J. Range Manage.
47:159-164, March 1994

Optimization of range improvements on sage-brush and pinyon-juniper sites

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Abstract

The optimum combination of 3 range improvements was determined for private lands on Utah ranches. While many promising range improvements are available, determination of which alternatives to implement must consider the total ranch operation. Linear programming (LP) makes it possible to simultaneously determine the profit maximizing combinations of range improvements and how these improvements will affect the total ranch operation. The study examined 3 range improvements (revegetation, burning, and chemical brush control) for big sagebrush (*Artemisia tridentata* Nutt.) and pinyon-juniper (*Pinus* spp.-*juniperus* spp.) on upland loam and upland shallow loam range sites. Net present value analysis and an LP model were used to identify the most efficient alternative, the limiting constraints, and the optimum levels and combinations of alternatives. The optimal solution ran 238 brood cows compared to 196 for the typical Utah ranch. Burning big sagebrush or pinyon-juniper infestations on crested wheatgrass (*Agropyron desertorum* Fisch. ex Link) foothill ranges was the most profitable range improvement. Annual net cash incomes after burning sagebrush or pinyon-juniper on the upland loam site were $37,873 and $37,770, respectively, compared to $31,278 on the typical Utah cow-calf operation. The optimal solution will change as input and product prices change. The model was designed for application to specific ranches rather than to make general recommendations for the typical Utah ranch.

Key Words: linear programming, revegetation, burning, chemical treatment, net present value

Range improvements have traditionally been economically analyzed on a case by case basis. Analysis and comparison of proposed improvements should consider impacts on the "total ranch" (White 1988) and must include the best available uses of time, funds, and other resources. White et al. (1988, p. 3) defined total ranch management as "the balancing of resource uses for the best and highest ranch benefits, directing ranch change, and maintaining diversity and flexibility to meet future consumer demands."

Many range improvements in the Intermountain area attempt to alleviate forage deficiencies on spring ranges. These shortages often limit year-long carrying capacity (Banner 1981). Crested wheatgrass (*Agropyron desertorum* Fisch. ex Link) production has substantially contributed to improved net ranch returns. Economic analysis of range improvements should be completed on a "total ranch" basis because other aspects of ranch management could be more limiting to net returns than the improvements in question.

Due to year-long herd size constraints imposed by unbalanced seasonal range forage, considerable efficiency may still be gained by practices designed to alleviate seasonal forage " bottlenecks" (Hewlett and Workman 1978). Proper selection of alternatives is crucial. According to White (1988), "selecting the right thing to do is more important than doing things right."

Economic comparisons among feasible alternatives are often difficult to make because of the complexity of the total ranch operation. Too often, comparisons are made between individual projects which can be misleading because the economics of the entire ranch are not considered. Linear programming (LP) can be used to determine the optimum combination of improvements. Personal computer linear programming software is readily available for use by ranchers, extension personnel, researchers, and range and ranch management consultants. These programs allow the optimum combination of improvements to be quickly and easily determined. Linear programming can also point out possible combinations of improvements where additive effects may increase the added net return more than if the 2 improvements were completed separately.

Methods

The data set consisted of interview data from 96 Utah cattle ranches. The resulting typical Utah ranch was used as the base for this study. Three promising range improvements to alleviate the spring forage bottleneck common (Evans 1992) on the typical Utah cow-calf operation were analyzed. Included were (1) reseeding crested wheatgrass on poor condition native range sites; and control of sagebrush and pinyon-juniper on established crested wheatgrass seedings by (2) burning or (3) chemical means. The first objective of the study was to determine the economic feasibility of each improvement by comparing the present value of added net returns above the variable costs to required added investment (net present value, NPV).

Next, it was important to determine the correct proportions of the economically feasible alternatives to maximize net returns. The second objective of the study was to determine the optimum intensities and combinations of range improvements to maximize net revenue using linear programming. Data were compiled in spreadsheet format using Lotus 1-2-3 (Lotus Development Corporation 1985). Spreadsheet data were then converted into linear programming format using Lotus-Lindo Connection (Booker 1987). The linear programming optimization package used was LINGO (LINDO Systems, Inc. 1991). Objective function coefficients were generated from the net present value analysis described above.

Results and Discussion

The typical Utah ranch runs 196 brood cows with a 14% heifer replacement rate (27 heifers). Replacements (31 head) are bred at

Supported by the Utah Agricultural Experiment Station, Utah State University, Logan 84322-4845. Approved as journal paper 4396.
Manuscript accepted 10 Sep. 1993.

Table 1. Typical Utah ranch private land holdings, carrying capacities, and grazing leases, 1990.

	Size	Carrying capacity
Land holdings	(ha)	(AUM)
Desert range	12	3
Native foothill	539	180
Low meadow pasture	45	264
Foothill crested wheatgrass	221	298
Irrigated alfalfa hay	41	987
Irrigated grass hay	6	90
Irrigated barley	13	199
Dryland wheat	19	147
Crop aftermath	79	303
Grazing leases		
U.S. Forest Service		415
Bureau of Land Management		707
State of Utah		11
Private	743	248

approximately 14 months of age to have their first calf at the age of 2. Heifer conception rate was set at 86% (Yates 1980). The cow to bull ratio is 27:1 and 8 bulls are used to breed mature cows and replacements. There are 158 calves born (an 81% calf crop based on cows in the calving herd) and 150 calves weaned (77%), of which 24% (36 head) are sold as yearlings. Mature cow death loss is 3.92% and heifer death loss is 2.34%. Results from our 96 Utah ranch sample compare closely with the aggregate profile for Utah ranches reported by Gee et al. (1986a, 1986b).

Private land holdings, carrying capacities, and grazing leases for the typical Utah ranch are shown in Table 1. The 1990 net variable cash ranch income for the typical Utah ranch ($31, 278) is calculated by subtracting the annual variable cash costs from the annual cash returns composed of income from cattle and crops (Table 2). Average cattle prices were from Cattle Fax Resources, Inc. (1988, 1989, 1990) weekly reports. A 4-month average price (August–November) was used for fall sales and a 2-month average price (April and May) for spring sales. A 3-year average price was used for calves and yearlings and a 2-year average price for cows and bulls. Average annual crop prices (1988–1990) for crops in excess of livestock needs were from Utah Department of Agriculture (1991).

Alleviation of Spring Forage Bottlenecks

The most limiting constraint on the typical Utah ranch is the availability of early spring forage (Evans 1992). The following sections analyze the economic feasibility of revegetating degraded range sites with improved species and controlling sagebrush and pinyon-juniper encroachment of previously seeded areas.

Revegetation of Degraded Sites

The typical Utah ranch has 539 ha of native foothill range. The spring forage bottleneck can be alleviated by seeding these deteriorated rangelands with crested wheatgrass, allowing a longer, and sometimes earlier, spring grazing period. Crested wheatgrass revegetation of 2 range sites (Upland Loam and Upland Shallow Loam), infested with 2 brush types (sagebrush and pinyon-juniper), were compared. The economic analysis of range revegetation included information on project benefits, value of project benefits, project costs, interest rate, project risk, expected project life, and range site selected for treatment (Workman and Tanaka 1991).

Table 2. Net variable cash ranch income for a typical Utah ranch selling excess crops (196 brood cows), 1990.

Item		Dollars
Annual cash returns		
Cattle:		
19 cull cows[a] (982# @ $46.88/cwt[b])	8,747	
3 cull bulls (1500# @ $61.41/cwt[b])	2,763	
26 hfr calves (425# @ $87.74/cwt[c])	9,695	
57 str calves (437# @ $97.33/cwt[c])	24,244	
18 yrlg hfrs (595# @ $75.64/cwt[c])	8,101	
18 yrlg strs (626# @ $82.71/cwt[c])	9,320	
4 open hfrs (700# @ $76.85/cwt[c])	2,152	
Crops[d]:		
alfalfa hay (164 ton @ $80.00/ton)	13,120	
barley (1467 bu @ $2.42/bu)	3,550	
wheat (1265 bu @ $3.46/bu)	4,377	
Total		86,069
Annual variable cash costs		-54,791
Net variable cash ranch income		31,278

[a]Death loss removed (3.92% for cows).
[b]Prices from Cattle Fax Resources, Inc. (1989, 1990), weekly reports.
[c]Prices from Cattle Fax Resources, Inc. (1988, 1989, 1990), weekly reports.
[d]Prices from Utah Department of Agriculture (1991).

The main benefit of crested wheatgrass reseeding is increased forage. Increased forage production for each range site was determined using yield and vegetation composition data from Mason (1971). Native foothill ranges for the typical Utah ranch currently produce 180 AUMs on 539 hectares (0.35 AUM/ha). The AUM requirement was set at 300 kg/AUM (National Research Council 1970). Carrying capacities of the Upland Loam and the Upland Shallow Loam range sites in poor condition were 0.51 AUM/ha and 0.27 AUM/ha, respectively (Table 3). Thus the current average carrying capacity of 0.35 AUM/ha for the native foothill range on the typical Utah ranch was similar to those of the 2 range sites chosen for this analysis. Seeding crested wheatgrass increased the carrying capacity by 1.76 AUM/ha and 1.66 AUM/ha on the Upland Loam and Upland Shallow Loam range sites, respectively (Table 3).

The annual value of this carrying capacity increase was calcu-

Table 3. Increased production from seeding crested wheatgrass on 2 range sites, 1990[a].

	Herbage *	Forage *	Utilization =	Usable / Forage	Forage Req. =	Carrying capacity	Increased production
	(kg/ha)	(%)	(%)	(kg/ha)	(kg/AUM)	(AUM/ha)	(AUM/ha)
Upland Loam							
Before	1,318	23	50	152	300	0.51	1.76
After	1,511	90	50	680	300	2.27	
Upland Shallow Loam							
Before	599	27	50	81	300	0.27	1.66
After	1,288	90	50	580	300	1.93	

[a]Adapted from Workman and Tanaka (1991).

Table 4. Added net present value of seeding crested wheatgrass on 2 sagebrush infested range sites, 1990.

Upland Loam
Returns:
Increased annual forage value = 1.76 AUM/ha * $5.96/AUM
= $10.49/ha
Present value of annual forage = $10.49/ha * $9.128_{20yr, 9\%}$
= $95.75/ha
Total returns: $95.75/ha

Costs:
Initial: $57.43/ha
Deferment:
Postponed forage = $95.75/ha – (95.75/ha * $0.917_{1yr, 9\%}$)
= $7.95/ha
Alternate forage = 0.51 AUM/ha * $5.96/AUM * $0.917_{1yr, 9\%}$
= $2.79/ha
Total costs: $68.17/ha

Added Net Present Value = $95.75/ha – $68.17/ha
= $27.58/ha

Upland Shallow Loam
Returns:
Increased annual forage value = 1.66 AUM/ha * $5.96/AUM
= $9.89/ha
Present value of annual forage= $9.89/ha * $9.128_{20yr, 9\%}$
= $90.28/ha
Total returns: $90.28/ha

Costs:
Initial: $57.43/ha
Deferment:
Postponed forage = $90.28/ha – ($90.28/ha * $0.917_{1yr, 9\%}$)
= $7.49/ha
Alternate forage = 0.27 AUM/ha * $5.96/AUM * $0.917_{1yr, 9\%}$
= $1.48/ha
Total costs: $66.40/ha

Added Net Present Value = $90.28/ha – $66.40/ha
= 23.88/ha

Table 5. Added net present value of seeding crested wheatgrass on 2 pinyon-juniper infested range sites, 1990.

Upland Loam
Returns:
Increased annual forage value = 1.76 AUM/ha * $5.96/AUM
= $10.49/ha
Present value of annual forage $10.49/ha * $9.128_{20yr, 9\%}$
= $95.75/ha
Total returns: $95.75/ha
Costs:
Initial: $119.84/ha
Deferment:
Postponed forage = $95.75/ha – ($95.75/ha * $0.917_{1 yr, 9\%}$)
= $7.95/ha
Alternate forage = 0.51 AUM/ha * $5.96/AUM * $0.917_{1 yr, 9\%}$
= $2.79/ha
Total costs: $130.58/ha

Added Net Present Value = $95.75/ha – $130.58/ha
= –$34.83/ha

Upland Shallow Loam
Returns:
Increased annual forage value = 1.66 AUM/ha * $5.96/AUM
= $9.89/ha
Present value of annual forage = $9.89/ha * $9.128_{20yr, 9\%}$
= $90.28/ha
Total returns: $90.28/ha

Costs:
Initial: $119.48/ha
Deferment:
Postponed forage = $90.28/ha – ($90.28/ha * $0.917_{1yr, 9\%}$)
= $7.49/ha
Alternate forage = 0.27 AUM/ha * $5.96/AUM * $0.917_{1yr, 9\%}$
= $1.48/ha
Total costs: $128.81/ha

Added Net Present Value = $90.28/ha – $128.81/ha
= –38.53/ha

lated by multiplying the increased production by the 3-year average (1988–1990) adjusted private range lease rate (USDA/ERS 1991). Published private lease rates include a 30% premium for landlord services and operating cost savings (Torell et al. 1989). Therefore, the forage portion of the private range lease rate was $5.96/AUM ($8.52/AUM * 70%).

Expected costs of sagebrush revegetation include initial project investment (seedbed preparation, seed, and seeding) and induced operating and maintaining costs. Specific revegetation requirements are explained in detail by Horton (1989). Induced costs include grazing deferment and fence and water facility construction and maintenance.

Initial investment for sagebrush revegetation consisted of 6.7 kg/ha of Fairway crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) seed at $2.67/kg and seedbed preparation and seeding costs of $39.54/ha. The total initial investment was $57.43/ha (USDA 1984). A 4% real interest rate was combined with a 5% risk (1 failure for every 20 seeding projects) resulting in a 9% risk included real interest rate (Workman and Tanaka 1991). The life of the project was set at 20 years. Deferment costs included a 1-year deferment for seedling establishment (no grazing until the end of the first year after seeding) and the resulting cost of alternate (leased) forage for the same period (Table 4), priced at the adjusted private lease rate.

The added net present values of reseeding the Upland Loam and the Upland Shallow Loam range sites infested with sagebrush were $27.58/ha and $23.88/ha, respectively (Table 4). This analysis demonstrates the importance of improving the best (most respon-

Table 6. Added net present values of controlling sagebrush and pinyon-juniper by burning and chemical treatments, 1990.

Treatment	Herbage	Useable forage	Carrying capacity	PB[a]	Initial cost[b]	Added NPV
	(kg/ha)	(kg/ha)	(AUM/ha)	($/ha)	($/ha)	($/ha)
Basin Big Sagebrush:						
Before treatment	562	253	0.84	53.08		
Burning	1364	614	2.05	129.46	29.16	47.22
Tebuthiuron	1364	614	2.05	129.46	46.44	29.94
Pinyon-Juniper:						
Before treatment	336	151	0.50	31.57		
Burning	900	405	1.35	85.28	40.28	13.43
Tebuthiuron	900	405	1.35	85.28	51.38	2.33

[a]Present benefit (PB) = carrying capacity * $5.96/AUM * $10.594_{20yr, 7\%}$
[b]Prices indexed to 1990

sive) range sites first in order to maximize net present value.

A similar analysis was performed for revegetation of the same 2 range sites infested with pinyon-juniper. Returns from increased forage and costs of postponed and alternate forage were the same as the above analysis. M. O'Dell (personal communication, 1992) estimated the cost of tree removal by double chaining on pinyon-juniper sites combined with aerial seeding to be $119.84/ha.

Added net present values from reseeding crested wheatgrass on Upland Loam and Upland Shallow Loam range sites infested with pinyon-juniper were -34.83/ha and -$38.53/ha, respectively (Table 5). This analysis also demonstrates the importance of improving the best range sites first.

Control of Sagebrush and Pinyon-Juniper

Another method of increasing spring forage availability is controlling brush on seeded areas. The typical Utah ranch has 221 hectares of crested wheatgrass foothill range producing 298 AUMs annually, resulting in a current average production of 1.35 AUM/ha. This is an average for seeded areas for the typical ranch and is somewhat less than the potential carrying capacity of revegetated rangelands (Table 3).

Control of unwanted vegetation in established seedings by burning and chemical treatments was analyzed using the methods described above. Control success on a given seeding may vary with treatment used, vegetation type, soil type, precipitation, stocking rate, and current condition of the seeding. Tanaka and Workman (1988) reported an optimum big sagebrush kill rate of 92 to 100%. Our target kill rate was set at 90% and the value of forage, treatment life, % forage (90), and % utilization (50) were unchanged from the previous analysis. A 4% real interest rate was combined with a lower 3% risk (lower chance of failure when controlling brush in established seedings) resulting in a 7% risk included real interest rate (Tanaka and Workman 1988).

Results of controlling basin big sagebrush (*Artemisia tridentata* subsp. *tridentata* Nutt.) by burning and chemical treatment appear in Table 6. Herbage production of crested wheatgrass/sagebrush areas before and after treatments are from Tanaka (1986) as are treatment costs, indexed to 1990. Added net present values for burning and tebuthiuron treatments were $47.22/ha and $29.94/ha, respectively (Table 6).

Results of controlling pinyon-juniper by burning and chemical treatment also appear in Table 6. Herbage production of crested wheatgrass/pinyon-juniper areas before and after treatments are from Clary (1987). Burning costs are from Tanaka and Workman (1988) and Bunting (1984), indexed to 1990. Herbicide treatment costs are from Tanaka and Workman (1988) and G.A. Rasmussen (personal communication, 1992), indexed to 1990. Added net present values were calculated in the same manner as in the big sagebrush analysis above. Added net present value for the burning and tebuthiuron treatments were $13.43/ha and $2.33/ha, respectively (Table 6).

Linear Programming Analysis

Linear programming was used to determine the optimum combinations and levels of range improvement options to maximize net variable cash ranch income for the typical Utah ranch. Four range site and brush type combinations (upland loam sagebrush, upland shallow loam sagebrush, upland loam pinyon-juniper, and upland shallow loam pinyon-juniper) were analyzed.

Model Description

The linear programming model included 3 potential range improvement alternatives (revegetation, burning, and chemical treatment) for 2 brush types (sagebrush and P-J) on 2 range sites (upland loam and upland shallow loam). The linear programming model was constructed in standard format (Dykstra 1984). The model for the upland loam sagebrush range site is shown in Table 7. Similar models were used for the other 3 site and brush type combinations. Objective function coefficients included net variable cash ranch income/brood cow, net variable cash ranch income/hectare improved by revegetation, burning, or chemical treatments, and net variable cash ranch income/hour of labor hired.

Objective function coefficients for revegetation were based on amortized investments (20 years, 9% risk included real interest rate) to determine the change in net variable cash ranch income for 1990. Objective function coefficients for brush control were based on amortized investments (20 years, 7% risk included real interest rate) to determine the change in net variable cash ranch income for 1990.

Constraints included labor, livestock investment, short-term capital, and forage. The labor requirement coefficient was 27.59

Table 7. Linear programming model for the upland loam sagebrush range site.

	Brood cow	Reveg April	Reveg May	Reveg June	Burn April	Burn May	Burn June	Chem April	Chem May	Chem June	Hired Labor		RHS Constraint
Objective Function: Maximize Net Return	159.58	-7.47	-7.47	-7.47	-2.75	-2.75	-2.75	-4.38	-4.38	-4.38	-6.0		dollars
Subject to:													
Labor	27.59										-1.0	<=	6,760 hours
Livestock Investment	854.44											<=	260,000 $
Short Term Capital	279.55	7.47	7.47	7.47	2.75	2.75	2.75	4.38	4.38	4.38	6.0	<=	130,000 $
January Forage	1.3010											<=	365 AUM
February Forage	1.3010											<=	365 AUM
March Forage	1.3010											<=	365 AUM
April Forage	1.2143	-1.76			-1.21			-1.21				<=	279 AUM
May Forage	1.2143		-1.76			-1.21			-1.21			<=	252 AUM
June Forage	1.2143			-1.76			-1.21			-1.21		<=	366 AUM
July Forage	1.2143											<=	290 AUM
August Forage	1.5765											<=	438 AUM
September Forage	1.5765											<=	438 AUM
October Forage	1.5765											<=	438 AUM
November Forage	1.3010											<=	365 AUM
December Forage	1.3010											<=	365 AUM
Native Rangeland		1	1	1								<=	539 ha
Crested Wheatgrass					1	1	1	1	1	1		<=	221 ha

hours labor required / brood cow, and the Right Hand Side (RHS) was the total amount of labor available on the typical Utah ranch [(10 hours/day × 26 days/month × 26 person months) = 6,760 person hours].

The livestock investment requirement coefficient was $854.44/brood cow and the Right Hand Side value was set at $260,000 (twice the current livestock investment of $130,000) to allow for herd expansion. Current livestock investment per brood cow was determined by valuing all existing ranch livestock at the 1990 market value.

The short-term capital constraint limited ranch operating capital. The operating capital requirement coefficient was $279.55/brood cow and the Right Hand Side value was set at $130,000, the current livestock investment. Short-term capital coefficients for range revegetation ($/ha) were based on 1990 amortized investments (20 years, 9% risk included real interest rate). Short-term capital coefficients for brush control ($/ha) were based on 1990 amortized investments (20 years, 7% risk included real interest rate).

The forage constraint limited available monthly forage. Forage requirement coefficients were required forage (AUMs/brood cow) and the Right Hand Side was the maximum monthly forage available. Forage for the month of May was set to reflect the proportion of crested wheatgrass actually available in May. Hay and grain AUMs were allowed to fluctuate to meet feed requirements.

Hired labor allowed labor to increase if necessary. Hired labor was valued at $6/hour and financed with short-term capital.

Production coefficients for range improvements allowed the forage Right Hand Side to be increased for appropriate months. Coefficients were provided for each treatment (revegetation, burning, chemical control) in combination with range site and brush type (upland loam sagebrush, upland shallow loam sagebrush, upland loam pinyon-juniper, and upland shallow loam pinyon-juniper). Right Hand Side values were limited to 539 ha of native foothill range for revegetation and 221 ha of brush-infested crested wheatgrass foothill range for brush control.

Model Analysis

Each of the optimum (most profitable) combinations of range improvements ran 238 brood cows and required no extra hired labor. For the upland loam sagebrush, upland shallow loam sagebrush, upland loam pinyon-juniper, and upland shallow loam pinyon-juniper combinations, 38.8, 41.3, 55.3, and 58.8 hectares of brush infested crested wheatgrass were burned to increase April and May forage, respectively (Table 8). Optimum net variable cash ranch income for the upland loam sagebrush, upland shallow loam sagebrush, upland shallow loam sagebrush, upland loam pinyon-juniper, and upland shallow loam pinyon-juniper combinations, was $37,873, $37,867, $37,770, and $37,757, respectively, compared to $31,278 for the typical Utah cow-calf operation. The short-term capital requirements for the upland loam sagebrush, upland shallow loam sagebrush, upland loam pinyon-juniper, and upland shallow loam pinyon-juniper combinations, were $66,640, $66,646, $66,743, and $66,756, respectively (Table 8).

Table 8. Linear programming optima for 2 brush types on 2 range sites, 1990.

Site and Brush Type	April Burn	May Burn	Shadow Price	Short-Term Capital	Objective Function
	(ha)	(ha)	($)	($)	($)
Upland Loam Sagebrush	8.2	30.6	2.27	66,640	37,873
Upland Shallow Loam Sagebrush	8.8	32.5	2.41	66,646	37,867
Upland Loam P-J	11.8	43.5	4.47	66,743	37,770
Upland Shallow Loam P-J	12.5	46.3	4.75	66,756	37,757

For the upland loam sagebrush, upland shallow loam sagebrush, upland loam pinyon-juniper, and upland shallow loam pinyon-juniper combinations, April and May AUMs were the limiting constraints with shadow prices of $2.27, $2.41, $4.47, and $4.75, respectively (Table 8). Therefore, only the value of the respective shadow price could be paid for 1 more AUM of April or May forage and the optimal solution would change only if 1 more AUM could be purchased at the shadow price or less. Since the current forage price was $5.96/AUM, the optimal solution is stable.

Summary and Conclusions

Many range improvements may increase the profitability of a ranching operation but it is difficult to select the best sizes and combinations of improvement alternatives. Linear programming (LP), a decision tool readily available to ranchers, makes it possible to determine how potential range improvements affect the whole ranch operation (a "total ranch" approach).

The typical Utah ranch runs 196 brood cows as a cow-calf operation. Net variable cash ranch income in 1990 was $31,278. Linear programming was used to determine the optimum (maximum net ranch income) sizes and combinations of range improvements to alleviate the spring forage bottleneck. Three improvements (revegetation, burning, and chemical brush control) were examined for 4 combinations of 2 brush types (sagebrush and pinyon-juniper) and 2 range sites (upland loam and upland shallow loam).

The optimal solution ran 238 brood cows compared to 196 on the typical Utah ranch. Burning brush on established crested wheatgrass seedings was the most economically efficient range improvement. The optimum combination of improvements required no additional off-ranch hired labor. Annual net variable cash ranch incomes after burning sagebrush or pinyon-juniper on the upland loam range sites were $37,873 and $37,770, respectively, compared to $31,278 before burning.

Linear programming is a useful tool to determine the optimum combination of range improvements for a particular ranch. The solutions presented here are general guidelines for Utah ranchers. Results for an individual ranch would vary with the current management system and input and product prices.

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