSES

THINK OF
SHARP BROS. SEED CO

SHARP BROS. SEED CO.
Healy, Kansas 67850
Phone (316) 398-2231

CLYDE ROBIN
NATIVE SEEDS

Castro Valley, California 94546