Economics of Range Fertilization in Eastern Oregon

Circular of Information 673
October 1978

Agricultural Experiment Station
Oregon State University, Corvallis

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ECONOMICS OF RANGE FERTILIZATION IN EASTERN OREGON

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SUMMARY

The primary objective of eastern Oregon range fertilization is increased forage production at competitive costs. However, other benefits are often possible. Increased forage utilization, an increase in plant vigor, and a reduction in soil erosion possibly can be achieved. In some cases, fertilization increases total crude protein and digestible nutrients of the forage. An indirect benefit of fertilization, often requiring additional management input, is increased animal distribution and, thus, forage utilization on adjacent under-utilized, non-fertilized range. This also may reduce grazing pressure on fertilized range areas.

A potentially negative effect of fertilization is a change in species composition. For example, on sites containing cheatgrass, fertilization leads to retrogression of the site. Also, large increases in forage production frequently are made up of less desirable forage species. Several other factors not well identified are the possible shortening of the growing season because of earlier maturity of fertilized grasses, the possibility of decreasing plant vigor through fertilization in below average rainfall years, and the possible increase in grazing pressure created by certain wildlife species.

To determine which fertilizers and application rates recover the cost of fertilization, forage responses to fertilization were economically analyzed. The responses were identified by using a literature survey of fertilization research which fits eastern Oregon rangelands.

Yield responses to fertilization of native, high desert range varied from a 6-pound yield increase at 15 pounds of nitrogen per acre on a poor condition range site to a 77-pound yield increase at 30 pounds of nitrogen on good condition range. Nitrogen fertilization did not result in positive returns to fertilization at a yield response valued at $40 per ton. A forage response of about 400 pounds per acre was needed at 15 pounds of nitrogen just for the present value of forage to equal fertilization costs, assuming no change in forage value or increase in forage utilization. Native, high desert range was judged least likely of the range types evaluated to produce returns in excess of fertilization costs. Nitrogen fertilization also was found to promote cheatgrass development at the expense of native grasses

Compared to native range, yield responses to nitrogen fertilization of seeded, high desert range were more substantial. Yield increases ranging from 103 pounds per acre from an application of 10 pounds of nitrogen to 900 pounds from an application of 20 pounds of nitrogen were reported. Yield responses, however, varied among years, sites, and grass species and were interrelated with winter precipitation. During periods of below average precipitation, nitrogen stimulated only a small yield increase in the first production year after fertilization, but significant yield increases from nitrogen carryover were evident the following year. Nitrogen also promoted the development of cheatgrass. The largest net return to fertilization was achieved with 40 pounds of nitrogen with a yield response valued at $40 per ton. Greater net returns, however, might be attained at even larger application rates, but this could not be confirmed from the data. The present value of nitrogen fertilization at the 40-pound rate would just equal the present cost of fertilization, even if the value of the yield response was only about $36 per ton.

Responses to fertilization of native, foothill ranges were highly variable. Much of this variability came from site factors and precipitation levels. On drier sites, 60 pounds of nitrogen increased yield an average of 300 pounds per acre. On sites with more favorable precipitation, yield increases ranged from 200 pounds per acre with the application of 30 pounds of nitrogen to 990 pounds per acre with the application of 120 pounds of nitrogen per acre. On many of the drier sites, cheatgrass made the biggest yield increase to fertilization. Fertilization of steeper slopes also induced heavier grazing on these sites. Although phosphorus and sulfur in combination with nitrogen significantly increased yields, only the application of 60 pounds of nitrogen showed a return over fertilization costs at a yield response valued at $40 per ton. However, nitrogen application rates ranging from 40 to 80 pounds may produce even greater returns, but this could not be determined from the data. Even if the value of the yield response was only about $35 per ton, the present value of the yield response would still equal the present cost of nitrogen fertilization at the 60-pound rate.

Although yields were biased downward because of early season grazing, yield responses of seeded foothill range receiving 12 to 15 inches of precipitation ranged from 250 pounds per acre with the application of 30 pounds of nitrogen to 510 pounds per acre with the application of 120 pounds of nitrogen per acre. On sites receiving more than 15 inches of precipitation annually, yield increases were noted even at an application rate of 140 pounds of nitrogen. Based on yield data affected by early harvest, fertilization did not produce a return exceeding fertilization costs. Some level of fertilization, however, might produce a positive net return, particularly if harvest is delayed until later in the growing season. A yield response of only about 570 pounds per acre valued at $40 per ton would be required to produce a positive net return to fertilization with an application of 30 pounds of nitrogen per acre. This response, or even a larger one, could be obtained on many seeded, foothill range sites in eastern Oregon.

Yield responses to fertilizing native, mountain meadows ranged from nonsignificant to highly significant responses. With an application of 90 pounds of nitrogen, yield response was only 80 pounds per acre at one site and 600 pounds at another location. The average yield increase from 16 mountain meadow areas approached 770 pounds of air dry forage per acre with an application of 80 pounds of nitrogen per acre. Based on average yield responses and a yield response valued at $40 per ton, fertilization of native, foothill meadows did not produce a positive net return to fertilization. On responsive sites, however, the application of 30 pounds of nitrogen produced a positive net return to fertilization.

Only nitrogen significantly increased yield of seeded mountain meadows. The greatest yield increase was 1,370 pounds per acre with an application of 60 pounds of nitrogen per acre. The largest net return to nitrogen fertilization at a yield response valued at $40 per ton was achieved at the 60-pound rate. Nitrogen rates of 70 or 80 pounds may produce even greater net returns, but this could not be determined from the data. Even if the value of the yield response was only about $35 per ton, the present value of the yield response would still equal the present cost of nitrogen fertilization at the 60-pound level.

Native flood meadows were found to be responsive to fertilizer, although not all meadows responded equally well. Nevada bluegrass and rush-sedge-grass meadows showed the greatest response to nitrogen. Mixed clover-rush-sedge meadows showed the greatest response to phosphorus. At 21 sites, mean yield responses to applications of 60 and 120 pounds of nitrogen were 0.75 and 1.15 tons per acre, respectively. At still other locations, yield responses approached 2.0 tons per acre with applications of 200 pounds of nitrogen or more. Applications of 18 pounds of phosphorus produced maximum yield responses of 0.3 to 0.4 tons per acre. Nitrogen changed the botanical composition of meadows by stimulating rush-sedge components, while phosphorus stimulated the annual whitetip clover component. Nitrogen had no effect on yield until late May; thereafter, yields increased until about mid-July. No single source of nitrogen was superior for fertilizing flood meadows. Fall and spring applications were equally effective, but spring application must be completed prior to June to attain maximum yield response. Minor elements did not influence yields when applied alone or in combination with nitrogen or phosphorus. Neither nitrogen or phosphorus stimulated regrowth after harvest, but nitrogen with supplemental irrigation after harvest stimulated regrowth.

A nitrogen rate of 200 pounds per acre at a yield response valued at $40 per ton resulted in the largest net return to the fertilization of native flood meadows. Even on mixed clover meadows, nitrogen fertilization appears to produce larger returns to fertilization than phosphorus fertilization. Nitrogen rates exceeding 200 pounds may result in even greater returns to fertilization, but this could not be determined from the data. Even if the value of the yield response was only about $27 per ton, the present value of the forage response would just equal the present cost of fertilization at a nitrogen rate of 200 pounds per acre. Of the range types evaluated, native flood meadows were most responsive to nitrogen fertilizer and judged most likely to result in returns to fertilization that exceed fertilization costs.

INTRODUCTION

Increased use of fertilizers on rangelands of eastern Oregon might provide the necessary stimuli for more intensive utilization of the area's range and range-related resources. But, is fertilization of these ranges economical, at what rate, and under what conditions? This report, based on previous fertilization research appropriate to Oregon range conditions, addresses these types of questions. The information should be helpful to ranchers considering range improvements through fertilization, Extension personnel in rangeland management, public land managers, and researchers contemplating rangeland fertilization research.

This report identifies anticipated responses of rangeland fertilization on high desert, foothill, and native flood meadow rangelands of eastern Oregon. The economics of fertilizing established rangelands is evaluated. Also identified and discussed, but not considered in the economic analysis, are important interrelationships between fertilization and forage composition, shrub growth, soil erosion, and other management practices.

RESPONSE TO FERTILIZATION

High Desert Range

The high desert shrub, also frequently called the cold desert shrub or intermountain shrub, covers approximately one-fourth of the state of Oregon. This loosely defined region includes the sagebrush-bunchgrass and salt desert shrub ranges. Average precipitation rarely exceeding 11 inches--coupled with hot, dry summers--characterizes the arid conditions of these ranges.

The response of sagebrush-bunchgrass ranges to nitrogen has been studied over a four-year period at the Squaw Butte Experimental Range in eastern Oregon. A yield increase of 77 pounds of 12 percent moisture forage per acre at 30 pounds of nitrogen indicated to Sneva (1963) the limited response of previously sprayed range judged to be in good condition. Nitrogen also caused changes in plant composition from perennial plants to cheatgrass (Bromus tectorum) at all (20, 30, 40 and 50 pounds N per acre) nitrogen levels applied. On a sagebrush (Artemisia tridentata) site in poor condition, 15 pounds of nitrogen per acre increased herbage yield only six pounds per acre, while 30 pounds actually depressed yield.

A larger data base is available on response to fertilization of seeded ranges in the high desert. Sneva et al, (1958), after a 4-year study of the influence of nitrogen on crested wheatgrass (Agropyron desertorum) yields, reported that the rate of nitrogen, year, and year-nitrogen interaction significantly affected mature yields (Table 1). Response varied among years and was related to winter precipitation between November 1 and June 1. Significant yield increases from nitrogen carryover occurred only in years following a near normal or dry year. No third year yield increases from nitrogen carryover were found. All plots started growth at the same time, but the growth rate of fertilized grasses was faster; 69 and 44 percent of the season's growth of fertilized and unfertilized grasses, respectively, occurred prior to June 1. Fertilized grasses also depleted soil moisture more rapidly than unfertilized grasses and, as a result, fertilized grasses matured earlier. Fertilization, however, increased efficiency of soil moisture use by plants.

In other fertilizer trials on the Oregon high desert, Sneva and Hyder (1965) also reported that yield response to nitrogen fertilization was closely correlated to annual levels of precipitation. During a period of below average

TABLE 1: Mature yield of crested wheatgrass range on the Oregon high desert as influenced by nitrogen fertilizer (Sneva, et al, 1958)

Year fertilized and yield year	Pounds of N per acre 0	10	20	30	40	LSD a/ 5%
	Yield: pounds per acre at 12% moisture					
1953						
1st year	1,053	1,043	1,628	1,551	1,985	257
2nd year	640	568	578	616	565	NS b/
1954						
1st year	707	803	920	1,021	1,093	251
2nd year	438	473	475	512	498	NS b/
1955						
1st year	373	476	506	520	452	NS b/
2nd year	1,364	1,615	1,972	2,206	2,409	287
Averages						
1st year	711	774	1,017	1,031	1,176	118
2nd year	814	885	1,008	1,111	1,157	129

a/ Least significant difference.

b/ Non-significant.

precipitation, Sneva (1963) found application of nitrogen stimulated only a small increase in crested wheatgrass production.

Hedrick et al, (1964) found that fertilization at Squaw Butte with 30 pounds of nitrogen per acre increased seeded range yields about 45 percent, but yield effects varied among grass species (Table 2). Crested and streambank wheatgrasses responded better and more consistently to nitrogen than other species. In trials with crested wheatgrass at Fort Rock and Diamond, Oregon, 20 pounds of nitrogen increased oven dry yield 900 pounds per acre, and 30 pounds increased oven dry yield 700 pounds per acre, respectively.

TABLE 2: Herbage yields of grasses planted alone and in mixtures on the Oregon high desert as influenced by nitrogen fertilization (Hedrick et al, 1964)

Species	Nitrogen fertilization rate pounds N per acre 0	30
	Mean yield: pounds oven dry forage per acre	
Crested wheatgrass	1,383	2,012
Beardless wheatgrass	1,125	1,360
Big bluegrass	1,042	1,382
Streambank wheatgrass	690	1,281
Canby bluegrass	193	177
Crested wheatgrass-streambank wheatgrass	1,355	1,854
Beardless wheatgrass-streambank wheatgrass	943	1,326
Big bluegrass-streambank wheatgrass	860	1,237
Crested wheatgrass-canby bluegrass	1,285	1,836
Beardless wheatgrass-canby bluegrass	795	1,420
Big bluegrass-canby bluegrass	832	1,079
Significant ranges at 5% level	411	

In a more recent paper, Sneva and Rittenhouse (1976) reported that the most efficient nitrogen rate for seeded range on the Oregon high desert was 20 pounds per acre, increasing yield by 64 percent (Table 3). Forage production increases

TABLE 3: Mean herbage yield of crested wheatgrass on the Oregon high desert on May 15 (Sneva and Rittenhouse, 1976)

N rate pounds per acre	Mean yield pounds air dry forage per acre
0	497 e/
20	814 b,c,d
30	795 c,d
50	850 a,b,c,d
80	882 a,b,c

Values designated by the same superscript are not significantly different from each other at the 5 percent level.

were statistically significant for all levels of nitrogen fertilization. Their data also showed a more rapid rate of soil moisture depletion on fertilized plots. However, at rates of 20 pounds of nitrogen per acre, soil moisture depletion did not greatly differ from control plots.

Nitrogen fertilization of Oregon high desert range was found to increase the crude protein content of crested wheatgrass (Hyder and Sneva, 1961). The largest differences in crude protein occurred during the first part of the growing season when protein levels were adequate for both treatments (Table 4). As forage matured, the advantage in crude protein content of fertilized grasses diminished. Sneva (1973) found that crude protein content of crested wheatgrass at maturity was about the same regardless of whether nitrogen was applied.

Nitrogen fertilization of seeded range, according to Sneva et al, (1958), also promoted growth of cheatgrass which directly influenced yield. The stimulation of cheatgrass production from nitrogen fertilization also was observed by Wilson et al, (1966) in southeastern Washington, with fertilized bluebunch wheatgrass (*Agropyron spicatum*) stands, Patterson and Youngman (1960) in central Washington, and Sneva (1963) on native rangelands of the Oregon high desert.

Nitrogen fertilizer also has been reported to affect sagebrush establishment on seeded, crested wheatgrass range on the Oregon high desert (Hyder and Sneva, 1961). In wet years, nitrogen has been known to improve conditions for sagebrush establishment; dry years have reduced establishment and increased mortality. The net effect on sagebrush from fertilizing poor condition range with nitrogen has been an increase in sagebrush density. No accumulative response was observed on sprayed, fair condition range, while a decrease in sagebrush density was noted on seeded range. Sneva (1963) later concluded that the short run effect on sagebrush numbers from nitrogen fertilizer of high desert range is probably small.

Additional fertilization work has been done in central Washington on bunchgrass ranges. However, climate on these ranges tends to be somewhat milder than

TABLE 4: Yield and crude protein content of crested wheatgrass on the Oregon high desert as influenced by nitrogen fertilizer and date of harvest (Hyder and Sneva, 1961)

Pounds N per acre	0			30		
Harvest date	Yield pounds per acre at 12% moisture	Crude protein %	Crude protein pounds per acre	Yield pounds per acre at 12% moisture	Crude protein %	Crude protein pounds per acre
May 7	356	16.1	57	530	23.1	122
21	490	12.1	59	952	17.6	168
June 4	970	9.4	91	1,830	10.2	187
18	1,344	6.1	82	2,973	7.4	220
July 1	1,480	4.8	71	2,785	6.0	167
16	1,576	3.3	52	3,000	3.7	111
30	1,423	2.6	37	2,911	3.4	99
Sept. 9	1,350	2.0	27	2,333	2.4	56

the climate of the Oregon high desert. These experimental sites receive an average of 12 to 13 inches of precipitation annually. Patterson and Youngman (1960) reported an increase in production on native ranges when fertilized with nitrogen (Table 5). Yield response to nitrogen, however, varied among years. In 1955, for example, 40 pounds of nitrogen per acre produced a total oven dry yield of 640 pounds per acre as compared to a total oven dry yield of 1,550 pounds in 1956. Increased rates of nitrogen promoted cheatgrass development at the expense of native grasses. Idaho fescue and bluebunch wheatgrass were greatly reduced by cheatgrass competition.

TABLE 5: Herbage production and cheatgrass development on native range of central Washington as influenced by nitrogen fertilization (Patterson and Youngman, 1960)

Pounds of nitrogen per acre	1953	1954	1955	1956	1957	Mean yield	Cheatgrass composition in 1957
	Yield:	Pounds oven dry	forage per acre				%
0	410	430	330	860	660	538	13
20	580	780	640	1,280	1,040	864	47
40	1,080	940	640	1,550	1,240	1,090	58
60	970	840	700	890	690	818	78
80	1,190	940	660	730	720	848	82

On a bluebunch wheatgrass, Sandberg bluegrass (Poa sandbergii) range in southeastern Washington, Wilson et al, (1966) reported similar yield responses. Nitrogen fertilization increased total forage production on these sites. However, the investigators found that heavy nitrogen fertilization caused bluebunch wheatgrass yields to decrease, while cheatgrass yields increased 400 to 600 percent. The increase of cheatgrass occurred regardless of the density of bluebunch wheatgrass.

Patterson and Youngman (1960), in a five-year study in central Washington on the influence of nitrogen on crested wheatgrass yields, also confirmed the nitrogen-yield response work of Sneva et al, (1958). In these experiments (Table 6), nitrogen levels ranging from 0 to 80 pounds per acre were applied to seeded, crested wheatgrass stands receiving 12 to 13 inches of precipitation annually.

TABLE 6: Mature yield of crested wheatgrass range in central Washington, as influenced by nitrogen fertilizer (Patterson and Youngman, 1960)

	Pounds N per acre				
Year	0	20	40	60	80
	Yield pounds oven dry forage per acre				
1953	2,130	2,680	3,350	4,020	4,180
1954	1,050	1,450	2,160	2,390	2,570
1955	850	1,180	1,870	1,780	1,310
1956	1,120	1,150	2,550	3,420	3,680
1957	970	990	1,590	2,040	3,050
Mean yield	1,220	1,490	2,300	2,730	2,960

Mason and Miltimore (1959) reported large responses of bluebunch wheatgrass to nitrogen fertilization on a British Columbia area receiving 11 inches of precipitation. Annual rates of nitrogen from 0 to 60 pounds per acre increased annual forage production on an oven dry basis from 640 to 1,060 pounds per acre in 1957 and from 678 to 1,725 pounds in 1958. They also found ground cover of bluebunch wheatgrass increased from 4.6 to 6.8 percent on fertilized plots.

In northeastern California, Kay and Evans (1965) reported a four-year fertilizer trial on rangeland seeded to intermediate wheatgrass (Agropyron intermedium). Prior to seeding, these sites were vegetated by big sagebrush, cheatgrass, squirreltail (Sitanion hystrix), and Sandberg bluegrass. The area is somewhat comparable to Oregon's high desert with a climate characterized by dry, hot summers and 10-inch average annual rainfall. The investigators found that fertilization favored cheatgrass. High rates of nitrogen fertilization, coupled with below average moisture, were the principal factors causing a reduction in intermediate wheatgrass. It should be noted that intermediate wheatgrass is normally planted on moister sites. Fertilization did not increase production in the two drier years but did significantly increase yield in the year receiving average precipitation.

Conclusion: Responses to fertilization on high desert ranges have been highly variable. Effects of fertilization on yields of native range varied from a six-pound (12 percent moisture) yield increase at 15 pounds of nitrogen per acre on a poor condition range site to a 77-pound (12 percent moisture) yield increase at 30 pounds of nitrogen per acre on good condition range. These responses are markedly different from yield increases ranging from 326 to 1,725 pounds of oven dry forage per acre found by fertilizing native ranges in Washington and British Columbia. These latter two sites, however, have climates which tend to be somewhat milder and, therefore, more productive than that characterizing the eastern Oregon high desert. Nitrogen fertilization of native, high desert ranges was found to have only a small effect on sagebrush density, but it did promote cheatgrass development at the expense of native grasses.

Effects of fertilization on yields of seeded, high desert range are more substantial than on native, high desert range. Yield increases ranging from 103 pounds of 12 percent moisture forage per acre at 10 pounds of nitrogen per acre to 900 pounds of oven dry forage at 20 pounds of nitrogen per acre have been reported. Yield responses, however, have varied among years, sites, and grass species and were interrelated with winter precipitation. During periods of below average precipitation, nitrogen fertilization was found to stimulate only a small yield increase in the first year of production after fertilization, but a significant yield increase from nitrogen carryover was noted the following year. No third year yield increases from nitrogen carryover were found. Of grass species, crested and streambank wheatgrasses responded better and more consistently to nitrogen than other species. Nitrogen fertilization also promoted faster growth of grasses, improved ground cover, and grasses matured faster. At higher rates of fertilization, soil moisture was more rapidly depleted. Fertilization, however, increased efficiency of soil moisture use. Crude protein content was higher early in the growing season with fertilization but diminished with forage maturity. At maturity, the crude protein content of crested wheatgrass was similar for fertilized and non-fertilized grasses. Nitrogen fertilization also has promoted the development of cheatgrass

Foothill Range

Native foothill rangelands is a term that covers numerous plant communities and site potentials. These sites are usually found above the desert floor and below the coniferous forest. Foothill rangelands are generally inclusive of most of the juniper, mid-elevation sagebrush species and certain mountain brush sites. Bunchgrasses are the primary grasses endemic to these sites. Mean precipitation, although highly variable, is more commonly 10 inches or above. Climatic conditions generally are not as harsh as the high desert.

In Utah, Cook (1963) reported that the addition of 60 pounds of nitrogen per acre increased herbage yields on nine native foothill range sites an average of 300 pounds of oven dry forage per acre. Fertilization on the steeper slopes (60 pounds of N per acre) also induced heavier grazing on these areas. However, Cook reported that it was usually necessary to drift animals on these fertilized areas to obtain any appreciable use and that once on these areas, cattle used them more intensely.

In fertilizer trials in central Utah on seeded, crested and pubescent wheatgrass (Agropyron trichophorum) foothill ranges receiving about 12 inches of precipitation annually, Cook (1965) reported that nitrogen and nitrogen in combination with phosphorus significantly increased yields (Table 7). Phosphorus alone, however, did not significantly increase yield. No yield increases from fertilizer carryover were observed. In other experiments at higher nitrogen rates, Cook concluded that 40 pounds of nitrogen increased yield as much as the 80-pound rate. At both 40 and 80-pound nitrogen rates, significant yield increases from nitrogen carryover were observed in the second year after fertilization but not in the third year.

In Cook's experiments in central Utah (Table 7), nitrogen (40 pounds per acre) produced about 70 percent more total protein and about 30 percent more total digestible nutrients per acre than unfertilized plots. The 20-pound nitrogen rate also increased protein and TDN content but to a smaller extent. Although TDN was increased, percent TDN remained at about 60 percent. Percent crude protein increased from 8.6 to 11.4 percent at the 40-pound nitrogen - 40-pound phosphorus rate. Phosphorus appeared to have only a slight effect on total protein and digestible nutrients.

TABLE 7: June 10 yield, protein, and digestible nutrient response of crested and pubescent wheatgrass foothill range in central Utah as influenced by nitrogen and phosphorus fertilizers (Cook, 1965)

	Yield: pounds oven dry forage per acre		
Treatment pounds per acre	Yield	Total protein	Total digestible nutrients
0	944	81.2	557.0
20N	1,259**	125.9	754.1
20P	942	72.5	580.3
20N-20P	1,133*	114.4	680.9
40N	1,294**	138.5	732.4
40P	1,011	86.9	590.4
40N-40P	1,345**	153.3	801.6

* Significantly different from the check plot yield at the 5 percent level.
** Significantly different from the check plot yield at the 1 percent level.

Cook also reported that on crested and pubescent wheatgrass foothill ranges of Utah, fertilization promoted more uniform grazing, even several years after fertilizer application (Table 8). These findings confirmed the earlier work of Smith and Lang (1958). Cook (1958) cautioned, however, that increased utilization in later years might not be entirely a result of fertilization. Degree of use the previous year has a profound effect on palatability the following year. Heavier grazing, Cook noted, results in less old plant growth in following years.

TABLE 8: Forage utilization of crested and pubescent wheatgrass on foothill ranges of central Utah as influenced by fall applied nitrogen and phosphorus fertilizer (Cook, 1965)

Treatment	20N	40N	20P	40P	20N 20P	40N 40P	Check
Harvest date				% utilization			
July 8, 1958	43.0*	49.6**	25.5	26.5	45.4 *	60.9**	26.0
July 30, 1958	51.5*	63.6**	32.6	32.5	52.0 *	68.6**	35.3
July 29, 1959	49.6*	61.0**	27.4	29.8	46.2*	63.8**	27.2
July 20, 1960	58.3*	57.5**	47.4	47.9	55.4**	58.9**	43.8

* Significantly different from check results at the 5 percent level.
** Significantly different from check results at the 1 percent level.

Also in Utah, Workman and Quigley (1974) reported large responses of crested wheatgrass to nitrogen fertilization on foothill range receiving about 16 inches of precipitation in the year of the fertilizer trial. At 140 pounds of nitrogen, the yield response was about 1,218 pounds of air dry forage per acre. Yield increases from nitrogen carryover were also significant (Workman and McCormick, 1977). Phosphorus had no effect on yield. At a drier site, neither nitrogen nor phosphorus significantly influenced yield.

Pumphrey and Hart (1973) reported results from fertilizer experiments on native and seeded foothill ranges and meadows in northeastern Oregon. They found yields on native bunchgrass rangeland were significantly increased by nitrogen alone and in combination with phosphorus and sulfur (Table 9). Yield increases from nitrogen carryover varied by site and nitrogen application rate. At 90 and 120 pounds of nitrogen, yield increases from nitrogen carryover were statistically significant regardless of site. Sites received about 22 inches of precipitation annually. On drier locations, only small increases in growth of crested wheatgrass and native grasses were observed. Cheatgrass appeared to make the biggest yield increases on the fertilized plots.

TABLE 9: Yield of native grass and forbs on foothill rangelands in northeast Oregon as influenced by fertilization (Pumphrey and Hart, 1973)

Treatment pounds per acre	Site I Year fertilized	Site I Following year	Site II Year fertilized	Site II Following year
	------- Yield pounds oven dry forage per acre ----------			
0	1,370	1,150	1,250	1,050
30N	1,970	1,250	1,450	1,070
60N	2,230	1,630	1,950	1,170
90N	2,080	1,740	2,060	1,480
120N	2,120	1,670	2,240	1,700
20S	1,340	1,220	1,290	1,070
60N-20S	2,240	1,190	2,170	1,360
60N-80P-20S	2,390	1,280	2,010	1,250
LSD 5% a/	520	290	600	305

a/ Least significant difference.

On seeded range receiving about 15 inches of precipitation, Pumphrey and Hart (1973) reported nitrogen fertilizer significantly affected forage production (Table 10). Yields were slightly but not significantly higher where sulfur fertilizer was applied alone or in combination with nitrogen fertilizer. Total yield observed in this trial is probably biased downard, because the site was pastured nearly a month in early spring.

TABLE 10: Yield of seeded range in northeast Oregon as influenced by fertilizer (Pumphrey and Hart, 1973)

Treatment	Yield
	Pounds oven dry forage per acre
0	720
30N	970
60N	1,050
90N	1,120
120N	1,230
20S	800
60N-20S	1,080
60N-80P-20S	1,060
LSD 5% a/	180

a/ Least significant difference.

<u>Conclusions:</u> Responses to fertilization on foothill rangelands have been highly variable. Much of this variability is from site factors and precipitation levels. On drier, native foothill ranges, 60 pounds of nitrogen per acre increased yield an average of 300 pounds of oven dry forage per acre; on sites with more favorable precipitation (22 inches annually), yield increases have ranged from 200 pounds of oven dry forage per acre at 30 pounds of nitrogen to 990 pounds of oven dry forage per acre at 120 pounds of nitrogen per acre. At these latter locations, phosphorus and sulfur in combination with nitrogen also increased yield, but usually the yield response was small and not statistically significant. On many of the drier sites, cheatgrass appeared to make the biggest yield increase on fertilized plots. Fertilization also induced heavier grazing on steeper sites. Significant yield increases from nitrogen carryover also were noted at nitrogen application rates of 90 and 120 pounds per acre.

On seeded foothill range receiving an average of 12 to 15 inches of precipitation annually, yield responses ranged from 250 pounds of oven dry forage per acre with 30 pounds of nitrogen per acre to 510 pounds of oven dry forage per acre with 120 pounds of nitrogen. On many of these sites, 40 pounds of nitrogen stimulated growth as much as 80 pounds of nitrogen. Phosphorus in combination with nitrogen also influenced yield. Yield increases from nitrogen carryover were significant in the second year after fertilization at nitrogen applications of 40 pounds or more per acre. Nitrogen fertilization also produced about 70 percent more total protein and 30 percent more TDN per acre than unfertilized plots. Increased TDN production was a result of increased forage yield, while protein production was a result of both increased yield and a higher crude protein content (8.6 percent crude protein non-fertilized versus 11.4 percent crude protein fertilized grasses). Nitrogen alone and in combination with phosphorus promoted more uniform grazing, even several years after fertilizer application.

At sites receiving more than 15 inches of precipitation annually, yield increases were noted even at an application rate of 140 pounds of nitrogen per acre. Phosphorus had no effect on yield.

Mountain Meadows

Responses of native mountain meadows to fertilizer were studied in Utah by Cook (1965). In these experiments, both nitrogen and phosphorus, singularly and together, significantly influenced herbage yield. Grass yield on mountain meadows was significantly increased by the application of nitrogen, but phosphorus alone had only a slight effect (Table 11). Nitrogen and phosphorus together appeared to have an additive effect. However, data collected on native foothill meadows in northeastern Oregon were not so clear-cut (Table 12). At one site, nitrogen alone and in combination with phosphorus and sulfur significantly increased yields, while at another location no significant fertilizer response was detected in either the year fertilized or the following year (Pumphrey and Hart, 1973).

TABLE 11: Average production from 16 mountain meadow areas in Logan Canyon, Utah (Cook, 1965)

Treatment	Grasses	Forbs	Total
	Yield: pounds air dry forage per acre		
80N	1,442*	803**	2,245**
80P	1,092	630	1,722*
80N-80P	1,880**	668*	2,548**
0	943	563	1,479

* Significantly different from the check plot yield at the 5 percent level.
** Significantly different from the check plot yield at the 1 percent level.

TABLE 12: Yield at hay stage of growth of native foothill meadows in northeast Oregon as influenced by fertilizer (Pumphrey and Hart, 1973)

Treatment pounds per acre	Site I Year fertilized	Site II Year fertilized	Site II Following year
	-------- Yield:	pounds oven dry forage	per acre ------
0	820	990	620
30N	1,500	1,030	590
60N	1,580	1,190	510
90N	1,420	1,070	470
180N	1,630	1,220	820
80P	870	1,000	700
60N-80P	1,660	1,090	470
60N-80P-20S	1,930	1,300	450
LSD 5% a/	403	NS b/	NS b/

a/ Least significant difference.

b/ Non significant.

On northeastern Oregon foothill meadows seeded to timothy (Phleum pratense), intermediate wheatgrass, and tall oatgrass (Arrhenatherum), nitrogen alone increased yield (Table 13), (Pumphrey and Hart, 1973). These meadows receive approximately 22 inches of precipitation annually. No significant yield increases from nitrogen carryover were noted except at 90 and 180 pound nitrogen rates.

In Utah, on mountain loam sites seeded to intermediate wheatgrass, nitrogen significantly increased yield in the year of fertilization and in the second year after application (Workman and Quigley, 1974 and Workman and McCormick, 1977). A maximum total yield of 3,668 pounds of air dry forage per acre was observed at

TABLE 13: Yield of seeded, dry foothill meadows in northeastern Oregon as influenced by fertilizer (Pumphrey and Hart, 1973)

Treatment pounds per acre	Year fertilized	Following year
	-- Yield: pounds oven dry	forage per acre--
0	1,390	650
30N	2,120	800
60N	2,760	780
90N	2,580	940
180N	2,520	940
80P	1,510	720
60N-80P	2,890	710
60N-80P-50S	3,120	790
LSD 5% a/	530	228

a/ Least significant difference.

an application rate of 338 pounds of nitrogen per acre. Phosphorus had no effect on yield. Average annual precipitation at this site is 16 inches, but slightly more than 19 inches was recorded in the year of fertilizer application.

Yield responses attributed to fertilization of seeded grasses on a mountain meadow site on the Hall Ranch in northeastern Oregon have been reported by Hedrick et al, (1965) (Table 14). This site receives about 16 to 20 inches of precipitation annually. Yields in the year of fertilizer application were at least doubled in all cases except for intermediate wheatgrass - nomad alfalfa. Creeping meadow foxtail, intermediate wheatgrass, and intermediate wheatgrass-legume mixtures showed the largest response to fertilization. Pure grass stands responded better to nitrogen than grass-legume mixtures. Crude protein content of forage measured as total protein production per acre showed a marked response to fertilization in the application year but not in later years. Grasses showed a greater increase in protein content from fertilization than grass-legume mixtures.

TABLE 14: Influence of 60 pounds nitrogen and 40 pounds phosphorus on late summer yields of grasses on the Hall Ranch in northeastern Oregon (Hedrick et al, 1965)

Species	Year of application		Year after application	
	Unfer-tilized	Fer-tilized	Unfer-tilized	Fer-tilized
	Yield: pounds air dry forage per acre			
Sherman big bluegrass	730	1,600	600	800
Whitman wheatgrass	990	1,960	900	960
Hard fescue	880	1,800	1,110	1,140
Pubescent wheatgrass	800	2,160	820	880
Whitman wheatgrass-hard fescue	1,060	2,260	860	1,350
Crested wheatgrass-hard fescue	1,280	2,820	910	800
Timothy	1,420	3,410	900	1,080
Crested wheatgrass	1,140	3,040	790	850
Meadow foxtail	900	2,940	990	1,250
Intermediate wheatgrass-granger birdsfoot trefoil	1,600	3,860		
Tall wheatgrass-granger lotus	1,610	3,080	1,420	1,180
Intermediate wheatgrass	1,510	3,800	1,640	1,260
Intermediate wheatgrass-nomad alfalfa	2,290	3,840	1,990	1,850

Conclusions: Effects of fertilization on yields of native mountain meadow have ranged from non-significant to highly significant responses. With an application of 90 pounds of nitrogen per acre, for example, yield increase of oven dry forage was only 80 pounds per acre at one site and 600 pounds at another location. The average yield increase from 16 mountain meadow areas of Utah approached 770 pounds of air dry forage per acre with 80 pounds of nitrogen. On these sites, nitrogen alone and in combination with phosphorus and sulfur significantly increased forage yield. Nitrogen and phosphorus together appeared to have an additive effect.

Nitrogen alone increased yield on seeded mountain meadows receiving 16 to 22 inches of precipitation annually. In northeastern Oregon, the greatest yield increase was 1,370 pounds of oven dry forage per acre with 60 pounds of nitrogen. Significant yield increases from nitrogen carryover were evident at nitrogen rates greater than 90 pounds per acre. Creeping meadow foxtail, intermediate wheatgrass, and intermediate wheatgrass-legume mixtures exhibited the largest yield response to nitrogen; however, pure grass stands responded better to nitrogen than grass-legume mixtures. Total protein production showed a marked response to nitrogen in the application year but not in subsequent years.

Native Flood Meadow

Hay yields on native flood meadows were found to be responsive to fertilizer, although not all meadows responded equally well. Rumburg (1961), summarizing hay yield response to nitrogen at 21 locations in southeastern Oregon, reported that yields were quite variable from area to area, while the mean yield at 0, 60, and 120 pounds of nitrogen per acre was 1.62, 2.37, and 2.77 air dry tons per acre, respectively. Other yield response data from eastern Oregon appearing in Tables 15 and 16 were reported by Cooper (1956) and Rumburg and Cooper (1961). Response to nitrogen was much less on meadows flooded by water deeper than 4 to 6 inches because almost pure rush stands predominated. Nevada bluegrass (*Poa nevadensis*) and rush (*Juncus sp.*) types appear to have the greatest potential to respond to nitrogen (Rumburg, 1961).

TABLE 15: Yield of flood meadow hay at alternative sites in eastern Oregon as influenced by nitrogen fertilizer (Cooper, 1956)

Pounds N per acre	Site I 1954	Site I 1955	Site II 1955
	air dry tons per acre		
0	1.78	2.15	1.56
50	2.54	3.04	2.28
100	2.99	3.57	2.59
150	3.23	3.86	2.93
200	3.47	4.10	3.40
LSD 5% a/	.25	.30	.33

a/ Least significant difference.

TABLE 16: Effect of nitrogen on yields of meadow hay in eastern Oregon over a four-year period (Rumburg and Cooper, 1961)

Year	0	200	400	600	Mean
	Pounds of N per acre				
	Hay yield averaged for levels of other fertilizers Tons per acre at 10% moisture				
1956	3.55	4.85	5.34	5.37	4.78
1957	3.05	4.76	4.95	4.68	4.36
1958	2.80	3.80	3.84	4.16	3.65
1959	1.85	3.67	4.26	4.60	3.60
Mean	2.82	4.27	4.60	4.70	--

a/ Least significant difference for comparing	N means	Year means
5%	0.22	0.15
1%	0.29	0.19

Nitrogen, phosphorus, and years were all statistically significant factors affecting flood meadow hay yield in experiments in eastern Oregon conducted by Cooper and Sawyer (1955), (Table 17). Interactions between nitrogen and phosphorus, or between these fertilizers and years, were not significant. No significant yield increases from nitrogen carryover were observed. No significant yield benefits occurred from applications of more than 18 pounds of phosphorus per acre (Table 18). Yield response to phosphorus was mainly attributed to stimulation of

TABLE 17: Yield of native flood meadow hay in eastern Oregon as influenced by nitrogen and phosphorus fertilizer (Cooper and Sawyer, 1955)

Year	0	20	40	60	Ave.	0	18	35	53	Ave.
	Pounds N per acre					Pounds P per acre				
	Tons per acre at 10% moisture					Tons per acre at 10% moisture				
1952	1.61	2.04	2.18	2.54	2.09	1.81	2.18	2.22	2.17	2.09
1953	1.89	2.17	2.70	2.95	2.43	2.21	2.49	2.60	2.42	2.43
Ave.	1.75	2.11	2.44	2.75		2.01	2.33	2.41	2.30	

Least significant difference at 5% level of probability for comparison of:
Ave. rate yields, 0.27 tons
Ave. year yields, 0.19 tons

annual white-tip clover. Minor elements did not influence yields when applied alone or in combination with nitrogen or phosphorus (Rumburg, 1961). Neither nitrogen nor phosphorus fertilizer stimulated regrowth on plots after harvest.

TABLE 18: Initial and residual yield increases of native flood meadow hay in eastern Oregon associated with phosphorus fertilizer (Cooper and Sawyer, 1955)

Pounds P per acre	1951 application	Carryover from 1951 application	Total
	Yield increase in pounds hay per acre at 10% moisture		
0	0	0	0
18	750	402	1,150
35	821	332	1,153
53	724	476	1,200

Least significant difference at 5% level of probability for comparison of total yield increase is 416 pounds

In fertilizer trials at the Squaw Butte Experimental Range by Rumburg et al, (1964), meadow hay yields were significantly affected by date of harvest and pounds of nitrogen applied (Table 19). Nitrogen had no significant effect on yields until May 24; thereafter, differences in yield among levels of nitrogen became progressively larger. Yields averaged for all levels of nitrogen increased until about July 12. Fertilizer extended the production period late into the season. Dry matter production ceased on June 28 on plots receiving no nitrogen but continued until about July 12 on fertilized plots. Yields were not significantly different at rates above 240 pounds of nitrogen per acre.

Yields of regrowth meadow hay at Squaw Butte were significantly affected by date of harvest of the initial crop, rate of nitrogen applied and date of initial harvest by rate of nitrogen applied interaction (Rumburg et al, (1964). Nitrogen increased regrowth yields when the initial crop was harvested early, with the regrowth gradually diminishing about 488 pounds per week with each successive week of delay of the initial harvest (Table 20). Little regrowth

TABLE 19: Seasonal production of dry matter from native flood meadows at the Squaw Butte Experimental Range fertilized with nitrogen (Rumburg *et al*, 1964)

Date of harvest		Pounds N per acre 0	80	160	240	Mean
		Yield: pounds of dry matter per acre				
May	10	80	89	114	123	102 [a]
	17	163	253	366	414	299 [a]
	24	507	884	1,160	1,310	965
	31	791	1,270	1,910	1,920	1,470
June	7	947	1,560	2,240	2,820	1,890
	14	1,420	2,130	2,620	2,990	2,290
	21	1,960	2,330	3,120	3,510	2,730
	28	2,020	2,720	3,380	3,830	2,990 [b]
July	5	1,860	2,980	3,400	4,640	3,220 [bc]
	12	2,010	2,710	3,960	4,770	3,360 [c]
	19	1,980	2,600	3,540	4,550	3,170 [bc]
	26	1,980	2,550	3,860	4,360	3,190 [bc]

Values underscored by the same line or designated by the same superscript letter are not significantly different from each other at the 5 percent level.

TABLE 20: Effect of nitrogen and date of harvest of the initial crop on regrowth flood meadow hay yields at the Squaw Butte Experimental Range (Rumburg *et al*, 1964)

Date of initial harvest		Pounds N per acre 0	80	160	240	Mean
		Yield: pounds of dry matter per acre				
May	10	1,760	2,350	3,420	3,960	2,872
	17	1,460	2,180	2,500	2,980	2,280
	24	1,350	1,770	1,990	2,740	1,962
	31	920	1,330	1,570	1,590	1,352
June	7	712	621	849	774	739
	14	457	364	498	447	442 [a]
	21	198	200	184	306	222 [a]
	28	43	88	93	89	78 [a]
Mean		862	1,113	1,388	1,611	

Values designated by the same superscript are not significantly different from each other at the 5 percent level.

was produced when initial harvest was delayed until June 14 or after. Total yield was greatest with a single harvest at the time of maximum production; however, on plots receiving no fertilizer, several two-harvest combinations yielded as much as a single harvest at the time of maximum yield.

Rumburg (1961), after noting that native species recover very slowly after clipping even though water is available, studied the influence of nitrogen, phosphorus and supplemental irrigation on regrowth of forage at Squaw Butte. Regrowth increased with increasing rates of nitrogen (Table 21), while phosphorus at 26 pounds of P per acre had no significant yield effect.

TABLE 21: Effect of fertilizer and supplemental irrigation on regrowth yields of native flood meadow at Squaw Butte (Rumburg, 1961)

Pounds phosphorus per acre	Pounds nitrogen per acre					
	0	60	120	180	240	Mean
	Pounds dry matter per acre					
0	600	1,420	1,630	2,120	2,640	1,680
26	630	1,060	1,700	2,300	2,510	1,640
Mean	615	1,240	1,665	2,210	2,575	

Least significant difference at the 5 percent probability level is 280 pounds for nitrogen

Nitrogen increased herbage production, but total yield declined as the date of application was delayed (Rumburg, 1972). Yields from plots fertilized in June or July were about 10 and 23 percent lower, respectively, than yields from plots fertilized in mid-May (Table 22).

Nitrogen content of herbage increased with increasing rates of nitrogen; however, there was no significant difference in nitrogen content if hay was harvested after June 21 (Rumburg et al, 1964). According to Cooper (1956), crude protein of forage increased slightly as nitrogen application rate increased. In all cases, it was lower than the crude protein content of unfertilized hay. Cooper (1956) concluded that crude protein differences in his

TABLE 22: Dry matter yield of native meadow forage in eastern Oregon fertilized at advancing maturity with 100 pounds of nitrogen per acre (Rumburg, 1972)

Date of harvest		Date of fertilization			
		None	May 19	June 16	July 14
May	19	820	760	760	850
	26	1,360	1,300	1,310	1,250
June	2	1,870	1,800	1,900	1,630
	9	2,020	2,230	2,120	1,980
	16	2,410	3,030	2,740	2,650
	23	2,650	3,360	2,800	2,630
	30	2,670	3,390	3,030	2,780
July	7	2,570	3,670	3,480	2,930
	14	2,450	3,480	3,180	2,830
	21	2,970	3,770	3,680	2,950
	28	3,080	3,850	3,680	2,950
Aug.	4	3,040	3,990	3,910	3,380
	11	3,040	4,090	3,990	3,170
	18	3,020	4,030	3,730	3,210
Sept.	1	2,880	4,030	3,880	3,420
Mean		2,450	3,120	2,940	2,570

experiments in eastern Oregon were because of a decline in the clover components of the meadows and an increase in the rush-sedge component resulting from nitrogen fertilization. Rumburg and Cooper (1961) also concluded that high rates of nitrogen and phosphorus fertilizer changed the botanical composition of native flood meadows while having little effect on the crude protein content of the hay.

No single source of nitrogen has been found to be consistently superior for fertilizing native flood meadows (Rumburg, 1961 and 1969). Fall and spring applications of nitrogen were equally effective in increasing hay yields.

Conclusions: Native flood meadow yields were found to be responsive to fertilizer, although not all meadows responded equally well. Nevada bluegrass and rush-sedge-grass meadows appeared to have the greatest potential to respond to nitrogen. At 21 site locations in southeastern Oregon, mean yield responses to 60 and 120 pounds of nitrogen per acre were .75 and 1.15 tons of air dry forage per acre, respectively. Yield responses at other locations in eastern Oregon approached 2.0 air dry tons at nitrogen rates of 200 pounds or more.

High rates of nitrogen fertilizer or the application of phosphorus were found to change the botanical composition of native flood meadows. Yield increases from nitrogen carryover were not found. Nitrogen application in late fall or early spring had no significant effect on yield until late May; thereafter, yields increased until about mid-July. Nitrogen extended production later in the growing season. Yields were not significantly different at rates above 240 pounds of nitrogen per acre. No single source of nitrogen was found to be consistently superior for fertilizing flood meadows. Fall and spring applications were equally effective, but spring applications must be completed prior to June to attain maximum response.

Minor elements did not influence yields when applied alone or in combination with nitrogen or phosphorus. Neither nitrogen nor phosphorus stimulated regrowth after harvest; however, nitrogen in association with supplemental irrigation after harvest stimulated regrowth.

Mixed Clover Native Flood Meadows

Cooper (1957) reported that in eastern Oregon, phosphorus was a limiting factor affecting yield of flood meadows with good stands of clover. Cooper and Hunter (1959) concluded from fertilizer trials in eastern Oregon that annual applications of about 18 pounds of phosphorus per acre produced maximum yields of mixed clover-rush-sedge hay, and that residual phosphorus was adequate for plant growth only when 53 pounds of phosphorus per acre or more had been applied the previous year. Yield response to phosphorus, according to Cooper and Sawyer (1959), was site specific. In general, poor responses were obtained on alkaline knolls and in deep swales which were submerged to a depth of more than one foot.

Phosphorus increased crude protein content of hay indirectly by stimulating an increased proportion of annual white-tip clover in the hay (Cooper and Hunter, 1959). Differences in the proportion of clover in the hay, however, were marked among years and were related to early spring temperatures and flood conditions. Increased clover production through the use of phosphorus and good management practices resulted in an increase of 6.49 percent crude protein in hay (Cooper and Sawyer, 1955).

Conclusions: Mixed clover-rush-sedge meadows appeared to have the greatest potential to respond to phosphorus if good stands of clover exist. Annual applications of about 18 pounds of phosphorus per acre produced maximum yield responses of from .30 to .40 tons of 10 percent moisture forage per acre. These responses were mainly due to stimulation of annual white-tip clover. Phosphorus resulted in increased crude protein content of forage by increased clover production, but this fluctuated widely with spring temperature and flood conditions.

ECONOMIC ANALYSIS

The economics of fertilizing high desert, foothill range, foothill meadows, and native flood meadow rangelands of eastern Oregon are evaluated in this section. The main purpose of the economic analysis is to provide general insight and direction for making fertilizer decisions for eastern Oregon rangelands rather than the development of conclusive fertilizer recommendations. Fertilization research, cited earlier in this report, provided basic yield response and fertilizer input rates used in the analysis. Analysis of these data identified fertilizers and application rates which result in returns that at least recover the cost of fertilization. If fertilization does not recover fertilization costs, minimum yield responses and the value that the yield response must attain to justify fertilization are determined.

DETERMINANTS OF ECONOMIC SUCCESS

Factors that influence the economic success of rangeland fertilization include: (1) site potential, (2) cost of fertilizer and its application, (3) yield response, (4) value of yield response, and (5) opportunity cost of money. All of these influences should be considered when contemplating rangeland fertilization decisions.

Site Potential

The potential for increased yields through fertilization is interrelated with such environmental characteristics as climate, vegetation, and soils. Yield responses to fertilizer are generally greatest on sites where soil moisture is the least limiting and on sites with deeper soils of medium texture and good structure but low in fertility. Response to fertilization is also greater for introduced forage species.

Fertilization Costs

Only those additional costs which are incurred by the rancher to fertilize rangeland and then utilize the forage response should be charged against returns to rangeland fertilization. These costs vary among ranchers because of the type and varying cost of fertilizers applied, rate of application, application method, size, location, and terrain of the area fertilized, and if needed, fencing and water development requirements.

Fertilization costs used in the economic analysis of fertilizing rangelands of eastern Oregon appear in Table 23. These costs represent typical charges for basic fertilizers in eastern Oregon in 1978. In the economic analysis, the

TABLE 23: Fertilizer ingredient and application costs for fertilizing eastern Oregon rangelands; 1978 prices

Item	Cost
Triple phosphate (45% P)	$270 per ton
Urea (46% N)	202 per ton
Ammonium sulfate (21% N - 24% S)	121 per ton
Aerial application (custom rate)	4.50 per acre

least cost forms of elemental nitrogen and phosphorus are used. The custom aerial application rate is a fairly typical charge for this type of custom service in eastern Oregon. Aerial application charges are often less than those for ground rig applications. For purposes of this analysis, no increase in other costs is considered necessary to utilize the forage response attributed to fertilization.

Yield Responses

The primary objective of fertilization is increased forage production at competitive costs. Other benefits, however, are often possible. Increased forage utilization might be achieved, and possibly an increase in plant vigor and a reduction in soil erosion can be accomplished. In some cases, fertilization increases total crude protein and digestible nutrients of the forage. An indirect benefit of fertilization is increased animal distribution and thus forage utilization on adjacent, non-fertilized range. This is usually achieved only with additional management input, however (Hooper et al, 1969). In certain cases, fertilization has resulted in yield increases from fertilizer carryover and forage utilization effects. Yield increases from fertilizer carryover, if they occur, are generally limited to the next production year after fertilization, but forage utilization effects have been observed in the third production year.

In the economic analysis of fertilization, increased forage production on the fertilized site is the only yield response from fertilization initially considered. This increase in production is considered available for 100 percent utilization. If fertilization is not economical, increases in forage utilization--either on or off site--necessary to justify fertilization are identified. Increased forage quality or plant vigor and reduced soil erosion attributable to fertilization are not considered in the economic analysis.

Value of Response

Yield responses to fertilization have economic value. This value can be stated in terms of livestock gains, lease or rent value, reproductive efficiency, grazing capacity, etc. Values, like fertilization costs, vary among ranchers. For example, a forage response that replaces a portion of a feed supplement has a relatively high value compared to a response that replaces purchased hay or leased grazing. In another situation, the forage response could be capable of providing increased carrying capacity which would generate additional income.

The value of the yield response in this study is specified at $40 per ton. This value approximates the expected price of grass hay in eastern Oregon during the summer and fall of 1978.

Opportunity Costs

Opportunity costs of a rancher (what the best investment alternative of capital with about the same risk will return) directly affects returns to fertilization. As opportunity costs increase, the economic feasibility of fertilization declines, assuming yield response and value of the response remain unchanged. In cases of limited capital, rangeland fertilization--although it may be profitable--might not be economical because of more productive uses of capital.

Opportunity costs are specified at 12 percent per year in the economic analysis of fertilization practices. The method of incorporating these costs in the analysis is called discounting. Discounting is nothing more than adjusting future incomes to a present day value directly comparable to the present day cost of fertilization. Discounting of a future income or income stream to a present value is necessary because of time preferences for income. An example may help clarify the time value of money. One dollar invested at 12 percent interest will grow to $1.12 a year from today. Therefore, this $1.12 payment receivable one year from today is worth only $1 today. This is because $1 today and $1.12 receivable one year from today are equal when the time preference for income is 12 percent. In other words, the $1.12 is discounted back to today's value based on its greatest earning power--in this case 12 percent. The rate of return on the investment (12 percent) is called the opportunity cost of capital (what the best investment alternative of capital will return). It is important that ranchers consider the cost of having money invested in fertilizer or other resources, because the rancher is giving up the opportunity of investing it elsewhere.

In this study, future returns are discounted to a present value based on fertilizer application in April of the growing season with harvest occurring in July of each production year.

Economics of Fertilization

High Desert Native Range

Four-year mean yields from fertilizer trials on high desert native range as reported by Sneva (1963) are used to determine the net returns of fertilizing sagebrush-bunchgrass range with various application rates of nitrogen. Effects of fertilization are illustrated in Table 24.

TABLE 24: Yield response, present value and cost, and net return to fertilizing high desert sagebrush-bunchgrass ranges at alternative levels of nitrogen; 1978 prices

Nitrogen rate	Yield response in pounds a/	Present value of response b/	Present cost of fertilization c/	Net return
- - - - -	- - - - -	acre basis	- - - - -	- - - - -
0	0	$ 00	$ 0	$ 0
15	.44	.85	7.80	-6.95
30	.77	1.49	11.10	-9.61
45	.98	1.90	14.40	-12.50
60	1.00	1.94	17.70	-15.76

a/ Yield data from Sneva (1963); see discussion of the data in the text following the section headings entitled, "Response to Fertilization," "High Desert Range." Herbage yield without nitrogen was 262 pounds of 12 percent moisture forage.

b/ Response valued at $40 per ton, discounted at 12 percent per annum for three months; 100 percent utilization of the yield increase is assumed.

c/ Costs include aerial application at $4.50 per acre plus urea at $0.22 per pound of actual N.

Nitrogen fertilization of high desert native range does not appear to be economical at a yield response valued at $40 per ton. A forage response of about 400 pounds per acre would be needed at 15 pounds of nitrogen just for the present value of forage to equal fertilization costs assuming no change in forage value or forage utilization. This type of response represents about an 800 percent yield increase above that attained in the experimental trial at the 15 pound nitrogen rate. It is highly unlikely that this large a response could be attained even in years with above normal precipitation. If forage response and utilization remain unchanged, a yield response value of about $365 per ton is required to recover fertilization costs--again, an unrealistic value. Although increased forage utilization through fertilization is possible on native range, forage utilization would have to increase about 356 pounds per acre for the present value of forage to equal fertilization costs if value and yield response were unchanged. This possibility is remote as herbage yield without fertilization on the site is only 262 pounds. Although yield increases from nitrogen carryover were not evaluated in Sneva's (1963) work, their effect would not appreciably alter the above economic conclusions since their magnitude is expected to be small.

High Desert Seeded Range

Net returns to fertilizing crested wheatgrass range on the Oregon high desert were estimated from data reported by Sneva et al, (1958). In this four-year study, nitrogen rates, in 10 pound increments, from 0 to 40 pounds were used, and first and second production year yield responses were reported. Effects of fertilization using mean yields appear in Table 25.

Present values of forage responses at nitrogen rates of 20, 30, and 40 pounds exceeded the present cost of fertilization. The largest net return was achieved with 40 pounds of nitrogen. Larger net returns, however, might be attained with application rates greater than 40 pounds per acre since net returns appear to be expanding at an increasing rate. Additional data at higher application rates would have to confirm this hypothesis. The present value of nitrogen fertilization at the 40-pound rate would just equal the present cost of fertilization, even if the value of the yield response was only about $36 per ton. To the extent that an increase in forage utilization results from fertilization, minimum yield responses required to cover fertilization costs could be reduced, or the use of fertilizer would be feasible at response values lower than $36 per ton.

TABLE 25: Yield response, present value and cost, and net return to fertilizing high desert crested wheatgrass range at alternative levels of nitrogen; 1978 prices

Nitrogen rate	Yield response [a/] 1st year	2nd year	Present value of response [b/]	Present cost of fertilization [c/]	Net return
- - - - - -	- - - - - -	- - - - - -	acre basis	- - - - - -	- - - - - -
	pounds	pounds			
0	0	0	$ 0	$ 0	$ 0
10	NS [d/]	NS [d/]	0	6.70	-6.70
20	306	194	9.28	8.90	.38
30	320	297	11.33	11.10	.23
40	465	343	14.94	13.30	1.64

a/ Yield data from Sneva et al, (1958) text Table 1. Herbage yield at 12 percent moisture without nitrogen was 711 pounds per acre in the first yield year and 814 pounds per acre in the second yield year.

b/ Response valued at $40 per ton, discounted at 12 percent per annum for 3 and 15 months for first and second year yield responses, respectively; 100 percent utilization of the yield increase is assumed.

c/ Costs include aerial application at $4.50 per acre plus urea at $0.22 per pound of actual N.

d/ Non-significant yield response was found.

Native Foothill Range

Net returns to fertilizing native bunchgrass foothill ranges in northeastern Oregon were estimated from data reported by Pumphrey and Hart (1973). The analysis is based on the average yield response attained on two sites receiving about 22 inches of precipitation annually. Various fertilizers and levels of application were used in this study. Effects of fertilization based on the average yield response obtained on the two sites appear in Table 26.

TABLE 26: Yield response, present value and cost, and net return to fertilizing native bunchgrass foothill rangelands of northeastern Oregon; 1978 prices

Treatment	Yield response a/ 1st year	2nd year	Present value of response b/	Present cost of fertilization c/	Net return
	- - - - - -	- - - - - -	acre basis	- - - - - -	- - - - - -
	pounds	pounds			
0	0	0	$ 0	$ 0	$ 0
30N	NS d/	NS d/	0	11.10	-11.10
60N	780	300	20.31	17.70	2.61
90N	760	510	23.54	24.30	-0.76
120N	870	585	26.97	30.90	-3.93
60N-20S	895	NS d/	17.37	21.90	-4.53
60N-80P-20S	890	NS d/	17.28	45.90	-28.62

a/ Yield data from Pumphrey and Hart (1973) text Table 9. Herbage yield on an oven dry basis with no fertilizer averaged 1,310 pounds per acre in the first yield year and 1,100 pounds per acre in the second yield year.

b/ Response valued at $40 per ton, discounted at 12 percent per annum for 3 and 15 months for first and second year yield responses, respectively; 100 percent utilization of the yield increase is assumed.

c/ Costs include aerial application at $4.50 per acre, urea at $0.22 per pound of actual N, ammonium sulfate at $0.29 per pound of N, and triple phosphate at $0.30 per pound of actual P.

d/ Non-significant yield response was found.

Although phosphorus and sulfur in combination with nitrogen and nitrogen alone, except at the 30-pound rate, significantly increased yields, only an application of 60 pounds of nitrogen showed a return over fertilization costs given a yield response value of $40 per ton. Other nitrogen application rates ranging from 40 to 80 pounds may produce even greater returns but this cannot be determined from the data. Even if the value of the yield response were only about $35 per ton, the present value of the yield response would still equal the present cost of nitrogen fertilization at the 60-pound rate. To the extent that an increase in forage utilization results from fertilization, minimum yield responses required to cover fertilization costs could be reduced, or the use of fertilizer would be feasible at response values lower than $35 per ton.

Similar conclusions as those above were obtained when the yield response from one of the sites was evaluated separately. At the other location, however, only an application of 60 pounds of nitrogen with 20 pounds of sulfur produced returns in excess of fertilization costs. This indicates the high degree of variability of yield responses to fertilization common to eastern Oregon rangelands and the resultant effect on the economics of fertilization.

Seeded Foothill Range

Fertilization trials reported by Pumphrey and Hart (1973) and Cook (1965) were used to estimate net returns to fertilizing seeded foothill ranges in northeastern Oregon. In these studies, yield responses to various fertilizers and levels of application were determined. Effects of fertilization are presented in Tables 27 and 28.

TABLE 27: Yield response, present value and cost, and net return to fertilizing seeded foothill rangelands in northeastern Oregon; 1978 prices

Treatment	Yield response in pounds [a/]	Present value of response [b/]	Present cost of fertilization [c/]	Net return
		acre basis		
0	0	$ 0	$ 0	$ 0
30N	250	4.85	11.10	-6.25
60N	330	6.41	17.70	-11.29
90N	400	7.76	24.30	-16.54
120N	510	9.90	30.90	-21.00
60N-20S	360	6.99	21.90	-14.91
60N-80P-20S	340	6.60	45.90	-39.30

a/ Yield data from Pumphrey and Hart (1973) text Table 10. Herbage yield with no fertilizer was 720 pounds per acre.

b/ Response valued at $40 per ton of oven dry forage, discounted at 12 percent per annum for 3 months; 100 percent utilization of the yield increase is assumed.

c/ Costs include aerial application at $4.50 per acre, urea at $0.22 per pound of actual N, ammonium sulfate at $0.29 per pound of nitrogen, and triple phosphate at $0.30 per pound of actual P.

TABLE 28: Yield response, present value and cost and net return to fertilizing crested and pubescent wheatgrass foothill range in Utah; 1978 prices

Treatment	Yield response a/ in pounds	Present value of response b/	Present cost of fertilization c/	Net return
- - - - - -	- - - - - - - -	- - - - acre basis	- - - - - - - -	- - - -
0	0	$ 0	$ 0	$ 0
20N	315	6.11	8.90	-2.79
20N-20P	189	3.67	14.90	-11.23
40N	350	6.79	13.30	-6.51
40N-40P	401	7.78	25.30	-17.52

a/ Yield data from Cook (1965) text Table 7. Herbage yield with no fertilization was 944 pounds of oven dry forage per acre.

b/ Response valued at $40 per ton, discounted at 12 percent per annum for 3 months; 100 percent utilization of the yield increase is assumed.

c/ Costs include aerial application at $4.50 per acre, urea at $0.22 per pound of actual N and triple phosphate at $0.30 per pound of actual P.

Although yields in these experiments were increased by the application of fertilizer, the present cost of fertilization in all cases exceeded the present value of the yield response given a forage value of $40 per ton. Yield responses, however, in these experiments were directly affected by early season grazing in one trial and an early (June 10) harvest in the other. These situations appear to have limited the yield response and directly affected the net return to fertilization. Because of these limitations and the absence of other appropriate data, conclusions about what fertilizers, if any, and application rates should be used to fertilize seeded foothill ranges remain undetermined. Based on the economic analysis of native foothill ranges reported earlier, it appears that some level of fertilization would produce a positive net return since seeded ranges are generally more responsive to fertilization than native ranges. For example, at a nitrogen rate of 30 pounds, a yield response of only about 570 pounds per acre valued at $40 per ton would be required to produce a positive net return to fertilization. This or even a larger response could be obtained on many seeded, foothill range sites in eastern Oregon. Site factor influences remain important to fertilization response, however, and must not be overlooked.

Native Foothill Meadows

Net returns to fertilizing dry, native foothill meadows in northeastern Oregon were estimated from data reported by Pumphrey and Hart (1973). The analysis is based on the average yield response attained on two sites receiving about 22 inches of precipitation annually. Various fertilizers and application levels were tested in this study. Effects of fertilization based on average yield responses are shown in Table 29.

TABLE 29: Yield response, present value and cost, and net return to fertilizing native foothill meadows in northeastern Oregon; 1978 prices

Treatment	Yield response a/ in pounds	Present value of response b/	Present cost of fertilization c/	Net return
		- - - acre basis - - -		
0	0	$ 0	$ 0	$ 0
30N	360	6.99	11.10	-4.11
60N	480	9.32	17.70	-8.38
90N	340	6.60	24.30	-17.70
180N	520	10.09	30.90	-20.81
80P	30	0.58	28.50	-27.92
60N-80P	470	9.12	41.70	-32.58
60N-80P-50S	710	13.78	45.90	-32.12

a/ Yield data from Pumphrey and Hart (1973) text Table 12. Herbage yield with no fertilization averaged 905 pounds of oven dry forage per acre at two sites.

b/ Response valued at $40 per ton, discounted at 12 percent per annum for 3 months; 100 percent utilization of the yield increase is assumed.

c/ Costs include aerial application at $4.50 per acre, urea at $0.22 per pound of actual N, triple phosphate at $0.30 per pound of P, and ammonium sulfate at $0.29 per pound of N.

Based on average yield responses, fertilization of native foothill meadows does not appear to be economical at a yield response valued at $40 per ton. A forage response of about 570 pounds per acre would be needed at 30 pounds of nitrogen just for the present value of forage to equal fertilization costs assuming no change in forage value or forage utilization. This minimum response represents a 58 percent yield increase above that attained in the experimental trial. If forage response remains unchanged and increased forage utilization is not possible, a yield response value of about $63 per ton is required to recover fertilization costs at a nitrogen rate of 30 pounds. Increased forage utilization, however, might be expected on many fertilized native foothill meadow sites. An increase in utilization of about 23 percent, or 212 pounds per acre, would make nitrogen fertilization at the 30-pound level economical. Even without an increase in forage utilization, fertilization may still produce positive net returns on some sites at the 30-pound rate. For example, on one of the experimental sites used to estimate the average yield response presented in Table 29, nitrogen application at the 30 pound rate resulted in a positive net return to fertilization. Present value of the response exceeded the present cost of fertilization by $2.10 per acre at this site.

Seeded Foothill Meadows

Fertilization trials reported by Pumphrey and Hart (1973) were used to estimate net returns to fertilizing seeded foothill meadows in northeastern Oregon. Various fertilizers and levels of application were studied. The experimental site received about 22 inches of precipitation. Effects of fertilization are presented in Table 30.

Nitrogen levels of 30, 60, and 90 pounds per acre produced returns to fertilization in excess of fertilization costs. The largest net return, given a yield response value of $40 per ton, was achieved at the 60-pound nitrogen rate. Nitrogen rates of 70 or 80 pounds per acre, however, may produce even greater net returns, but this cannot be determined from the data. Even if the value of the yield response was only about $35 per ton, the present value of the yield response would still equal the present cost of nitrogen fertilization at the 60-pound rate. To the extent that an increase in forage utilization results from fertilization, minimum yield responses required to cover fertilization costs could be reduced, or the use of fertilizer would be feasible at response values lower than $35 per ton. Increased forage utilization on range immediately surrounding a fertilized site could also improve the net return to fertilization.

This advantage, particularly for foothill range, may be even more important than increased forage utilization on the fertilized area.

TABLE 30: Yield response, present value and cost, and net return to fertilizing timothy, intermediate wheatgrass and tall oatgrass dry foothill meadows in northeastern Oregon; 1978 prices

Treatment	Yield responses [a/] 1st year	2nd year	Present value of response [b/]	Present cost of fertilization [c/]	Net return
	- - - - - -	- - - - - -	acre basis	- - - - - -	- - - - - -
	pounds	pounds			
0	0	0	$ 0	$ 0	$ 0
30N	730	NS [d/]	14.17	11.10	3.07
60N	1,370	NS [d/]	26.59	17.70	8.89
90N	1,190	290	28.10	24.30	3.80
180N	1,130	290	26.93	44.10	-17.17
80P	NS [d/]	NS [d/]	0	28.50	-28.50
60N-80P	1,500	NS [d/]	29.12	41.70	-12.58
60N-80P-50S	1,730	NS [d/]	33.58	45.90	-12.32

a/ Data from Pumphrey and Hart (1973) text Table 13. Herbage yield on an oven dry basis without fertilization was 1,390 pounds per acre in the first yield year and 650 pounds per acre in the second yield year.

b/ Response valued at $40 per ton, discounted at 12 percent per annum for 3 and 15 months for first and second year yield responses, respectively; 100 percent utilization of the yield increase is assumed.

c/ Costs include aerial application at $4.50 per acre, urea at $0.22 per pound of actual N, ammonium sulfate at $0.29 per pound of actual N, and triple sulfate at $0.30 per pound of P.

d/ Non-significant yield response was found.

Native Flood Meadow

Net returns to fertilizing native flood meadows in eastern Oregon were estimated from data reported by Cooper (1956) and Cooper and Sawyer (1955). Various application rates of nitrogen were evaluated in Cooper's work while Cooper and Sawyer's data assessed phosphorus fertilization. Effects of nitrogen and phosphorus fertilization of native flood meadows are presented in Tables 31 and 32, respectively.

TABLE 31: Yield response, present value and cost, and net return to fertilizing native flood meadows of eastern Oregon at alternative levels of nitrogen; 1978 prices

Nitrogen rate	Yield response a/ in tons	Present value of response b/	Present Cost of fertilization c/	Net return
- - - -	- - - -	acre basis	- - - -	- - - -
0	0	$ 0	$ 0	$ 0
50	.79	30.67	15.50	15.17
100	1.22	47.36	26.50	20.86
150	1.51	58.62	37.50	21.12
200	1.83	71.05	48.50	22.50

a/ Data from Cooper (1951) text Table 15. Herbage yield without fertilization averaged 1.83 air dry tons per acre for two sites and for two years (1954 and 1955) at one site.

b/ Response valued at $40 per ton, discounted at 12 percent per annum for 3 months months; 100 percent utilization of the yield increase is assumed.

c/ Costs include aerial application at $4.50 per acre and urea at $0.22 per pound of actual N.

TABLE 32: Yield response, present value and cost, and net return to fertilizing native flood meadows of eastern Oregon at alternative levels of Phosphorus; 1978 prices

Phosphorus rate	Yield response a/ in tons	Present value of response b/	Present cost of fertilization c/	Net return
- - - -	- - - -	acre basis	- - - -	- - - -
0	0	$ 0	$ 0	$ 0
18	.32	12.42	9.90	2.52
35	.40	15.53	15.00	0.53
53	.29	11.26	20.40	-9.14

a/ Data from Cooper and Sawyer (1955) text Table 17. Herbage yield without fertilization averaged 2.01 tons per acre.

b/ Response valued at $40 per ton, discounted at 12 percent per annum for 3 months; 100 percent utilization of the yield increase is assumed.

c/ Costs include aerial application at $4.50 per acre and triple phosphate at $0.30 per pound of P.

A nitrogen rate of 200 pounds per acre resulted in the largest net return to nitrogen fertilization, Nitrogen rates exceeding 200 pounds may result in even greater net returns to fertilization, but this cannot be determined from the data. The present value of nitrogen fertilization at the 200-pound rate would just equal the present cost of fertilization, even if the value of the yield response was only about $27 per ton.

A phosphorus application of 18 pounds resulted in the largest net return to phosphorus fertilization. The present value of phosphorus fertilization at the 18-pound rate would just equal the present cost of fertilization, even if the value of the yield response was only about $32 per ton.

Although the nitrogen and phosphorus trials of Cooper (1956) and Cooper and Sawyer (1955) are not directly comparable, the magnitude of the net returns to these fertilizers suggests that the use of nitrogen on native flood meadows may result in greater net returns to fertilization than the use of phosphorus. This, however, must be confirmed by additional experimental work.

Conclusions: Nitrogen fertilization can generate returns in excess of fertilization costs on many of the range sites in eastern Oregon. Of the range types evaluated (Table 33), native flood meadows were most responsive to nitrogen fertilizer and judged most likely to result in returns to fertilization that exceed fertilization costs. Next most responsive ranges were: seeded foothill meadows; native foothill ranges, seeded high desert ranges, native foothill meadows, seeded foothill ranges, and native high desert ranges. Native high desert range, in addition to being least responsive to nitrogen fertilizer, was judged least likely of the range types evaluated to result in returns to fertilization that exceed fertilization costs.

Rangelands of eastern Oregon showed significant variation in yield response and net return to fertilization from one site location to another and from one production year to the next. The fertilization of rangelands, therefore,

TABLE 33: Minimum yield responses by range type required at alternative yield response values just for the present value of forage to equal fertilization costs; 1978 prices

Range type	Nitrogen rate a/	Experimental yield response	Value of yield response			
			$20	$30	$40	$50
	Pounds per acre	Pounds per acre	Minimum yield response, pounds per acre b/			
Native high desert	15	44	800	540	400	320
Seeded high desert	40	808 c/	1,370	910	690	550
Native foothill	60	1,080 c/	1,820	1,220	910	730
Seeded foothill	60	330 d/	1,820	1,220	910	730
Native foothill meadows	30	360	1,140	760	570	460
Seeded foothill meadows	60	1,370	1,820	1,220	910	730
Native flood meadows	200	3,660	5,000	3,330	2,500	2,000

a/ Nitrogen rates which are likely to result in returns in excess of fertilization costs.

b/ Minimum yield response values based on the application of fertilizer in the spring and fertilization costs which include an application cost of $4.50 per acre and urea at $0.22 per pound of actual nitrogen.

c/ Yield response also includes the yield increase from nitrogen carryover.

d/ Yield response was limited because of early spring grazing. Yield responses that were grazed were not measured.

should be periodically and carefully evaluated in light of fertilization costs, yield response values and expected yield increases attributed to fertilization. Good yield responses to fertilization can be expected in years of above normal precipitation and on sites where soil moisture is least limiting, fertility is low, and deeper soils of medium texture and good structure exist. Fertilization can also increase utilization of forage on lightly grazed areas which, in effect, increases the yield response to fertilization and improves returns to fertilization.

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