

Hay Quality in West Virginia – Final Report Hay Yield and Economics Project

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Hay is expensive to produce given the cost of labor, machinery, fuel, and fertilizer prices. However, it is an important crop providing feed for cattle, horses, and sheep when pasture is not available. Hay and haylage provide a means of preserving forage for use during drought and winter and for sale off the farm as a cash commodity. The value of hay is based on its nutritional quality. To make producing hay profitable, the hay's nutritional quality needs to be greater than its cost of production.

The nutritional needs of the animals to which hay is fed determines the quality of hay required or the need for additional supplemental feeds. The animal's nutritional requirements are determined by its species, age, size, and production level. Young animals need nutrients for growth. Lactating animals need nutrients for milk production. After water, digestible energy is the nutrient needed in the greatest abundance and its availability is dependent on the forage's digestibility. The animal's need for protein is related to the animal's energy intake and its type and level of production. For high-producing animals fed cool-season forages, energy will usually limit production. When feeding energy supplements with hay, if the supplements are fed in excess to the availability of crude protein (CP) in the forage, protein supplements will also be required. When feeding low-quality hay, CP may be the limiting factor.

Mineral intake from hay is dependent on the concentration and availability of the mineral in the forage and forage intake by the animal. Mineral content in forage is a function of plant species, plant maturity, and soil type and fertility. However, on a soil low in a mineral required for plant growth, forage species adapted to using that mineral in low amounts will be most competitive and will probably be the dominant species in the stand. Such adapted plants usually have low concentrations of the mineral in their tissue. A classic example is sweet vernal grass that is adapted to low soil phosphorus and pH. This grass is common in West Virginia and is often the dominant species on acid soils low in phosphorus. When the site is treated with phosphorus and lime, orchardgrass is able to grow better and can then compete with the sweet vernal grass and become dominant in the field.

Forage dry matter intake (DMI) by an animal is a function of the animal's size, production status, and the quality of the forage. Large animals eat more than small animals. High-producing animals generally consume more than less productive animals. In general, forage DMI is highest for young forages that are highly digestible and low in neutral detergent fiber (NDF). As plants mature, their digestibility, CP content, and DMI decrease while NDF increases. Legumes are

lower in NDF than grasses. As the legume content increases in a hay or pasture it allows livestock to consume more forage.

In many parts of West Virginia it is not possible to feed livestock on pasture 365 days of the year due to snow cover (4) or drought. The West Virginia University Grassland Team within the Agriculture and Natural Resources Program Unit developed an on-farm research project to evaluate management effects on the economics of hay production and nutritional quality of hay produced. This paper reports findings of the nutritional quality of hay produced in West Virginia.

Hay Sampling

To determine the nutritive value of hay produced in West Virginia, West Virginia University Extension Service faculty, Conservation District, WV Department of Agriculture, NRCS staff, and farmers sampled hay (5) from 1994 to 2006 under several projects which were combined in this project. Forage samples were sent to commercial forage testing laboratories and analyzed for dry matter, CP, ADF, NDF, lignin, non-structural carbohydrates, ash, and macro and microminerals. Total digestible nutrient content (TDN) was calculated from fiber fractions by regression or summative equations. Samples were not analyzed for all nutrients in all years due to different project protocols over years. The primary forage species in the hay samples were cool-season grasses and legumes typical to the Appalachian region. Management effects on the nutritional components measured were compared using analysis of variance and regression. In 2002 and 2003, paired hay samples were taken from the same field mowed at one time with part of the round baled hay harvested as plastic-wrapped haylage and part harvested as dry hay. Six bales from each harvest method were sampled and composited by harvest method for analysis. The nutritional components measured by this forage analysis were compared using paired t-test. All statistical analyses were conducted using NCSS-2007 Statistical Software (2)

Hay Quality

The nutritional quality of the hay samples analyzed was, on average, adequate for beef animals, with a reasonable range in quality (Table 1). Another way to look at the summary of these nutritional values is as the percentage of samples that would meet the needs of given classes of livestock. For the following discussion beef cattle will be used. The same comparison can be made using the nutrient requirements for other classes of livestock such as dairy cattle, sheep, or horses.

To identify the probability of these representative hay samples meeting the needs of a given livestock class, the percentile ranking (cumulative distribution) of nutrient concentration in the sampled hays is provided in Tables 2 and 3. These tables identify the percent of samples that fall below a given concentration of a nutrient. To use the percentile ranking tables, first identify the requirement for the nutrient of interest for the livestock class being fed. Then, go to the table column for the nutrient in question and within that column find the value of the nutrient concentration needed by the animal. Project across to the percentile rank column. The value in this column is the percentage of hay samples in the database that would not have met this

nutritional requirement. If the exact value of interest is not listed, interpolate between listed values that are above and below the value of interest. For practical purposes, when using the percentile ranking tables, rounding to the nearest 5% is reasonable.

Table 1. Number of samples (N), mean, and variability as measured by the standard deviation (SD), minimum (min), and maximum (max) of collected hay samples.

	Measure	N	Mean	SD	Min	Max
Carbohydrates Protein and Calculated Values	ADF	1214	42.1	4.7	21.0	51.8
	ADF/NDF	1200	0.65	0.05	0.49	0.85
	CP	1213	11.5	3.4	5.8	32.3
	CP/TDN	1213	0.21	0.05	0.10	0.38
	DM	1187	79.6	14.4	14.3	96.2
	Lignin	779	6.19	0.98	3.00	11.3
	NDF	1200	64.9	6.6	34.5	79.3
	NSC	825	13.4	4.7	0.1	31.5
	TDN	1214	55.4	4.8	41.0	73.0
Macro Minerals	Ash	779	7.68	0.94	5.00	15.1
	Ca	1209	0.648	0.246	0.140	1.860
	K	1211	1.82	0.47	0.15	3.42
	Mg	1202	0.198	0.100	0.060	1.970
	P	1201	0.285	0.076	0.080	0.630
	S	1082	0.169	0.040	0.050	0.42
Micro Minerals	Cu	148	7.05	1.56	4.00	15.00
	Fe	133	394	575	70	3510
	Mn	148	86.7	54.4	6.0	373.0
	Mo	63	4.36	10.31	0.20	60.00
	Zn	135	22.2	4.6	10.0	48.0

ADF – acid detergent fiber

DM – dry matter

NSC – non-structural carbohydrates

Ca – calcium

Fe – iron

Mg – magnesium

Mo – molybdenum

S – sulfur

CP – crude protein

NDF – neutral detergent fiber

TDN – total digestible nutrients

Cu – copper

K – potassium

Mn – manganese

P – phosphorus

Zn – zinc

Table 2. Percentile ranking of hay samples based on acid detergent fiber (ADF), neutral detergent fiber (NDF), lignin, non-structural carbohydrate (NSC), crude protein (CP), and total digestible nutrients (TDN) and ratio of ADF to NDF and CP to TDN.

Percentile	ADF	NDF	Lignin	NSC	CP	TDN	ADF/NDF	CP/TDN
99	49.7	76.2	9.74	26.8	21.6	68	0.79	0.35
95	48.3	72.4	7.71	21.7	18.0	64	0.74	0.31
90	47.4	70.3	7.20	19.2	16.3	62	0.71	0.28
85	46.6	69.7	7.00	17.2	15.3	61	0.70	0.26
80	46.1	69.4	6.80	16.4	14.1	59	0.69	0.25
75	45.5	69.2	6.70	15.8	13.3	58	0.68	0.24
70	45.1	69.0	6.60	15.4	12.6	57	0.68	0.23
65	44.4	68.4	6.50	15.0	12.1	57	0.67	0.21
60	43.9	68.2	6.30	14.6	11.6	56	0.67	0.21
55	43.5	68.1	6.20	14.2	11.0	55	0.66	0.20
50	43.2	67.3	6.00	13.7	10.6	54	0.65	0.19
45	42.5	66.8	6.00	13.2	10.1	54	0.65	0.19
40	41.9	65.7	6.00	12.6	9.8	53	0.64	0.19
35	41.3	64.8	6.00	12.0	9.5	53	0.63	0.18
30	40.2	63.1	5.87	11.3	9.2	53	0.62	0.17
25	39.2	61.9	5.70	10.5	8.8	52	0.61	0.17
20	38.2	59.7	5.60	9.7	8.5	52	0.61	0.16
15	37.1	57.8	5.29	8.6	8.2	51	0.59	0.16
10	35.6	55.3	5.00	7.3	7.9	50	0.58	0.15
5	33.6	51.3	4.60	5.7	7.7	49	0.56	0.14
1	28.8	44.1	4.00	2.7	7.3	46	0.52	0.13

ADF – acid detergent fiber

DM – dry matter

NSC – non-structural carbohydrates

CP – crude protein

NDF – neutral detergent fiber

TDN – total digestible nutrients

Table 3. Percentile ranking of hay samples based on macro and micromineral content of hay samples taken across West Virginia.

Percentile	Ash	Macro Minerals					Micro Minerals				
		Ca	K	Mg	P	S	Cu	Fe	Mn	Mo	Zn
99	11.87	1.45	2.9	0.43	0.47	0.27	13.5	3354	348	60.00	44
95	9.10	1.13	2.6	0.34	0.42	0.25	9.0	1700	197	9.20	32
90	8.50	0.97	2.4	0.29	0.38	0.23	9.0	733	118	4.60	27
85	8.10	0.87	2.3	0.26	0.36	0.22	8.0	443	102	4.00	24
80	8.00	0.81	2.2	0.24	0.35	0.21	8.0	375	95	4.00	24
75	7.90	0.76	2.1	0.22	0.34	0.20	8.0	354	93	4.00	23
70	7.90	0.73	2.1	0.22	0.32	0.18	8.0	313	93	3.48	22
65	7.86	0.69	2.0	0.21	0.31	0.17	7.0	272	93	3.30	22
60	7.80	0.66	1.9	0.19	0.29	0.17	7.0	255	89	3.00	22
55	7.80	0.63	1.9	0.18	0.29	0.17	7.0	241	81	3.00	22
50	7.70	0.60	1.8	0.17	0.28	0.16	7.0	221	81	3.00	21
45	7.60	0.58	1.8	0.17	0.27	0.16	7.0	206	81	2.80	21
40	7.60	0.56	1.7	0.16	0.26	0.15	7.0	195	74	2.00	21
35	7.50	0.53	1.6	0.16	0.25	0.15	7.0	185	71	2.00	21
30	7.30	0.51	1.6	0.15	0.24	0.15	6.0	169	68	0.96	21
25	7.20	0.48	1.5	0.14	0.23	0.14	6.0	151	67	0.90	21
20	7.00	0.45	1.4	0.14	0.22	0.13	6.0	122	60	0.70	19
15	7.00	0.43	1.3	0.13	0.21	0.13	5.9	112	58	0.52	18
10	6.80	0.38	1.2	0.13	0.19	0.12	5.0	99	52	0.40	18
5	6.39	0.34	1.0	0.12	0.17	0.12	5.0	82	8	0.30	17
1	5.62	0.23	0.8	0.11	0.13	0.11	4.0	71	6	0.20	12

Ca – calcium

Fe – iron

Mg – magnesium

Mo – molybdenum

S – sulfur

Cu – copper

K – potassium

Mn – manganese

P – phosphorus

Zn – zinc

Nutritional quality of sampled hays relative to animal requirements

Total Digestible Nutrients (TDN) is an estimate of the hay's digestible energy content. Of the samples analyzed 5% did not meet the needs for a mature dry cow (49% TDN), 60% did not meet the needs of an average milking mature beef cow (56% TDN), and 80% did not meet needs of a 500-lb growing steer gaining 1 lb/day (59% TDN) (Table 2).

Crude protein (CP) is an estimate of the hay's protein content. Of the samples analyzed, 10% did not meet the needs for a mature dry cow (7.0% CP), 30% did not meet needs of an average milking mature beef cow (9.3% CP), and 30% did not meet the needs of a 500-lb growing steer gaining 1 lb/day (9.5 % CP).

Acid detergent fiber (ADF) is a measure of total cellulose, lignin, and acid detergent insoluble ash such as silica, which limit cellulose digestion. The ADF is often used to estimate the hay's digestibility. This is somewhat accurate in first-cut hay but less so in aftermath hay. Forage ADF is within the cell wall so is part of the plant's NDF. There is no general requirement listed for beef cattle for ADF. However, when feeding rations high in supplemental energy feeds, such as corn, adequate ADF in the ration is needed to maintain rumen health.

Neutral detergent fiber (NDF) is a measure of the cell wall content of the plant. In high-producing livestock, such as near peak milk-producing dairy cattle, NDF is a good measure of potential DMI; lower levels of NDF in a hay result in higher DMI of the hay. However, dry beef cattle fed adequate levels of protein will accommodate greater gut fill of high NDF forage than do near peak dairy cattle and may not be as limited in DMI by high NDF forages. Legumes are lower in NDF at a given stage of growth than grasses. There is no general requirement listed for beef cattle for NDF. However, when feeding rations high in supplemental energy feeds such as corn, adequate NDF in the ration is needed to maintain rumen health.

Macrominerals

Calcium (Ca) was below the needs of a mature dry cow (0.19% Ca) in only 10% of the samples, while 30% of samples did not meet needs of an average milking beef cow (0.27% Ca), and 30% did not meet the needs of a 500-lb growing steer gaining 1 lb/day (0.32 % Ca).

Phosphorus (P) was below the needs of a mature dry cow (0.19% P) in only 10% of the samples tested, while 30% of samples did not meet the needs of an average milking beef cow (0.22% P), and 30% did not meet needs of a 500-lb growing steer gaining 1 lb/day (0.20 % P).

Magnesium (Mg) was adequate for a mature dry cow (0.10 % Mg) with less than 1% of hay samples not meeting her Mg need. However, 60% of hay samples did not meet the needs of a lactating beef cow (0.20% Mg).

Potassium (K) was adequate for all classes of beef cattle with less than 1% of samples not meeting the nutritional needs of beef cattle (0.60 % K).

Sulfur (S) is moderately deficient in hay samples tested with 25% of samples not meeting the needs of beef cattle (0.15% S).

Microminerals

Copper (Cu) is deficient in hay crops with 95% of samples not meeting the 10 parts per million (ppm) level recommended for beef cattle.

Iron (Fe) is well supplied in hay crops with 99% of hay samples meeting the 50 ppm level recommended for beef cattle.

Manganese (Mn) is generally sufficient in hay crops with less than 10% of hay samples not meeting the 20 ppm level recommended for beef cattle.

Molybdenum (Mo) has no stated requirement for cattle by the NRC.

Sodium (Na) is deficient in hay crops with 95% of samples being below the 0.06 ppm level recommended for cattle.

Zinc (Zn) is deficient in hay crops with 90% of hay samples falling below the 30 ppm level recommended for cattle.

Samples were not tested for Cobalt (Co), Iodine (I), and Selenium (Se). Forage crops are frequently deficient in these microminerals in West Virginia and it is recommended that mineral supplements containing these elements be included in the ration for beef cattle.

Constituent ratios useful in management

The ratio of CP/TDN is an index of the ability of CP in the hay to meet the needs of the rumen bacteria for digesting the available energy in the hay. This ratio relates to the rumen bacteria's need for nitrogen while it is digesting organic matter in the rumen. Based on a modified interpretation of the research data of M. H. Brant (1) provided by Dr. J. E. Moore (University of Florida), when the ratio of CP/TDN is less than 0.2, rumen bacteria do not have enough nitrogen to make protein for themselves to reproduce and digest the forage at their optimal rate. This results in the cattle's DMI being limited by the rate of forage digestion due to the lack of adequate crude protein in the diet (Figure 1. A.). When feeding hay crops with a low CP/TDN ratio, feeding a high-protein supplement will provide the nitrogen needed by the rumen bacteria so that they can reproduce and digest the hay more rapidly. This causes an increase in DMI of the hay by the cow which provides additional energy from hay and protein to the cow.

Brant and Moore's data shows that DMI (as a percentage of body weight) is related to the ratio of CP/TDN by the following regression model ($R^2 = 0.75$, $SD_{reg} = 0.35$, $N = 135$):

When CP/TDN is less than 0.2 then:

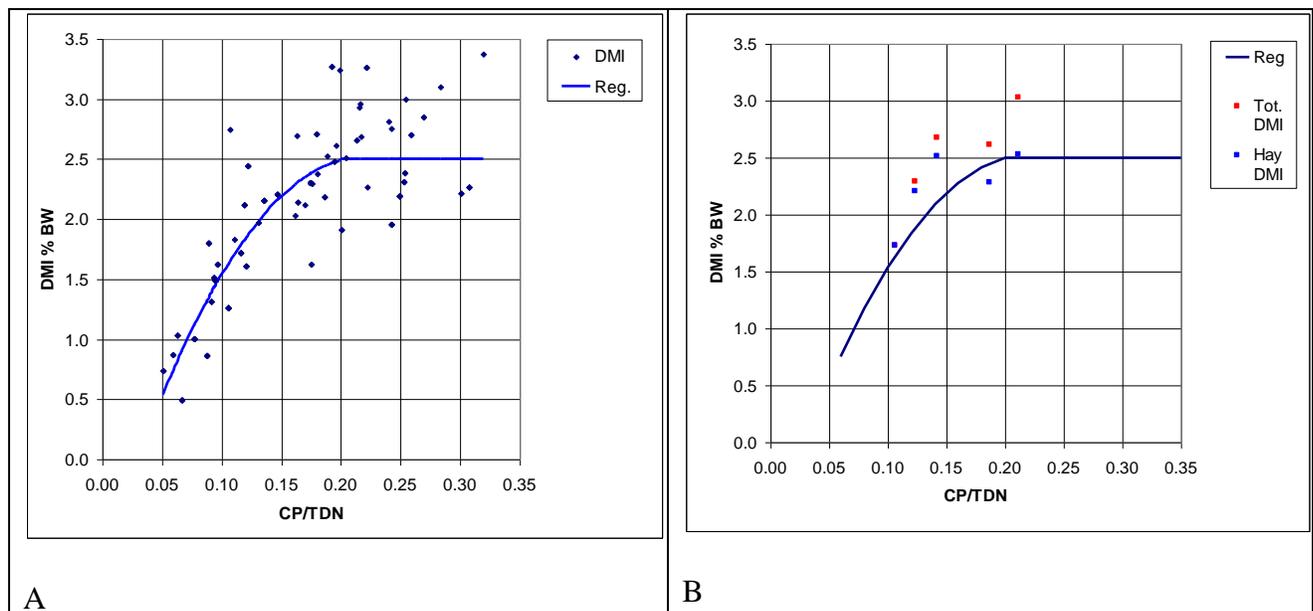
$$\text{DMI \% BW} = -0.84 + 30.9 \text{ CP/TDN} - 71.3 (\text{CP/TDN})^2$$

When CP/TDN is greater than 0.2 then:

$$\text{DMI \% BW} = 2.5$$

Data from Mathis (3) shows how the DMI of a hay testing low in CP/TND is increased when supplemented with a high-CP feed such as soybean meal (Figure 1. B.). The DMI of this low-CP hay was increased with feeding of soybean meal. Brant and Moore's model described the combination of hay and soybean meal DMI with an R^2 of 0.62 and prediction error (measured - predicted) of 0.14 (with a standard deviation {SD} of 0.23 and a confidence interval {CI} of 0.28) and described total ration DMI with an R^2 of 0.84 and prediction error of 0.36 (with SD of 0.21 and CI of 0.26).

Figure 1. A. Relationship between CP/TDN ratio and dry matter intake (DMI) of forage expressed as a percentage of the animal's body weight (% BW). B. The effect of feeding soybean meal with a low-CP hay and its effect on total diet CP/TDN ratio, hay DMI and total ration DMI compared to the CP/TDN vs. DMI model based on Moore's data.



Ratio of ADF/NDF

As previously stated, ADF is a measure of total cellulose, lignin, and acid detergent insoluble ash and NDF is a measure of the cell wall content of the forage plant. Forage ADF is within the cell wall so is part of the plant's NDF. Within both legumes and grasses the ratio of ADF to NDF is

relatively constant across growth stages so the ratio of ADF/NDF in a mixed forage is an index of the content of grass versus legume and other forbs in the forage. Pure grass hays have an ADF/NDF ratio between 0.50-0.55 while pure legumes have a ratio between 0.70-0.75. Since livestock can consume more legume than grass forage due to a higher rate of digestion of the legume forage, a high ADF/NDF ratio will indicate a forage that may be consumed at a higher rate for a given level of NDF.

Management determines hay quality

When energy or protein quality of hay does not meet the animals' nutrient requirement, improved harvest management will often improve the hay's nutritional quality so that lower amounts of purchased supplements are needed.

The date of mowing first-cut hay has a major impact on the hay's TDN and CP content. Delaying the harvest of first-cut hay reduces the hay's nutritional quality.

For dry hay the relationship between date of first cut (measured as day of the year (DOY)) and TDN percentage (Figure 2 A) was:

$$\text{TDN} = 101 - 0.264 \text{ DOY} \quad R^2 = 0.48$$

For dry hay the relationship between date of first cut and CP percentage (Figure 2 B) was:

$$\text{CP} = 24 - 0.084 \text{ DOY} \quad R^2 = 0.30$$

For haylage the relationship between date of first cut and TDN percentage (Figure 2 A) was:

$$\text{TDN} = 92 - 0.213 \text{ DOY} \quad R^2 = 0.34$$

For haylage the relationship between date of first cut and CP percentage (Figure 2 B) was:

$$\text{CP} = 30 - 0.115 \text{ DOY} \quad R^2 = 0.45$$

Delaying the harvest of first-cut hay also reduces the forage yield for aftermath haying or grazing.

Method of baling hay as dry hay or haylage and the moisture content in haylage (wet hay less than 30% moisture vs. haylage greater than 30% moisture) and first-cut versus aftermath hay also affected some component of hay's nutritional quality (Tables 4 and 5).

Hays baled as haylage or harvested as aftermath were higher in CP than dry hay or first-cut hay respectively (Table 4). Haylage was lower in ADF and NDF than dry hay and aftermath hay was lower in NDF than first-cut hay (Table 4). Haylage averaged higher in TDN than dry hay but there was no difference between first-cut and aftermath hays. The content of Ca, P, K, and Mn were higher in haylage than in dry hay. The content of Ca, P, Mg, and Zn were higher in haylage

and aftermath than in dry hay and first-cut hay. The content of NSC, Lignin, S, Fe, Mo, were not affected by harvest management or hay cut while Mg, ash, and Zn were not affected by harvest management and ADF, TDN, K, Cu, Mn were not affected by hay cut.

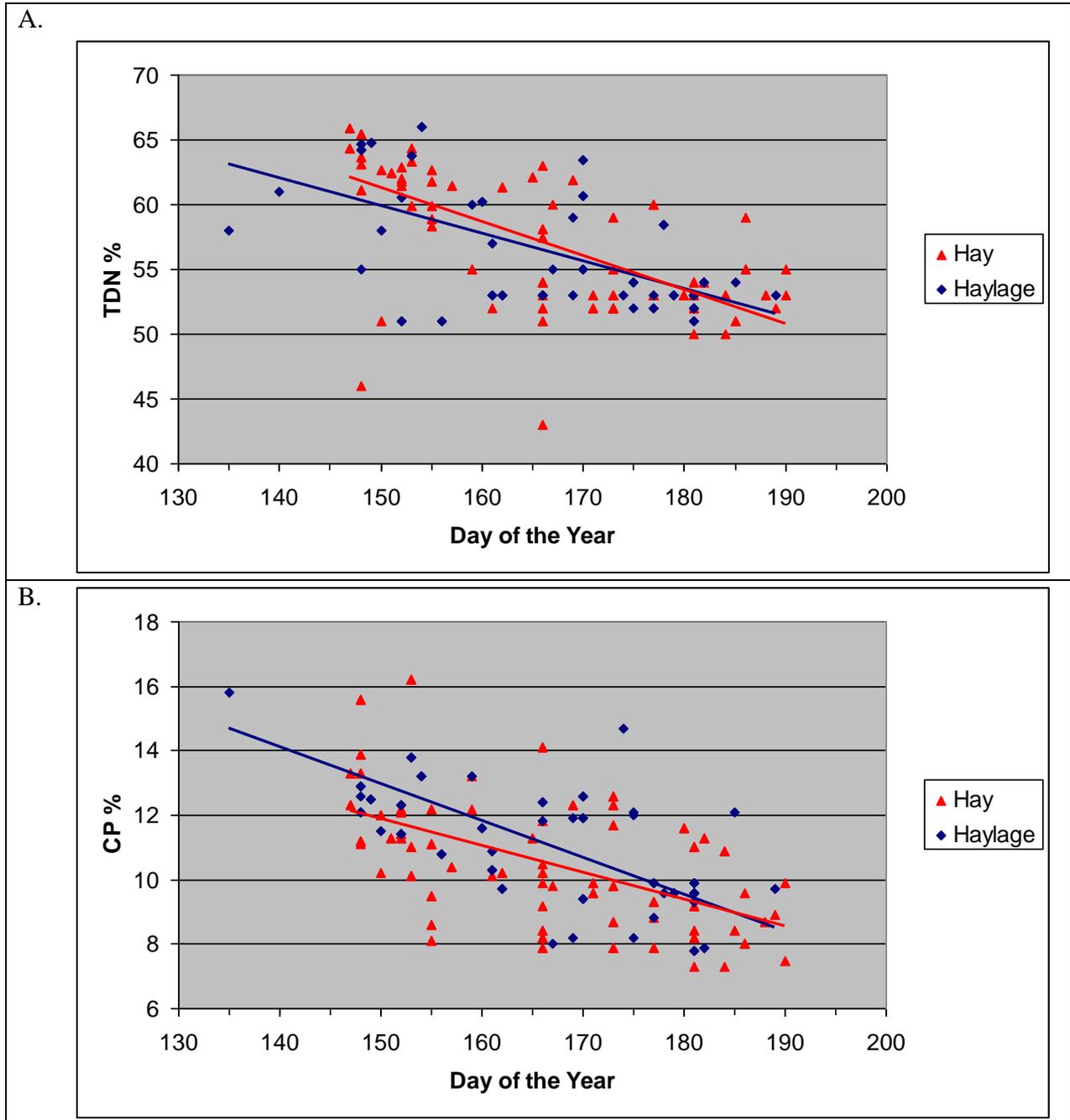


Figure 2. Effect of first-cut date of harvest measured as day of the year (DOY) on A. total digestible nutrient (TDN) and B. crude protein (CP) content of hay (May 20 is DOY 140, July 9 is DOY 190).

Table 4. Analysis of variance for hay harvest management and first-cut versus aftermath forage for moisture and chemical composition of West Virginia hay samples (treatments producing no significant effect in the response variable are not listed, means within a response followed by different letters are significantly different).

Response	Comparison	Treatment	N	Mean
DM	Mgmt	Haylage	161	51.4 a
		Wet Hay	122	71.1 b
		Hay	890	85.7 c
CP	Mgmt	Hay	889	11.2 a
		Wet Hay	122	12.1 b
		Haylage	169	13.1 c
	Cut	First	732	11.6 a
Aftermath		448	12.7 b	
ADF	Mgmt	Haylage	169	40.3 a
		Hay	890	42.4 b
		Wet Hay	122	42.8 b
NDF	Mgmt	Haylage	169	61.8 a
		Hay	884	65.5 b
		Wet Hay	121	65.6 b
	Cut	First	726	64.8 a
Aftermath		444	63.7 b	
TDN	Mgmt	Hay	890	55.1 a
		Wet Hay	122	55.2 a
		Haylage	169	57.1 b

Table 5. Analysis of variance for hay harvest management and first-cut versus aftermath forage for mineral composition of West Virginia hay samples (means within a response followed by different letters are significantly different).

Mineral	Comparison	Treatment	N	Mean
Ca	Mgmt	Hay	888	0.641 a
		Wet Hay	122	0.656 a
		Haylage	166	0.773 b
	Cut	First	732	0.638 a
		Aftermath	444	0.742 b
P	Mgmt	Hay	883	0.285 a
		Wet Hay	121	0.294 a
		Haylage	164	0.312 b
	Cut	First	731	0.277 a
		Aftermath	437	0.317 b
Mg	Cut	First	732	0.184 a
		Aftermath	437	0.227 b
K	Mgmt	Hay	888	1.79 a
		Wet Hay	122	1.79 a
		Haylage	168	1.95 b
Mn	Mgmt	Haylage	31	48.7 a
		Wet Hay	17	75.4 b
		Hay	100	92.2 b
Cu	Mgmt	Haylage	31	6.31 a
		Hay	100	7.18 b
		Wet Hay	17	8.07 c
Zn	Cut	First	107	22.6 a
		Aftermath	28	25.5 b
Ash	Cut	First	398	7.56 a
		Aftermath	348	7.85 b

Plastic-wrapped haylage versus dry hay

When comparing plastic-wrapped haylage to dry hay harvested from the same field cut the same day, plastic-wrapped haylage had slightly higher nutritional quality than the dry hay (Table 4). This was probably due in part to more field loss in harvesting dry hay and there appears to be less quality loss in fermentation of wrapped haylage than occurs during the sweating or heating of dry large round bales. Neutral detergent insoluble crude protein (NDICP) is a good measure of heat damage that occurs during fermentation of haylage and sweating in dry hay and was higher in the dry hay than in the haylage. There was no difference between storage methods in ADF, NDF, NFC, and major minerals.

Table 6. Nutritional quality of hay cut on the same day and stored as plastic-wrapped haylage or dry hay (10 fields, 6 bales per field per storage method).

Measure	Wrapped	Dried	Method P
CP	12.1	10.7	0.05
Deg CP	68.8	55.4	0.05
Sol CP	50.6	21.4	<0.01
NDICP	2.7	4.5	<0.01
TDN	56.8	52.2	0.07
NEL	0.53	0.43	0.07
NEM	0.51	0.42	0.04
NEG	0.26	0.17	0.05
Crude Fat	3.6	2.2	<0.01

ADF - acid detergent fiber
 NDF - neutral detergent fiber
 NEL - net energy lactation
 NEM - net energy maintenance

CP - crude protein
 TDN - total digestible nutrients
 NEG – net energy gain

Grass hay yield response to nitrogen fertilizer

A major cost in hay production is the cost of fertilizer. When growing nitrogen-fertilized grass hay, the optimum rate of nitrogen is based on the cost of fertilizer and the value of the hay. A summary of orchardgrass response to nitrogen fertilizer found that dry matter yield (DMY) (lbs/acre) increased with diminishing returns to N rate (Figure 3. A.)(R² of 0.64, regression SD of 1939):

$$DMY = 4790 + 39.9 N - 0.0580 N^2$$

Relative dry matter yield (RelDMY) measured as the fraction of maximum yield across species, years, and locations was even more consistent (Figure 3. B.)(R² of 0.79, regression SD of 0.15):

$$RelDMY = 0.40 + 0.00294 N - 0.00000354 N^2$$

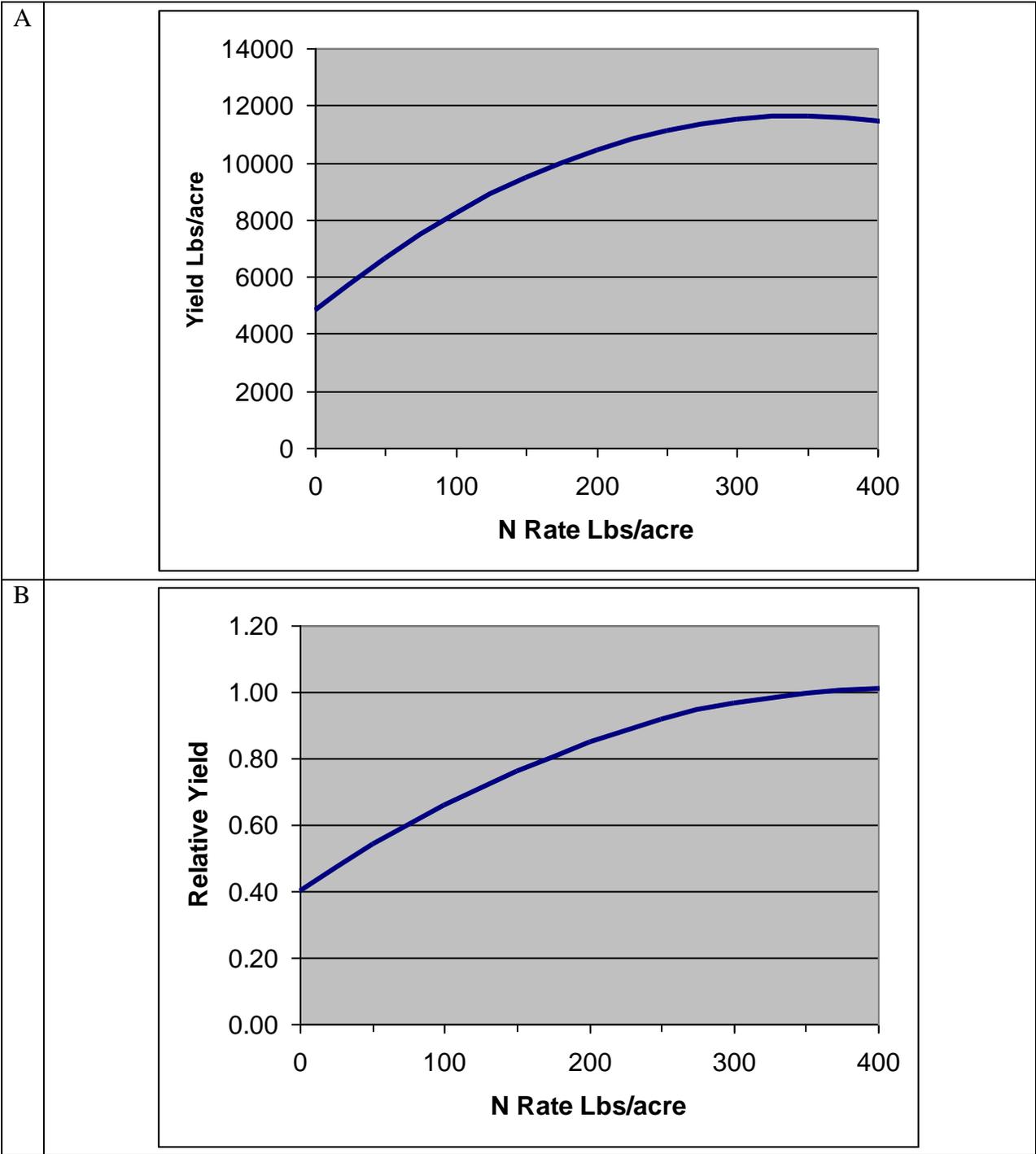


Figure 3. A. Response of orchardgrass yield to nitrogen (N) fertilization. B. Relative yield response for all grasses to N fertilization across the Northeastern states.

For these experiments, maximum yields ranged from 5 to 7 tons DM per acre before drying, raking, and baling losses. Under good management drying, raking, and baling losses average about 90 percent when making haylage and 75 percent when making dry hay.

Average yields for different forage grasses under nitrogen fertilization and alfalfa and red clover were estimated from regional forage variety trials (Table 7). These trials are most often conducted on good soils at experiment station sites.

Table 7. Average hay yield, their standard deviation (SD), and coefficient of variation (CV, SD divided by mean) for tested varieties of forage species in variety trials conducted in West Virginia, Virginia, Pennsylvania, and Kentucky (N rate 100, 210, 220, and 150 lbs/acre/year respectively).

Species	Mean Yield tons/acre	SD	CV	Site Years
Alfalfa	6.23	1.18	0.19	122
Red clover	4.35	1.47	0.34	46
Orchardgrass	4.81	1.23	0.25	67
Perennial Ryegrass	3.58	1.39	0.39	25
Reed Canarygrass	4.78	1.46	0.31	36
Smooth Bromegrass	4.39	1.08	0.25	35
Tall Fescue	5.05	1.38	0.27	55
Timothy	4.25	1.24	0.29	54

Mixed grass-legume hay yield relative to legume content

Producers often want to know the legume content need in a hay stand to achieve high production. The fraction of legumes in a forage stand required to make maximum yield is dependent on prior site management (Figure 4). The two sites presented in Figure 4 were established by no-till planting. Site 1 was a field previously used to produce corn and small grain crops over several years. This management resulted in a lowering of organic matter in the soil. Site 2 was an old hayfield where the organic matter had not been reduced by cropping. The annual weeds on site 1 and the sod on site 2 were killed using different forms and rates of herbicides with plots planted to red clover or birdsfoot trefoil. Higher legume content was needed to achieve maximum yield on site 1 than on site 2. Presumably the lower soil organic matter on site 1 was not able to provide adequate N for maximum yield and higher content of legumes was needed to provide the N for maximum yield. On site 2, the higher soil organic matter was able to provide more N, and lower legume content provided adequate N, for maximum yield on that site.

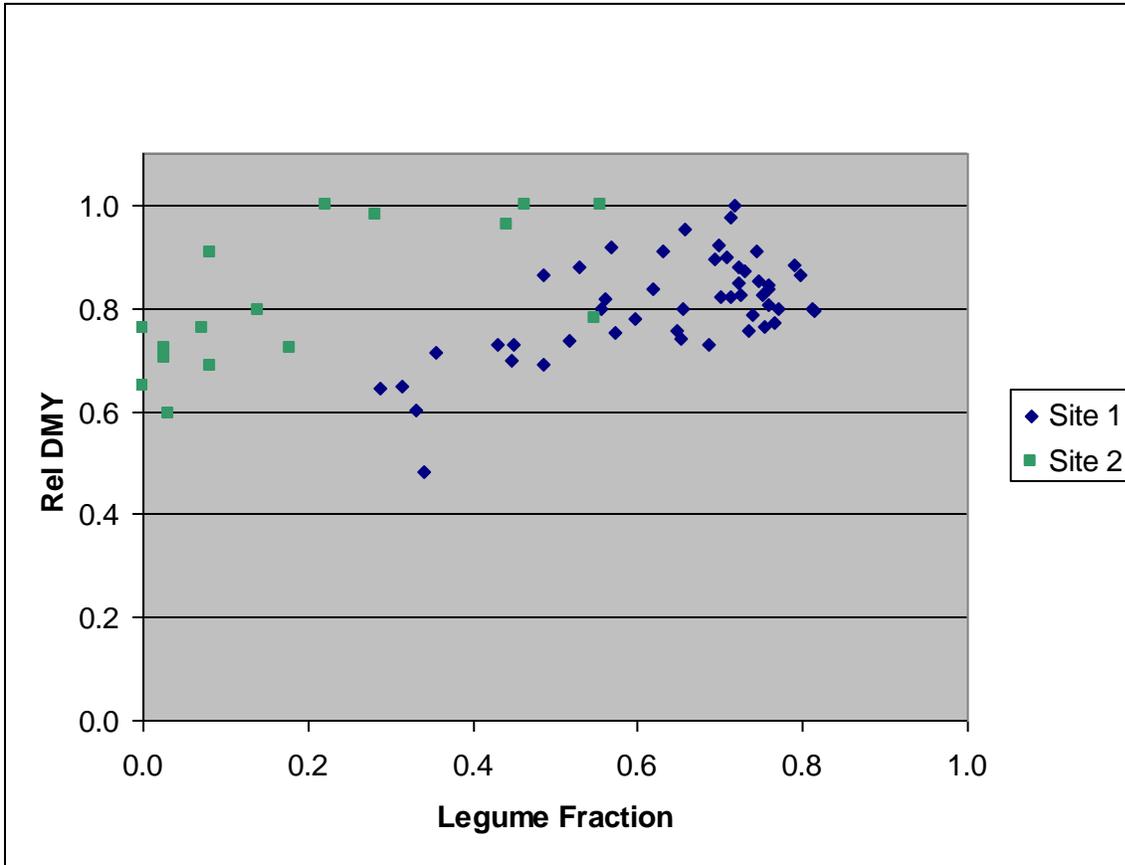


Figure 4. Hay yield at two locations the year after no-till establishment of red clover and birdsfoot trefoil. Site 1 was on land previously cropped to corn and small grains with the soil low in organic matter. Site 2 was land that was old hay sod killed using herbicides prior to establishment with the soil relatively high in organic matter.

Economic risk due to annual yield differences and use of legumes or nitrogen fertilizer

Hay production varies from year to year due to weather. Market conditions and risk aversion determine the optimum N fertilization rate or the farmer's decision to use legumes to fix N for hay production. There is good information on the effect of nitrogen and legume management on the average and variability in hay production due to weather. This information was used in production cost budgets to evaluate the effect of year to year production variability on the breakeven price. Production costs were based on machinery and time costs typical of a small West Virginia beef cattle farm. Fertilizer prices were based on 2005 spring prices. For rates of N fertilizer greater than 50 lbs/acre/year it was assumed that the N would be split applied and two or three hay cuts taken per year. The cost of hay production is expressed as a breakeven price, the value to cover all fertilizer, machinery, and labor (\$10/hr) but not the value of the land. The risk of rain damage on hay was not counted in this study.

The mean hay yield increased with N rate but variation in hay yield for this data was assumed constant across N rates (Figure 5). Average yields and the odds of having higher or lower yields are presented in the figure. The 15% level represents a one in six year chance of yields being lower than indicated while the 85% level represents a one in six year chance of yields being higher than indicated. The space between the 15% and 85% probabilities represent where yields will be two out of three years.

As N-fertilization rate was increased, hay production increased. At the 2005 price level for N there was little difference in the 15-85% probability yield spread for any of the systems evaluated. Under N-fertilization, the zero N-rate had the highest average cost (breakeven price of \$63/ton) while the 100 lbs N/acre had the lowest cost (\$53/ton) (Figure 6). The orchardgrass-legume hay management provided lowest cost (\$44/ton). The largest 15-85% yield spread in breakeven price occurred for the zero N-rate while the smallest spread occurred for the orchardgrass-legume system. This spread indicates the risk in the management system.

When fertilizing at the 100-lb N/a rate, the N-rate that had the lowest breakeven price for N-fertilized hays, the price of N has to increase to \$0.72/lb (1.9 times the 2005 price) before the breakeven price of N-fertilized hay increased to \$63/ton, the breakeven price of hay receiving no N-fertilizer and having no legume.

Under the 2005 N price (\$0.38/lb N) these budgets point out that machinery and other variable costs have a greater influence on hay breakeven price than does N-fertilizer price. From a business management perspective it appears that maintaining legumes in hay stands to provide N is an important way to keep hay production costs down. When legume content in the stand is insufficient to maintain adequate N-fixation, N-fertilization of the grass hay stand will increase hay production and keep unit production costs of hay lower than using no N-fertilizer, which will result in low hay yields.

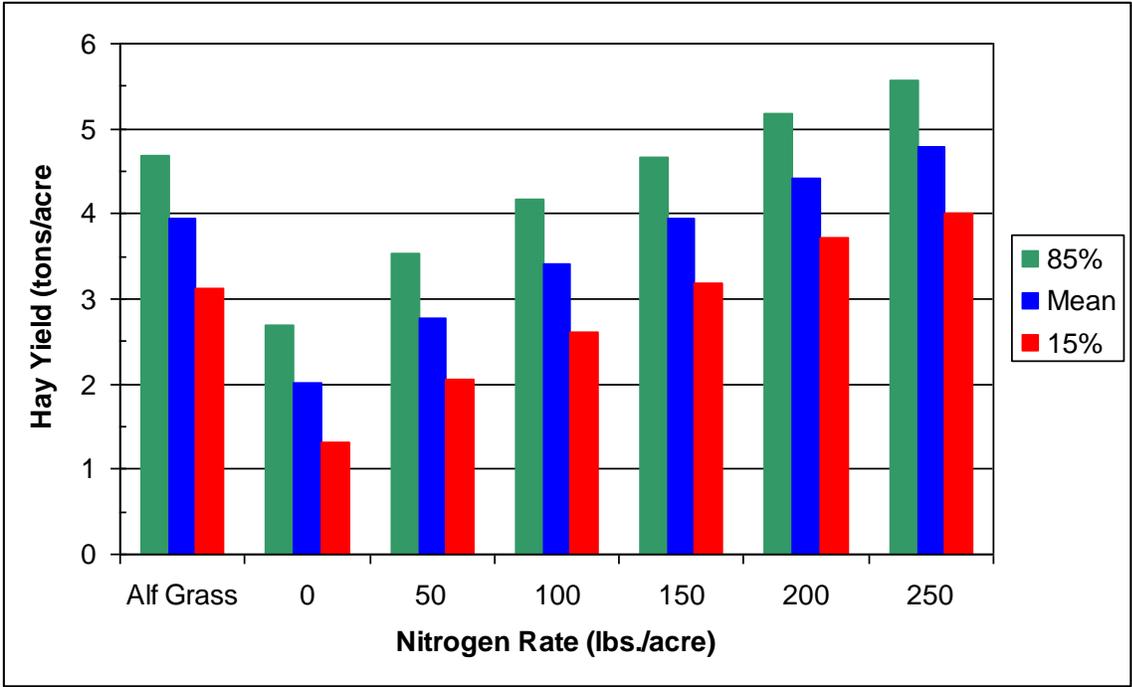


Figure 5. The effect of nitrogen rate and legume combination on the mean and 15% and 85% probability levels of orchardgrass and alfalfa-orchardgrass hay yield.

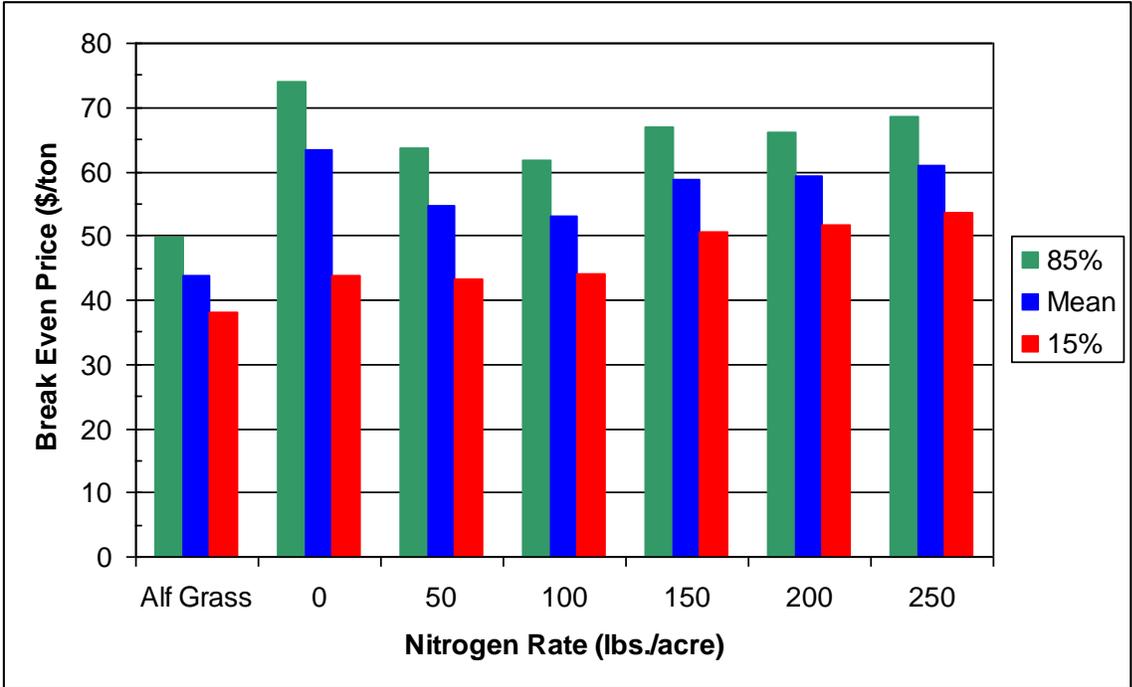


Figure 6. The effect of nitrogen rate and alfalfa combination on the mean and 15% and 85% probability level of orchardgrass hay breakeven price.

Economics of winter hay feeding efficiency

The cost of return to winter hay feeding is dependent on the efficiency with which hay is fed to livestock and the efficiency with which the manure is returned to the soil where it is needed. When less hay is wasted in storage or during feeding more animals can be maintained on a given supply of hay (Table 8).

Table 8. Effect of hay feeding efficiency on cows fed over a 120-day wintering period and potential marginal income to the farm at current calf prices. Hay cost based on 2008 fuel, machinery, and fertilizer costs without manure management. Proper manure management can reduce the cost of on-farm hay production by \$50/ton.

Hay feeding efficiency	0.5	0.6	0.7	0.8	0.9
Hay cost/ton	\$100	\$100	\$100	\$100	\$100
Bales fed/year	200	200	200	200	200
Bale weight	750	750	750	750	750
Tons fed/year	75	75	75	75	75
Hay cost/year	\$7500	\$7500	\$7500	\$7500	\$7500
Hay feeding days/year	120	120	120	120	120
Hay intake required/cow	30	30	30	30	30
Cows fed	20.8	25.0	29.2	33.3	37.5
Income/cow	\$550	\$550	\$550	\$550	\$550
Gross Income/herd	\$11,440	\$13,750	\$16,060	\$18,315	\$20,625
Net over hay/herd	\$3,940	\$6,250	\$8,560	\$10,815	\$13,125
Increased income/herd	\$0	\$2,310	\$4,620	\$6,875	\$9,185

Economic value of plant nutrients in hay

The majority of hay produced in West Virginia is fed to livestock on the farm. The rest of the hay is sold and fed to livestock on other farms or possibly used for mulch hay in seedings. In either case, the hay is removing plant nutrients from the soil and the manure or mulch is providing plant nutrient to the soil where it is applied. Plant nutrients and animal nutrients are the same but are measured differently. In plant nutrition we measure nitrogen as nitrogen while in animal nutrition we measure nitrogen as crude protein. For phosphorus in plant nutrition we measure the phosphate oxide while in animal nutrition we measure it as mineral phosphorous. For potassium in plant nutrition we measure it as the oxide potash while in animal nutrition we measure it as mineral potassium. The multiplicative factors for converting plant to animal or animal to plant nutrients are presented in Table 9.

For 1 ton of hay dry matter or 1.1 tons of hay as-fed, the fertilizer value of the major nutrients in hay are calculated as follows:

- 11.5% CP x 0.160 = 1.84% N or 36.8 lbs N/ton hay dry matter (33 lbs/ton as-fed)
- 0.285% P x 2.29 = 0.653% P₂O₅ or 13.1 lbs P₂O₅/ton hay dry matter (12 lbs/ton as-fed)
- 1.82% K x 1.20 = 2.18% K₂O or 43.7 lbs K₂O/ton hay dry matter (40 lbs/ton as-fed)
- 0.648% Ca x 2.50 = 1.62% CaCO₃ or 32.4 lbs CaCO₃/ton hay dry matter (29 lbs/ton as-fed)
- 0.198% Mg x 3.47 = 0.68% MgCO₃ or 13.7 lbs MgCO₃/ton hay dry matter (12 lbs/ton as-fed)

This results in 140 lbs of plant nutrients/ton of hay dry matter or 127 lbs per ton of hay as-fed. This includes 46 lbs CaCO₃ and MgCO₃ lime equivalent being removed in the hay. There is an additional acidification effect of 66 lbs CaCO₃ due to N removed equal to 1.8 lbs CaCO₃ /lbs of N removed (36.8 x 1.8 = 66.24). This applies to the use of urea fertilizer or legumes.

In 2008 fertilizer prices were above historical values. If the price of a ton of urea, triple super phosphate, and muriate of potash are each \$1000/ton (fall 2008 estimates for 2009) then a pound of N and P₂O₅ will cost \$1.09 each and a pound of K₂O will cost \$0.83. Dolomitic limestone in the fall of 2008 was priced at \$50/ton delivered and spread, resulting in a plant nutrient cost of N at \$40.11, P₂O₅ at \$14.28, K₂O at \$36.27, and lime at \$2.80 for a total of \$93.46/ton hay dry matter or \$84.96 /ton hay as-fed (90% dry matter).

Table 9. Conversion factors for converting plant to animal or animal to plant nutrients.

6.25 N = CP	0.160 CP = N
2.29 P = P ₂ O ₅	0.436 P ₂ O ₅ = P
1.20 K = K ₂ O	0.830 K ₂ O = K
2.50 Ca = CaCO ₃	0.400 CaCO ₃ = Ca
3.47 Mg = MgCO ₃	0.288 MgCO ₃ = Mg

Conclusion

Harvest date is the single most important management factor affecting the quality of first-cut hay. Cool, rainy weather makes it difficult to make dry hay early in the season. Plastic wrap technology allows farmers to cut early and make round bale haylage within one or two days rather than trying to dry the hay and risk the hay being rained on. However, many producers using plastic wrapping do not cut hay much earlier than those who make dry hay. This results in their not getting as much improvement in forage quality as is possible when using this technology.

When using plastic wrap, if the manager waits and cuts the hay at the same maturity as when making dry hay, the hay will be at a lower quality and much of the economic value of the plastic wrap technology will be lost. On average, farmers who plastic wrap are making hay only 1 point higher in CP (11 vs. 12% CP dry vs. wrapped hay) and about 2 points higher in TDN (55 vs. 57% TDN dry vs. wrapped hay).

Plastic wrap does allow better managers to do a better job. The top 25% of producers making dry hay produced hay with greater than 13% CP and 58% TDN; while the top 25% of producers making wrapped hay produced hay with greater than 15% CP and 61% TDN.

The highest-quality hay is cut in late May or early June, depending on the field's elevation. As the season progresses hay TDN decreases by 0.26 units per day and CP decreases by 0.08 units per day. The hay's CP content is not as closely related to date of the cut because CP is affected by nitrogen fertilization rate, source, and timing of application, legume content, and hay-making practices.

If the hay made does not meet the needs of the livestock being fed, the manager needs to modify management practices to increase the nutritive quality of the hay. Forage quality is increased by earlier harvest date, increasing the legume content in the hay, and by using plastic wrap to reduce field losses and rain damage.

Management of manure produced during hay feeding is a major way to reduce the cost of hay production and reduce loss of expensive plant nutrients in surface water. Due to the high cost of fertilizers in recent years, all hay crops and supplemental feeds have a major economic value in the plant nutrients that they contain. Manure and urine resulting from hay feeding needs to be applied back to hayfields to return plant nutrients to the soil. This management will reduce the need to purchase expensive fertilizers, which will help reduce the cost of hay production. Good management practices that return these nutrients to where they are needed provide significant benefits to crop productivity.

Making quality hay in a cost-effective manner is one way to reduce feeding costs during the part of the year that hay must be fed. When feeding livestock it is essential for the manager to have knowledge of the nutritional quality of the hay being fed and not feed based on average "book values." Livestock producers need to increase hay testing to ensure that they know the nutritional value of their hay and if it meets the needs of the animals being fed. The manager will then know what supplemental feeds will be cost effective and what management changes are needed in the future to reduce the need for purchased supplements. Combining a knowledge of animal nutrition, on-farm hay quality, and management of plant nutrients provides for cost-effective crop production and vigorous animal growth, which are essential for a sustainable and profitable farm.

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Appendix Tables

Correlation matrix $P < 0.01$

	CP	NSC	ADF	NDF	TDN	Ca	P	Mg	K	S	Mn	Cu	Zn	Fe	Mo	Ash	Lignin
CP	1.00	0.29	-0.78	-0.70	0.69	0.66	0.56	0.57	0.44	0.65	-0.32	0.39				0.17	-0.32
NSC		1.00	-0.52	-0.63	0.61	0.20		0.10	0.28	0.21	-0.26			-0.33		-0.21	-0.35
ADF			1.00	0.79	-0.84	-0.44	-0.54	-0.42	-0.56	-0.42		-0.32		-0.05		-0.21	0.37
NDF				1.00	-0.56	-0.59	-0.56	-0.47	-0.58	-0.47		-0.43	-0.29			-0.36	0.16
TDN					1.00	0.26	0.27	0.25	0.45	0.47	-0.30		-0.23	-0.38		-0.27	-0.36
Ca						1.00	0.54	0.59	0.23	0.40	-0.39	0.45				0.31	-0.35
P							1.00	0.60	0.56	0.38		0.48	0.50	0.39		0.50	-0.09
Mg								1.00	0.19	0.64		0.41	0.35			0.28	-0.35
K									1.00	0.21		0.27			-0.33	0.26	
S										1.00							
Mn											1.00		0.31	0.34		0.16	0.48
Cu												1.00	0.75	0.75		0.80	-0.32
Zn													1.00	0.78		0.80	-0.15
Fe														1.00		0.89	
Mo															1.00	-0.12	
Ash																1.00	
Lignin																	1.00