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FERTILIZING WYOMING HAY MEADOWS:
How Much Nitrogen Can You Afford?

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Fertilizing Wyoming Hay Meadows: How Much Nitrogen Can You Afford?

J.J. Jacobs, D.T. Taylor, W.J. Seamands, R.H. Delaney, and D.J. Menkhaus

INTRODUCTION

Hay meadows are an essential component of western mountain-valley cattle ranches. In addition to hay harvesting, these meadows are frequently grazed in early spring and late fall, when range forage is limited. It is estimated that there are approximately 1,700,000 acres of irrigated hay in the mountain and intermountain regions of California, Oregon, Idaho, Utah, Nevada, Montana, Colorado, and Wyoming (Jacobs and Kearl 1979). There are about 390,000 acres of irrigated hay meadows in Wyoming, yielding on the average 1.2 tons per acre.

Yields on many of these hay meadows can be improved by management practices. The question producers must ask prior to investing in these improvements is: "What improvement practices are available, feasible, and cost effective?" While there are many types and combinations of improvement practices, four major components of improved meadow management are (1) fertilization; (2) structures to control water for intermittent irrigation; (3) establishment of improved plant species; and (4) timeliness of harvest.

Each of the four meadow-improvement components has been studied individually, as well as in various combinations. Research on high-elevation hay meadows shows that hay yield and quality can be increased with these improvement practices. Of the four components, nitrogen (N) fertilization and its effect on yield has received the most research effort. This bulletin concentrates on the yield response to fertilization of Wyoming hay meadows and the determination of the most economic level of N fertilizer.

Previous studies show that both increased yield and higher crude protein content can be obtained by fertilizing hay meadows (Seamands and Roehrkasse 1971; Lewis and Lang 1957; Whillhite et al. 1955). On a meadow of improved-grass species with a small percentage of sedges and rushes, as well as an application of 100 lbs. of P_2O_5/A, forage yields increased from 1.7 tons/A to 2.5 and 3.1 tons/A for N applications of 80 and 160 lb./A, respectively (Seamands and Roehrkasse 1971). Lewis and Lang (1957) reported increased yields per acre for eight grass species from 0.8 tons to 2.9 and 3.7 tons/A with N applications of 80 and 160 lb./A, respectively. A rancher states that his average yield per acre increased from 0.89 ton with no fertilizer to 1.88 tons after applying 81 lb. of N/A and 27 lb. of P_2O_5/A (Sims 1979).

Ludwick (1979) stated that a production response to fertilization on high-elevation meadows can be expected because N is generally deficient and must be applied annually. The average response reported by Ludwick (1979) is 20 lb. of additional hay per pound of available N/A at 80 lb. of N/A. However, because plant species composition, physical environment, and management conditions are diverse in mountain hay meadows, response to fertilization varies. Ludwick (1979) reported a variation from 7 lb of hay per pound of N to 45 lb. of hay per pound of N applied per acre. Such variation clearly indicates that the profitability of N fertilization of hay meadows varies with each site depending on plant species present, physical characteristics and meadow management. An analysis of data on yield response to fertilization is needed to estimate the economic level of N fertilizer to apply on hay meadows.

PURPOSE

As indicated, most hay meadows will respond to applications of N. Because few meadows are average, the purpose of this bulletin is to develop a method for estimating the most profitable amount of N to apply. To estimate the most profitable amount of N, producers need to know (1) the value of hay at their ranch less harvest cost; (2) the price of available N applied; and (3) the forage yield response to N fertilizer. Because the value of hay and fertilizer are indicated by available prices, the purposes of this study are (1) to estimate N response functions for three meadow types in Wyoming (native, improved-grass, and grass-alfalfa) and (2) to illustrate the use of the N response functions in estimating the profitability associated with fertilization rates.

PROCEDURE

Nitrogen response curves for three types of hay meadows were estimated using data from fertilization trials in selected Wyoming locations. Multiple regression analysis was used to estimate the response of these hay meadows to fertilization. In addition to the amount of N, such variables as application of phosphorus, check plot yields (soil fertility and management practices), and yearly variation in location and climate were considered. The regression models, for native, improved-grass, and grass-alfalfa are presented in the appendix.

DATA

Data from fertilizer trials were collected from locations within six Wyoming counties for the period 1965-1980, except 1968 and 1979. Nitrogen application rates ranged from 0 to 160 lb./A. The number of trials for each meadow type were 29, 10, and 16 for native, improved-grass, and grass-alfalfa, respectively.

Native meadows typically included sedges, rushes, red top, timothy, and alsike clover. Improved-grass meadow species included smooth bromegrass, Garrison creeping foxtail, orchardgrass, or tall fescue. Grass-alfalfa meadow species were dominated by smooth bromegrass or orchardgrass, but included some alfalfa.

Average check plot yields for native, improved-grass, and grass-alfalfa meadows were 1.52, 1.20, and 2.02 tons/A, respectively. The average check plot yield for improved-grass was lower than expected, particularly when compared with native. This may be explained by the fact that the majority of these meadows were sod-bound smooth bromegrass. As expected, the average check plot yield for grass-alfalfa was highest due to the influence of alfalfa.

DISCUSSION OF RESULTS

The estimated yield response functions are reported in appendix table 1. Forage yields on native, improved-grass, and grass-alfalfa hay meadows increased as N application rates increased, at least up to N rates of 160 lb./A. Grass-alfalfa meadow yields were more responsive to P_2O_5 because of the legume component than native and improved grass meadow species. Relative to the base year, there was a significant variation in yields due to location and climate between the trial sites.

Total and marginal yield responses (additional 1bs. of forage for an additional lb. N) are illustrated for the three meadow types at selected N application rates in table 1. For example, at 80 lb. of N/A, estimated yields were 2.33, 2.15, and 2.42 tons/A for native, improved-grass, and grass-alfalfa, respectively. At 160 lb. of N/A, estimated yields were 2.87, 2.74, and 2.70 tons/A. For native, improved-grass, and grass-alfalfa meadows, the estimated additional (marginal) yields/lb. of N at 80 lb. of N/A were 20.2, 20.4, and 13.0 lb./A respectively.[1] Additional yields/lb. of N at 160 lb. of N/A were 7.0, 9.4, and 1.0 lb./A, respectively. This indicates how additional yield/lb. of additional N decreases as application rates increase.[2]

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[1]The additional yield in lb. obtained from an additional lb. of N is estimated from the equations on page 6, where N equals the lb. of N/A.
[2]This represents what is often referred to as a diminishing marginal response, that is, the additional yield per additional unit of fertilizer decreases as the amount of fertilizer applied increases.

Table 1. Estimated total and marginal yield responses of native, improved-grass, and grass-alfalfa hay meadows to N.

N Application Rate	Total[a/]			Marginal[b/]		
	Native	Improved-Grass	Grass-Alfalfa	Native	Improved-Grass	Grass-Alfalfa
lb./A	Tons/A			lb./A/lb. N		
0	1.26	1.11	1.66	----	----	----
40	1.86	1.69	2.10	28.6	26.0	19.0
80	2.33	2.15	2.42	20.2	20.4	13.0
120	2.67	2.50	2.62	13.6	14.8	7.0
160	2.87	2.74	2.70	7.0	9.4	1.0

[a/] Average estimated yields for experiment years at average check plot yeilds with no phosphorus.

[b/] Marginal yield estimates for an additional lb. of N are calculated using equations for native, improved-grass, and grass-alfalfa found on page 6.

As expected, native and improved-grass meadow species were more responsive to N than grass-alfalfa. Improved meadow species exhibited a greater yield response at higher levels of N than the other two meadow types.

ECONOMIC ANALYSIS

To estimate the most profitable level of N fertilization, a rancher needs to determine (1) the value of hay less harvest cost; (2) the price of N; and (3) the yield response to fertilizer. The price of hay and nitrogen can be estimated or obtained by the individual producer. The estimated response functions provide the information for the latter, which is used to calculate the additional yield obtained for an additional unit of N. However, individual hay meadows may not respond identically to N fertilizer as indicated by the estimated response function. The response to N on individual hay meadows will vary because of differences in such factors as soil type and fertility, dominant grass species present in the meadow, grazing management, irrigation practices, and harvest management. To determine the response on individual meadows, producers may want to run some fertilizer trials at different rates of N.

Using the response functions from appendix table A-1, the additional yield in pounds obtained for the last unit of N for each of the three meadow types is given by the following relationships:[3]

Native: Yield = 33.42 - 0.1652N
Improved-Grass: Yield = 31.54 - 0.1388N
Grass-Alfalfa: Yield = 24.98 - 0.1498N

where N is equal to the lb./A of available N applied. If ammonium nitrate costs $190/ton, the fertilizer costs per pound of N would equal $0.28 (illustrated below).

2000 lb. x .34 (34%) N in ammonium nitrate =
680 lb. of N/ton

$190/ton ÷ 680 lb. of N/ton =
$0.28/lb.

Using a net value for hay (value after paying for the additional harvest costs for an additional ton of hay) of $50/ton, the above information can be used to determine the most profitable amount of N to apply by fol-lowing the example shown in the sample worksheet on page 4. Due to the variation in the prices of hay, har-vesting, and fertilizer, individual operators will want to use their own harvest costs and fertilizer and hay prices. With these figures ranchers can estimate whether the value of the increased yield exceeds the cost of N ferti-lizer by completing the example worksheet for their own situation. (Additional worksheets are provided in the appendix). As long as the value of the change in yield per lb. of N (item 7) exceeds the price of N (item 8), it would pay ranchers to apply additional N.

To show the effects of different prices of hay and fertilizer on the optimum rate of fertilizer to apply, table 2 was developed for the three meadow types. Table 2 gives some idea of the sensitivity of the most profitable level of N fertilization to changes in hay an N prices.

Table 2. Profit maximizing levels of N on native, improved-grass, and grass-alfalfa meadows at selected hay and N prices.

Meadow type and hay prices less harvest cost	N prices ($/lb.) $0.26	$0.28	$0.30
		lb. N/A	
Native			
$40	123	117	111
$50	138	134	129
$60	150	145	141
Improved-grass			
$40	134	127	120
$50	154	148	142
$60	166	161	156
Grass-alfalfa			
$40	80	73	67
$50	97	92	87
$60	109	104	100

Table 3 illustrates what happens to returns above fertilizer and harvest costs as the rate of N application increases. In particular, the results show that at 80-100 lbs. of N most of the added returns above fertilizer and harvest costs have already been captured. Using native hay and a net price of $50 for hay, the difference in added returns above fertilizer and harvest costs for 80 compared to no nitrogen N/Ais $31.22, while the difference is only $6.10 for 80 compared to 130 lbs. of N/A. The 130 lb. level was selected as it represents the largest return over fertilizer and harvest cost with the net price of hay at $50/ton.

This decrease in added returns as the application of nitrogen increases raises an interesting question. Given the increased environmental concerns regarding nutrient runoff from agricultural lands and the emphasis on low-

[3]This is the first derivative of the response function in appendix table A-1. That is, the additional yield per unit of N is the N coefficient minus the product of two times the coefficient associated with N^2 times the application rate of N (1b. N/A). The marginal equations in the text are also converted from tons of hay to lb. of hay by multiplying the coefficients by 2000.

Sample Worksheet 1

Item	Sample meadow	Rancher's meadow
1. Meadow type	Native	________________
2. Market value of hay ($/lb.)	0.03	________________
3. Harvest costs ($/lb.)	0.005	________________
4. Value of hay less harvest cost (#2-#3) ($/lb.)	0.025	________________
5. Application of N (lb./A)	120	________________
6. Yield change by meadow type for the last lb. of N applied (lb./A) (#5 substituted for N in the appropriate equation below: a, b, or c)		
a) Native (33.42 - 0.1652N)[a/]	13.6	________________
b) Improved (31.54 - 0.1388N)[a/]		________________
c) Grass-alfalfa (24.98 - 0.1498N)[a/]		________________
7. Value of yield change per lb. of N above harvest cost (4x6)	$0.34	________________
8. Price of N ($/lb.)	$0.28	________________

[a/] N in the above equations is the application of N in lb./A. The value of N from #5 is substituted into the appropriate equation in #6 to obtain an estimate of the additional hay produced for the last lb. of N applied. In the example above: (33.42 - 0.1652 x 120) = 13.6

Table 3. Returns above fertilizer and harvest costs for nitrogen application rates on native, improved-grass, and grass-alfalfa meadows given net hay prices of $50 and $60/ton.[a/]

Nitrogen	Native		Improved-Grass		Grass-Alfalfa	
Applied	$50/T	$60/T	$50/T	$60/T	$50/T	$60/T
lb./ac	$/Acre					
0	63.00	75.60	55.50	66.60	83.00	99.60
10	68.35	82.58	60.41	73.05	86.25	104.07
20	73.28	89.06	64.98	79.09	89.14	108.09
30	77.81	95.05	69.19	84.71	91.65	111.66
40	81.92	100.54	73.06	89.91	93.78	114.78
50	85.61	105.54	76.58	94.70	95.54	117.45
60	88.90	110.04	79.76	99.07	96.93	119.67
70	91.77	114.04	82.58	103.02	97.94	121.45
80	94.22	117.55	85.06	106.56	98.58	122.77
90	96.25	120.56	87.20	109.67	98.84	123.65
100	97.90	123.08	88.98	112.38	98.73	124.07
110	99.12	125.10	90.42	114.66	98.24	124.05
120	99.92	126.63	91.51	116.53	97.38	123.57
130	100.32	127.66	92.25	117.98	96.14	122.65
140	100.30	128.20	92.64	119.01	94.53	121.27
150	99.86	128.24	92.69	119.63	92.54	119.45
160	99.02	127.78	92.39	119.83	90.18	117.18

[a/] Calculated at mean check plot yields, with no phosphorus and average estimated yields for experiment years. Prices used are $0.28/lb. for N and $50 and $60/ton for hay after subtracting a harvest cost of $10/ton.

input agriculture, can applications of nitrogen above 80-100 lbs. of N/A on mountain hay meadows be justified from society's point of view? While there are no easy answers, it is certainly a question that needs to be considered based on the results given in table 3, because added profits associated with rates above 80-100 lbs. are very minimal at best.

PRICE VARIABILITY

The season average price for all hay in Wyoming in 1989 was $87.50 per ton, but as recently as 1987 that price was $48. Because the decision to apply fertilizer must be made several months before the hay is harvested, determining the price of hay to use in deciding on the amount of fertilizer to apply is a difficult decision that farmers/ranchers face. This price variability creates a risk because the actual outcome is not known at the time the decision to apply fertilizer must be made.

There are several elements to any decision involving risk. First, there are several strategies available to the decision-maker. Second, there are the possible outcomes that can occur as a result of variations in weather, price, and other factors. The third element is the result associated with each strategy for each possible outcome.

An example, using native hay and the variability of hay price, will illustrate these elements. In particular, ranchers are faced with the problem of deciding how much nitrogen to apply, without knowing the price of hay. If a low level of nitrogen is applied and the price of hay is high, the opportunity for additional returns is given up. If a high level of nitrogen is applied and price is low, then returns are reduced.

In terms of strategies, suppose the rancher has three choices: to apply 90, 120, or 150 lbs. of N/A. After reviewing 30 years of data on hay price, the price outcomes and their probabilities are given below:

Hay Price $/Ton	Probability
< 50	.1333
51-60	.4333
61-70	.2667
71-80	.1000
> 80	.0667

The probabilities were obtained from 1960-89 average seasonal hay prices for Wyoming indexed to 1989. The same five price outcomes are possible for each of the three fertilizer levels. This creates 15 possible consequences or results to be considered.

Having outlined the elements of the problem, it is helpful to organize the information so it is useful in making a decision. A diagram that traces out the chosen strategies, potential outcomes, and their consequences will be used. This diagram is shown in table 4 and is called a decision tree. Note that five potential consequences for each strategy and the returns over variable costs for each one are depicted in table 4. For example, if 90 lbs. of nitrogen fertilizer is applied, the return over variable cost is $59.83, with the hay price at $45 per ton; and $157.00 with the hay price at $85 per ton.

The expected values for each strategy are the summation of the returns over variable costs weighted by their respective probabilities. Based on these values, the rancher wanting the highest average return might be expected to select the 120 lb. application strategy. However, there are also other possible decision rules such as selecting a strategy with the maximum possible returns over variable costs of $170.79, which would mean applying 150 lbs. of nitrogen. Another possible decision rule is the strategy with the most likely outcome, which is the $55 price of hay. Selecting the

Table 4. Decision tree for native hay fertilization.

Strategy	Price[a/] Outcome	Probabilities	Returns Over V.C.[b/]	Expected Value[c/]	Std. Dev.[d/]
	<45	.1333	59.83		
90 lb.	55	.4333	84.12		
N/A	65	.2667	108.42	97.08	25.66
	75	.1000	132.71		
	>85	.0667	157.00		
	<45	.1333	59.87		
120 lb.	55	.4333	86.57		
N/A	65	.2667	113.28	100.82	28.21
	75	.1000	139.98		
	>85	.0667	166.69		
	<45	.1333	57.30		
150 lb.	55	.4333	85.68		
N/A	65	.2667	114.05	100.81	29.97
	75	.1000	142.42		
	>85	.0667	170.79		

[a/] Hay price is the mid-point of each specified range.

[b/] Returns over variable costs are calculated by taking hay yield at the specified fertilizer level times the price outcome less $10 for harvest cost and then subtracting the cost of fertilizer at $0.28/lb. of nitrogen.

[c/] Expected value is derived by summing the products of "returns over V.C." times their respective probabilities, e.g. for the 90 lb. application rate: exp. values = .1333(59.83) + .4333(84.12) + ... + .0067(157.00) = 97.08

[d/] The standard deviation is a statistical measure of dispersion of outcomes around the expected value, such that higher values represent greater income variability or risk. Using the 90 lb. application rate, it is calculated as follows:

$$\text{Std. Dev.} = [(.1333)(59.83-97.08)^2 + (.4333)(84.12-97.08)^2 + ... + (.0067)(157.00-97.08)^2]^{1/2} = 25.66$$

greatest returns over variable cost at the $55 price would occur with the application of 120 lbs. of nitrogen. Finally, the variability of returns over time, as measured by the standard deviation in table 4, may be a concern. If so, a rancher may be willing to accept a lower expected return from applying 90 lb. ($97.08) versus 120 lb. ($100.82) in exchange for a lower standard deviation ($25.66 vs. $28.21) associated with the 90 lb. rate. At the other extreme, applying 150 lb. (vs. 120 lb.) would not be desirable, since greater income variability is incurred ($29.97 vs. $28.21) with no benefit of higher expected return.

SUMMARY COMMENTS

To conduct the type of analysis outlined above, the decision maker needs the following information:

1) The response of hay to fertilization;
2) The price of fertilizer; and
3) The net price of hay.

The procedure presented here provides an approach to estimate the amount of nitrogen to apply. However, ranchers need to be cautioned regarding the use of these fertilizer response functions in determining the amount of N to apply. These response functions, which are based on data from several locations and individual meadows, should not be expected to respond identically to specific case situations due to several factors, such as soil type, temperature, and management practices.

The price of nitrogen can be obtained from a local supplier and can be locked in before a decision is made. The price of hay less harvest cost is more difficult to determine and is a decision each individual has to make considering his own particular situation. However, using historical prices and some probability distribution of hay prices may provide some insights into that decision.

While all decisions involve some risk, the procedures outlined here do provide a logical approach to evaluating potential consequences of alternative strategies before a decision is made. Taking the time to implement such an approach should improve the final decisions.

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APPENDIX

MODEL

Previous research has demonstrated the advantages of using a quadratic function and ordinary least squares regression to estimate the response of yield to fertilization (NAS/NRC 1963 and Heady 1954). This approach was used in this study to estimate response functions. Because serial correlation was a problem (as was indicated by the Durbin-Watson statistic) the Cochrane-Orcutt iterative technique was employed.[a/] Following these procedures, the following statistical model was developed:

$$Y_j = b_0 + b_1 x_{1j} + b_2 x_{1j} + b_3 x_{2j} + b_4 x_{3j} + c_1 D_{1j} + \ldots + c_n D_{nj} + e_j$$

when: Y_j = the estimated yield of native hay in tons/A;

b_i & c_i = regression coefficients;

x_{1j} = lbs. of active N applied per acre;

x_{2j} =check plot yields (a measure of soil fertility management practices);

x_{3j} =0 or 1 phosphorus application variable 0 or 100 lbs. of active phosphorus);

D_{1j} ... D_{nj} = 0 or 1 variable for year (a measure of year-to-year yield variation in trial location and climate);

e_j = random error term; and

j = individual observations.

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a/ Serial correlation is often a problem in time series data. If this problem is not remedied in some manner, e.g., the Cochrane-Orcutt iterative technique, the estimates of the regression coefficients are not accurate.

Appendix Table A-1. Estimated response functions, coefficients, and summary statistics for native, improved-grass, and grass-alfalfa hay meadows (tons/A).

Variable	Native	Improved-Grass	Grass-Alfalfa
Intercept	0.6029	0.1625	0.6359
	(5.36)*[a]	(0.91)	(3.10)*
Nitrogen[b]	0.01671	0.01577	0.01249
	(9.03)*	(7.77)*	(3.95)*
$Nitrogen^2$	-0.00004130	-0.00003474	-0.00003745
	(-3.45)*	(-2.73)*	(-1.64)*
Phosphorus	0.1575	0.2087	0.3449
	(3.39)*	(3.29)*	(5.10)*
Base yield	0.5730	0.6746	0.3135
	(12.38)*	(7.34)*	(6.64)*
Dummy yr. var.			
1990	-0.8704	0.3842	
	(-5.36)*	(2.79)*	
1978		-0.1752	
		(-1.41)*	
1977		0.3074	
		(2.57)*	
1976			0.0256
			(0.09)
1975		0.3546	0.5265
		(3.68)	(2.47)*
1974			-0.1739
			(-0.72)
1973			1.1043
			(4.38)*
1972	-0.6304	-0.0107	0.3614
	(-4.14)	(-0.08)	(1.45)+
1971	0.1160	0.1067	0.4883
	(1.00)	(0.96)	(1.84)+
1970	-0.2503		
	(-1.64)+		
1969	0.1041		
	(0.97)		
1967	-0.1511		0.7337
	(-1.72)+		(3.72)*
1966	-0.0482		0.4222
	(-0.62)		(2.03)*
Base year	1965	1970	1965
R2	0.62	0.64	0.59
n	734	264	421

+,*Statistically significant at the 0.10 and 0.05 levels, respectively.

[a] The numbers in parentheses are t-values.

[b] Nitrogen application rates are in lb./A.

Sample Worksheet

Item	Sample meadow	Rancher's meadow
1. Meadow type	Native	________________
2. Market value of hay ($/lb.)	0.03	________________
3. Harvest costs ($/lb.)	0.005	________________
4. Value of hay less harvest cost (#2-#3) ($/lb.)	0.025	________________
5. Application of N (lb./A)	120	________________
6. Yield change by meadow type for the last lb. of N applied (lb./A) (#5 substituted for N in the appropriate equation below: a, b, or c)		
a) Native (33.42 - 0.1652N)[a/]	13.6	________________
b) Improved (31.54 - 0.1388N)[a/]		________________
c) Grass-alfalfa (24.98 - 0.1498N)[a/]		
7. Value of yield change per lb. of N above harvest cost (4x6)	$0.34	________________
8. Price of N ($/lb.)	$0.28	________________

a/ N in the above equations is the application of N in lb./A. The value of N from #5 is substituted into the appropriate equation in #6 to obtain an estimate of the additional hay produced for the last lb. of N applied. In the example above: (33.42 - 0.1652 x 120) = 13.6

Sample Worksheet

Item	Sample meadow	Rancher's meadow
1. Meadow type	Native	________________
2. Market value of hay ($/lb.)	0.03	________________
3. Harvest costs ($/lb.)	0.005	________________
4. Value of hay less harvest cost (#2-#3) ($/lb.)	0.025	________________
5. Application of N (lb./A)	120	________________
6. Yield change by meadow type for the last lb. of N applied (lb./A) (#5 substituted for N in the appropriate equation below: a, b, or c)		
a) Native (33.42 - 0.1652N)[a/]	13.6	________________
b) Improved (31.54 - 0.1388N)[a/]		________________
c) Grass-alfalfa (24.98 - 0.1498N)[a/]		
7. Value of yield change per lb. of N above harvest cost (4x6)	$0.34	________________
8. Price of N ($/lb.)	$0.28	________________

a/ N in the above equations is the application of N in lb./A. The value of N from #5 is substituted into the appropriate equation in #6 to obtain an estimate of the additional hay produced for the last lb. of N applied. In the example above: (33.42 - 0.1652 x 120) = 13.6