DIGESTIBILITY AND RATE OF PASSAGE OF KANSAS NATIVE HAYS FOR THE HORSE

by

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INTRODUCTION AND LITERATURE REVIEW

Interest in horses is on the rise with the horse population today of 9 million, up from 7.7 million in 1970 with an average of $1000 to keep a horse (Ensminger, 1977). Research in this field is on the rise but there still are few economic rations for the horse and the relationship between plant nutrients and their use by the horse remains a question.

The horse is unique when compared with the ruminant in that its microbial population for cellulolytic degradation is located caudal to the small intestine in the cecum and colon while in the ruminant the rumen is cranial. The capacity of the stomach is quite small thus increasing the rate of passage to the large intestine. The amount and method of absorption of nutrients in the large intestine are not known. This may account for the lower digestibility coefficients obtained with horses.

Hintz (1969) stated that horses digest fiber of grass hays with about 2/3 the efficiency of the cow. Vander Noot and Gilbreath (1970) found the dry matter and organic matter of grass hays were used more efficiently by ruminants than horses, but crude protein and nitrogen free extract were equally digested. Horses were unable to digest crude fiber and ether extract as well as steers and they were less efficient at utilizing the energy in the forages. Koller, et al. (1978) found ruminal bacteria digest the dry matter and cell wall fractions of forages more efficiently than do cecal bacteria

even when exposed to the forages for the same length of time using in vitro and nylon bag techniques. This contradicts the suggestion by Alexander (1963) that cecal microbes would be more efficient if the forage was exposed to them for the same amount of time as in the ruminant. The effect of enzymatic and chemical secretions of the stomach and small intestine on the digestibility of fiber as it passes into the cecum and colon remains unknown.

Information on the digestibility of the proximate nutrients from various forages by horses is scarce compared to that available for ruminants. Many horse trials have been conducted with alfalfa and timothy hays but the others need more work. Fonnesbeck et al. (1967) determined the digestibility of several hays including brome, alfalfa, fescue, red clover, timothy, and canarygrass comparing the values to those established by the N. R. C. They found crude fiber digestibility to be higher for brome, alfalfa, fescue, and timothy hays and their nitrogen free extract (NFE) digestion values for brome, fescue, and timothy hays lower. The legume hays were the most digestible.

In the past, partitioning problems have been recognized with the crude fiber and NFE fractions so an attempt to find better methods have been made. The methods of Van Soest (1963) and Van Soest and Wine (1967) seem to be the best for partitioning the fibrous fractions of forages. This system divides forage dry matter into two fractions, cellular contents and cell wall. The cellular contents consist of lipids, soluble carbohydrates and protein as well as some endogenous components. The cell wall components are cellulose, hemicellulose, and lignin (Van Soest, 1967).

Fonnesbeck (1968 and 1969) using Van Soest's method to partition the nutrients in forages for horses, found cell wall constituents of bromegrass to be more digestible than the other hays studied; it also had more digestible acid detergent fiber (ADF). In 1969 he found the apparent digestibilities for hemicellulose, cellulose, and lignin were close to the estimated true digestibility coefficients. Digestible cell solubles may be erroneous because of endogenous fecal excretions. The apparent digestibility of crude protein was much lower than the estimated true digestibility coefficient. In the horse protein is digested by enzymes in the intestinal tract but microbial protein formed in the cecum may not be efficiently utilized. Ether extract is also of questionable value for forages in the horse. For correct partitioning we need to analyze for true protein, true metabolizable lipids, and carbohydrates should be divided into fibrous carbohydrates digested by microorganisms and soluble carbohydrates digested by enzymes (Fonnesbeck, 1969).

The utilization of nonprotein nitrogen in horses has recently become of interest. Nelson and Tyznik (1971), Houpt and Houpt (1971), and Hintz and Schryver (1972) confirm that some urea can be utilized by the horse. Hintz and Schryver (1972) found urea to increase nitrogen retention when fed in low protein diets but the efficiency of utilization of absorbed nitrogen from urea is less than that of nitrogen from preformed protein.

The horse is quite prone to calcium and phosphorus imbalances in the diet. When fed nearly all roughage, calcium is high; if fed large amounts of grain, especially bran, phosphorus is high. Most

calcium is absorbed in the upper part of the small intestine but the lower portion of the small intestine may also absorb some with none absorbed in the large intestine (Schryver et al., 1970). Schryver et al. (1970) found the requirements for calcium were 5 g/100 kg body weight which was double the 1966 N. R. C. recommendation but the new revised N. R. C. recommends the use of 4.5 g/100 kg body weight. Others have found yet other values so this remains to be accurately established. The major site of phosphorus absorption is the dorsal large colon and the small colon (Schryver et al., 1972). Schryver et al. (1971) found renal excretion of phosphorus is the most important mechanism in the maintenance of phosphorus homeostasis in horses. When phosphorus intake is low, endogenous fecal excretion of phosphorus is the major obligatory loss. Schryver et al. (1971) found the requirements for phosphorus to be 21 mg P/kg body weight which is lower than the established N. R. C. value of 28 mg/kg body weight.

It has been recommended that the mature idle horse can maintain its body weight on 1½ - 2% of its body weight in hay (Pfander and Bradley, 1975, Schryver and Hintz, 1975, Ensminger, 1975, and Evans et al., 1977). However, all hays do not contain the same percentage of nutrients making this recommendation questionable.

This study was set up to determine the digestibility coefficients for the proximate components of brome, fescue, and prairie hays for horses in Kansas. The Van Soest method of partitioning fiber was used to determine digestible cell wall constituents (neutral detergent fiber), cell solubles, hemicellulose, and ADF. Nitrogen, calcium, and phosphorus balances were determined for each of the hays.

MATERIALS AND METHODS

Three grade geldings (defined by Spencer, 1978), 3 to 4 years old were fed the three native hays, prairie, brome, and fescue in 6 digestion trials using a completely randomized factorial experimental design. The animals were adjusted to the diet one week outside in a drylot. They were weighed prior to going into metabolism stalls (designed similar to those of Stillions and Nelson, 1968) for one week. A two day adjustment period was allowed before collections began for a five day period. The horses were weighed at the end of the collection period. A week of rest was allowed between each trial.

The horses ranged in weight from 429 to 544 kg. They were fed 2% of their body weight per day, ½ in the morning and ½ in the evening. The hay refused was weighed and subtracted from the amount fed to determine the total eaten. Each hay was fed in duplicate trials. The animals were watered 4 times daily and exercised for 15 minutes each day to prevent stiffness.

Feces were collected and weighed twice daily with a 5% sample taken each time. It was stored frozen until prepared for analysis.

The urine was acidified with dilute sulfuric acid to prevent ammonia loss. Total volume was measured daily and a 10% sample was stored in a refrigerator at 4° C. At the end of each trial these urine samples were combined and thoroughly mixed so that a single sample for each horse was taken for nitrogen, phosphorus, and calcium analysis.

Hay and fecal samples were dried at 45° C in a draft oven and ground in a Cristy Norris mill. They were analyzed for prox-

imate components, calcium, phosphorus, and gross energy (A.O.A.C., 1975). Van Soest fiber components (neutral and acid detergent fibers) were determined using the method of Goering and Van Soest (1970) with the modification made by Robertson and Van Soest (1977). The hays were further analyzed for the nitrogen components of acid detergent nitrogen, hot water insoluble nitrogen (Goering and Van Soest, 1970), ammonia nitrogen (A.O.A.C., 1975), and urease nitrogen (Conway, 1963) to calculate the estimated true protein digestibility.

Digestibility coefficients were calculated for dry matter, crude protein, ether extract, crude fiber, nitrogen free extract, energy, cell wall constituents, acid detergent fiber, cell solubles, and hemicellulose. Only two means were used for each hay from two horses for each of those values because the third horse was removed from the experiment after 4 trials because of a nervous temperment. Total digestible nutrients (TDN) values were also calculated from these coefficients. Nitrogen, calcium, and phosphorus balances were calculated. Two way analysis of variance (Barr et al., 1976), Duncan's new multiple range test (Steel and Torrie, 1960), and Fisher's least significant difference (LSD) test (Snedecor and Cochran, 1967) were used to analyze the data.

RESULTS AND DISCUSSION

When our nutrient values for brome were compared to the N. R. C. values for late bloom brome hay (1-00-888) (table 1) they were lower except for the Van Soest components of cell walls and acid detergent fiber, and the calcium and phophorus values which

TABLE 1. N. R. C. VALUES FOR THE HAYS STUDIED

	Brome 1-00-588	Fescue 1-01-912	Prairie Hay 1-03-191
Dry Matter %	90	88	90
Digestible energy Mcal/kg	2.38	2.02	2.02
TDN %	54	46	46
Crude Protein %	7.4	10.5	6.7
Digestible Crude Protein %	5	5.8	3.2
Crude Fiber %	40	33	33
Cell Wall Constituents %	72	65	—
ADF %	44	43	—
Calcium %	0.32	0.57	0.41
Phosphorus %	0.22	0.37	0.15

were similar.

The nutrient values for fescue hay followed a similar pattern as brome when compared to N. R. C. values for fescue hay (1-01-912) (table 1) except percent crude fiber was similar to the N. R. C. Our Van Soest values were higher and mineral values were lower.

All values for prairie hay were lower when compared to the N. R. C. values (1-03-191) (table 1). There were no Van Soest values given by the N. R. C.

The animals lost some weight in every trial (Appendix table A) due to the inadequate energy and protein in their rations, and reduced water intake in the stalls. The animals regained the weight lost in the week between trials.

The total dry matter intakes ranged from 38.58 to 41.53 kg for the various hays (table 4) which were not significantly different ($p = .3693$). The daily dry matter intakes were 7.72 kg/day for prairie hay, 8.31 kg/day for brome, and 7.80 kg/day for fescue (table 3). These were above or within the recommended daily feed allowances of 6.63 kg/day for a 429 kg horse to 7.91 kg/day for a 544 kg horse as interpolated from the 1978 N. R. C. for horses (table 2). There was a significant difference between the digestibility coefficients for the dry matters ($p = .0363$), fescue was significantly less digestible than brome or prairie hay (table 5).

Digestibility coefficients for ether extract were calculated for the hays even though it is a questionable calculation for horses (Fonnesbeck et al., 1967). The variance was so large that it showed no significant differences between hays. It ranged from -8.35% to 64.70%. Fraps and Rather (1912) reported the digestible ether extract

TABLE 2. N. R. C. REQUIREMENTS FOR MAINTENANCE OF MATURE HORSES

Horse Weight kg	Digestible Energy Mcal	TDN kg	Crude Protein kg	Digestible Crude Protein kg	Ca g	P g	Daily Feed kg
429	14.59	3.32	0.57	0.25	19.50	11.90	6.63
544	17.45	3.97	0.67	0.31	24.76	15.32	7.91

* Daily values on dry matter basis
** Interpolated values from the 1978 N. R. C. for Horses

TABLE 3. DAILY INTAKE VALUES

Hays	Dry Matter Intake kg/day	Crude Protein kg/day	Digestible Crude Protein kg/day	Digestible Energy Mcal/day	TDN kg/day	Ca g/day	P g/day
Prairie	7.72	0.36	0.12	14.52	3.21	24.95	7.35
Brome	8.31	0.73	0.51	16.27	3.64	19.05	20.45
Fescue	7.80	0.61	0.39	12.61	2.68	17.95	22.11

component for forages is often erroneous. The actual digestible ether extract content of the hay was quite low (table 5).

The digestibility coefficient for crude fiber was calculated to be significantly different ($p = .0222$). It was lower ($p < .05$) for fescue (40.32%) than prairie hay (53.07%), however there was no difference between brome (47.54%) and prairie hay or brome and fescue.

The digestibility coefficient for nitrogen free extract (NFE) for fescue was significantly lower than that for brome or prairie hay ($p = .0158$). The values were prairie hay, 51.33%; brome, 55.25%; and fescue, 38.01% (table 4).

Fescue was significantly lower ($p < .05$) in digestible energy (41.08%) than prairie hay (47.95%) or brome (48.88%) according to Duncan's test, however the analysis of variance showed no statistical difference between hays ($p = .0880$). The daily digestible energy intake was not different for brome and prairie hay or prairie hay and fescue, but fescue was lower ($p < .05$) than brome. The daily digestible energy intake level for fescue (12.61 Mcal/day) was much lower than the N. R. C. requirements of 14.59 Mcal/day for the small horse to 17.45 Mcal/day for the large horse. Prairie hay was also low (14.52 Mcal/day). Brome fell within the range at 16.27 Mcal/day however it still was not enough for the larger horse.

The total digetible nutrients (TDN) for the hays were significantly different ($p = .0352$). The TDN value for fescue (34.14%) was lower ($p < .05$) than that for brome (43.70%) or prairie hay (41.52%). This was due to the lower digestible crude fiber and nitrogen free extract. The daily amounts of TDN consumed were below those

TABLE 4. DIGESTIBILITY COEFFICIENTS AND BALANCE VALUES

	Prairie Hay	Brome	Fescue	p	Standard Error
Nitrogen Balance g/day	-11.72	-5.19	-17.87	.4281	± 16.80
Calcium Balance g/day **	9.40	2.89	-0.43	.0173	± 7.68
Phosphorus Balance g/day	-1.95*	2.75*	0.06	.0740	± 3.13
Total Dry Matter Intake kg	38.58	41.53	39.00	.3693	± 4.39
Dry Matter % **	50.13	52.19	41.52***	.0363	± 4.07
Ether Extract %	24.38	1.32	34.82	.1224	± 28.69
Crude Fiber % **	53.07*	47.54	40.32*	.0222	± 5.58
Crude Protein % ****	32.71***	64.51	63.75	.0042	± 11.52
NFE % **	51.33	55.25	38.01***	.0158	± 4.12
Energy %	47.95	48.88	41.08***	.0880	± 4.85
Energy Intake Mcal/day	14.52	16.27*	12.61*	.1939	± 2.10
TDN % **	41.52	43.70	34.14***	.0352	± 4.34
Cell Wall Constituents % **	49.69	52.62	41.87***	.0401	± 5.07
ADF % **	47.32	41.54	30.94***	.0449	± 5.88
Cell Solubles %	50.40	51.14	40.45***	.1947	± 3.70
Hemicellulose % **	54.24	66.84***	57.68	.0139	± 5.41

* Significant at .05 by Duncan's test, one column is different from the other one signified but no difference exists between the one not starred
*** Significant at .05 by Duncan's test meaning that that column is different from both the others
** Significant at the .05 level by analysis of variance
**** Significant at the .01 level by analysis of variance

recommended by the N. R. C. for prairie hay and fescue. Brome was adequate for the smaller horse but inadequate for the larger one.

The digestible crude protein coefficient was highly significantly different ($p = .0042$). The value for prairie hay was much lower ($p < .05$) (32.71%) than that for brome (64.51%) or fescue (63.75%). The percentage of digestible crude protein in prairie hay was lower than the N. R. C. requirement, but was more than adequate for brome and fescue which contained 6.09% and 4.94% digestible crude protein, respectively (table 5).

Nitrogen balance was not significantly different for the hays but the plot of the nitrogen absorption vs. nitrogen balance showed a difference between prairie hay compared with brome and fescue. Zero balance for prairie hay was extrapolated to occur at 36 g N absorbed/day (figure 1). The animals were all in negative nitrogen balance on prairie hay at -11.72 g/day which was understandable considering the inadequate amount of protein in the diet and the borderline digestible energy content. The animals on brome were in positive balance in one trial and negative in the other even though the amount of digestible crude protein fed was more than adequate and the digestible energy was nearly adequate for both animals. A zero balance would have occurred at 89 g N absorbed/day for brome and at 75 g N absorbed/day for fescue (figure 1). Fescue also produced negative nitrogen balance even though it had adequate protein but its digestible energy content was much less than that required. This discrepancy with brome and fescue may be due to a large amount of nonprotein nitrogen from fertilizer residues in the crude protein value, or due to

Figure 1 N absorbed vs. N balance

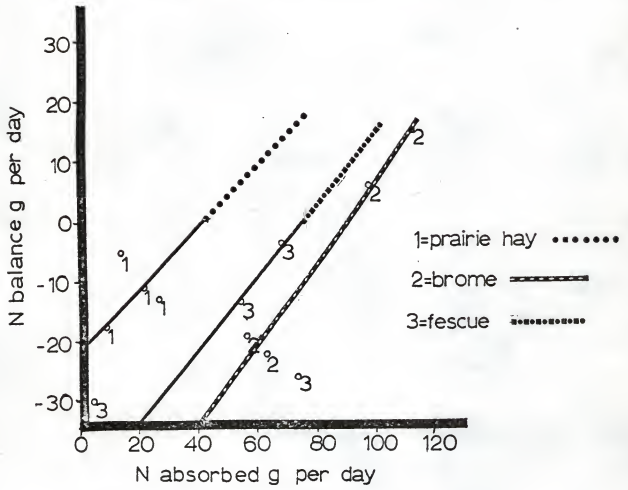


TABLE 5. DIGESTIBLE NUTRIENT CONTENT

	Prairie Hay	Brome	Fescue
TDN %	41.52	43.70	34.14
Digestible Crude Protein %	1.53	6.09	4.94
Digestible Ether Extract %	0.46	0.03	0.98
Digestible Crude Fiber %	15.52	15.06	13.91
Digestible NFE %	23.41	22.34	12.55
Digestible Dry Matter %	44.98	47.50	36.91

the high retention of protein to be utilized as energy since energy was borderline or low in the diets. Further analysis of the hay samples for acid detergent nitrogen, hot water insoluble nitrogen, ammonia nitrogen, and urease nitrogen were made to partition nitrogenous components. The totals of these were subtracted from Kjeldahl nitrogen to give an unidentified nitrogen component (table 6). If we assume the hot water insoluble N to be the true protein value available to the animal, we found the estimated digestible true protein values to be 1.99% for prairie hay, 2.97% for brome and 2.48% for fescue which were less than the 3.77% - 3.92% digestible crude protein required for the animals in this trial. The only other components that might be available are ammonia N and urease N, however if these were available the animals could not use them efficiently because of the lack of energy fed in this trial. This confirms that nonprotein nitrogen made up 24% to 45% of the Kjeldahl nitrogen which explains the negative nitrogen balances.

The digestible cell wall constituents were lower ($p = .0401$) for fescue (41.87%) than brome (52.62%) and prairie hay (49.69%). Digestible cell solubles were significantly lower ($p < .05$) for fescue (40.45%) than for brome (51.14%) and prairie hay (50.40%). Digestible acid detergent fiber was also significantly lower ($p = .0449$) for fescue (30.94%) than brome (41.54%) and prairie hay (47.32%). The digestible hemicellulose was higher for brome (66.84%) than prairie hay (54.24%) and fescue (57.68%) ($p = .0139$). The digestibility of the cell solubles were lower than expected probably due to endogenous compounds in the feces.

TABLE 6. BREAKDOWN OF NITROGENOUS COMPONENTS OF THE HAYS USED IN THIS STUDY

Hays	Trial	% Dry Matter					
		Acid Detergent N	Hot Water Insoluble N	Ammonia N	Urease N	Kjeldahl N	Unidentified N
Prairie	1	0.27	0.70	0.0016	0.0085	0.905	-0.08
Prairie	2	0.07	0.57	0.0074	0.0093	0.759	0.10
Brome	3	0.05	0.96	0.0031	0.0165	1.360	0.33
Brome	4	0.18	0.87	0.0034	0.0155	1.951	0.88
Fescue	5	0.09	0.95	0.0019	0.0103	1.362	0.31
Fescue	6	0.09	0.94	0.0010	0.0139	1.424	0.38

Daily calcium intake was more than adequate in prairie hay (24.95 g/day) when compared to the N. R. C. value of 24.76 g/day for the largest horse (tables 2 and 3). It was borderline for brome (19.05 g/day); the N. R. C. value is 19.5 g/day for the smaller horse. Calcium intake was much less than adequate with fescue (17.95 g/day). The balance studies showed fescue produced a positive balance in one trial and negative balance the next. Brome and prairie hay both produced positive balances. When absorption vs. balance were plotted zero balance occurred at 4 g calcium absorbed/day by extrapolation (figure 3). The plot of calcium intake vs. calcium balance showed an intake of 16 g/day was adequate for a zero balance (figure 2) yet this value is less than that of the N. R. C. suggesting that the established requirement might be high for horses in this age group. The analysis of variance showed significant differences in calcium balance ($p = .0173$) but Duncan's test showed no significant difference between the hays. Since the calcium balances were so highly significantly different in the analysis of variance we performed the least significant difference test and found prairie hay (9.40 g/day) to be significantly higher ($p < .05$) than fescue (-0.43 g/day) and brome (2.89 g/day). This shows a problem with Duncan's test since it uses the mean square value of the error term as its basis for calculation.

Phosphorus balance was negative when prairie hay was fed. This is to be expected since the daily phosphorus intake was much less than the N. R. C. requirement. Prairie hay was statistically lower than brome ($p < .05$) but brome and fescue and fescue and prairie hay were similar. The phosphorus contents of brome and fescue were more than

Figure 2. Ca intake vs. Ca balance

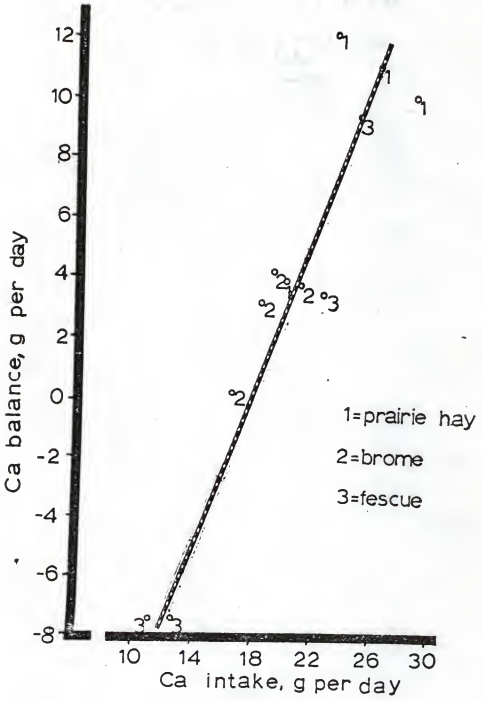
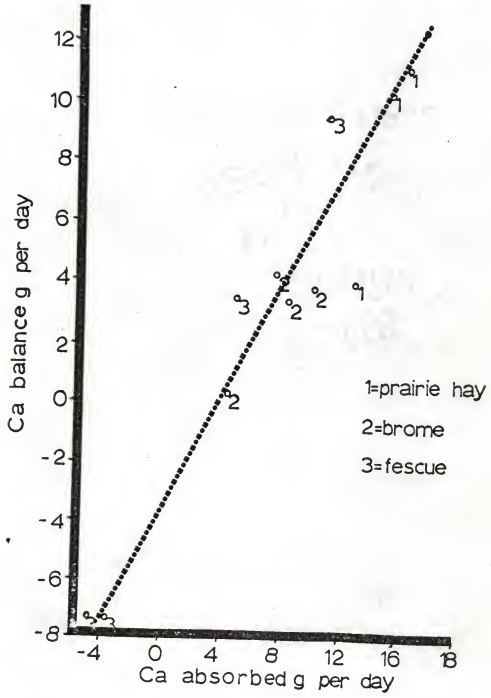


Figure 3. Ca absorbed vs. Ca balance



adequate and a positive balance was attained. The high phosphorus content of these hays is attributed to fertilizer residues. When intake was extrapolated to zero balance a value of 15 g/day was obtained (figure 4) which corresponds with the N. R. C. values. When absorption was extrapolated to zero balance a value of nearly 0 was obtained (figure 5) showing the horse has a tremendous ability to recycle phosphorus.

In order to correct for the low energy, protein, and minerals we recommend supplementation. Depending on price one might add 500 g cracked corn plus a mineral supplement containing 10.97 g Ca, or 500 g oats with a mineral supplement containing 9 g Ca, or 500 g cracked milo plus a supplement containing 8.92 g Ca. These would provide more than enough energy and a slight excess of protein. Calcium supplements would be necessary since these hays are deficient in calcium and we are adding grain which has an excess of phosphorus which needs to be balanced toward the correct calcium to phosphorus ratio.

CONCLUSIONS

For years it has been recommended that the maintenance diet for the idle mature horse be 100% roughage. The results of these studies show that prairie, brome and fescue hays do not contain adequate protein, energy, or minerals to constitute the sole maintenance diet for a horse. If intake could have been increased, which it might in a natural environment, brome might have been adequate in energy. We would recommend some sort of supplementation to meet the limitations in protein, energy, calcium, and phosphorus. This supports the

Figure 4. P intake vs. P balance

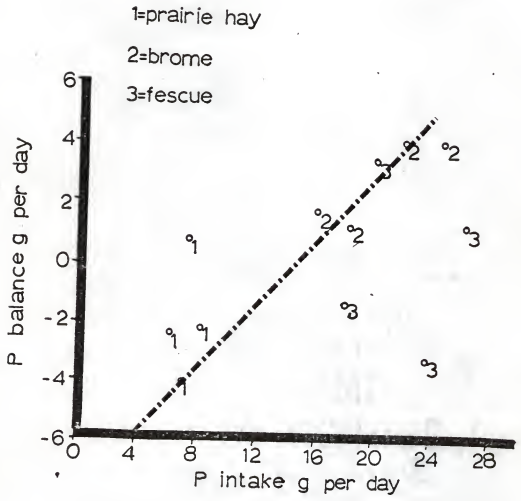
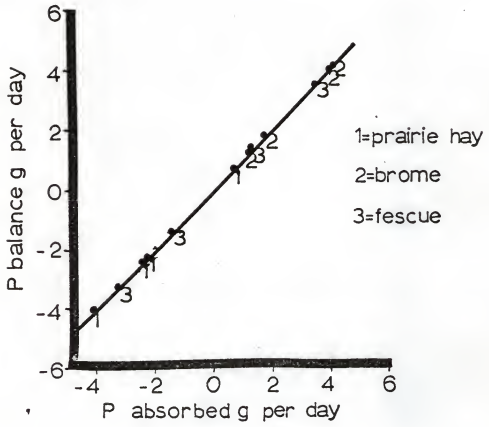


Figure 5. P absorbed vs. P balance



new trend that when all hay diets are fed ½ should be grass hay and ½ alfalfa or some legume hay but this still does not solve all of the deficiency problems. It appears more appropriate to add ½ kg of grain and a calcium supplement to solve these problems.

Of the hays evaluated fescue was the least valuable to the horse. It was low in digestible dry matter, crude fiber, nitrogen free extract, energy, TDN, cell wall constituents, ADF, and cell solubles. It was adequate in digestible crude protein but the actual availability of this is questioned due to the nitrogen balance values.

Prairie hay and brome were similar in digestible dry matter, crude fiber, energy, nitrogen free extract, TDN, cell wall constituents, ADF, and cell solubles. Prairie hay was lower in digestible crude protein and brome was higher in digestible hemicellulose.

Calcium was nearly adequate in all hays studied which was to be expected. Phosphorus was inadequte in prairie hay which was expected since roughages have lower phosphorus content than grains. Brome and fescue were exceptions probably due to the fact that they were harvested from waterways and fields that probably had heavy accumulations of fertilizer.

The nutrient values that we obtained for the components of the hays were generally lower than those in the N. R. C., showing just how variable these components can be and that the standard value is probably high for our hays in Kansas. We should analyze our hays for calcium, phosphorus, and true protein (hot water insoluble nitrogen) especially if these hays are known to have been fertilized before ration formulation to be sure that we are feeding a balanced diet.

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DIGESTION OF BROME, FESCUE, AND PRAIRIE HAYS IN THE HORSE AS OBSERVED WITH THE SCANNING ELECTRON MICROSCOPE

INTRODUCTION AND LITERATURE REVIEW

Since the advent of the first commercial scanning electron microscope in 1965 many improvements have been made so that it has been recognized to bridge the gap between the light microscope and the transmission microscope (Hayat, 1978). It has been instrumental to the study of three dimensional microanatomy of animal and plant tissues, metal, and fossils.

The scanning electron microscope (SEM) has been a valuable tool in the study of forages and their digestion by ruminants. Akin and Burdick (1975), Akin and Amos (1975), and Hanna, et al. (1973) concluded that mesophyll and phloem are the first to be degraded followed by epidermis and parenchyma; sclerenchyma, lignified vascular tissue, and cuticle remaining nondegradable. Brazle (1976) showed similar results with brome, fescue, and big and little bluestems in Kansas.

It has been shown that both structural and non-structural inhibitors in forages are significant to their digestion. Silica was introduced as a structural inhibitor by Deinum (1973). Silica was found in the epidermal cells which may be elongate or short in most grasses (Twiss et al., 1969). The shape of the silica bodies (phytolithes) may be circular, elliptical, dumb-bell or saddle shaped (Fahn, 1974). Brazle (1976) showed that the phytolithes may inhibit microbial degradation of surrounding epidermal tissues. Van Soest and Jones (1968), and Goering and Van Soest (1970) showed 1% of silica

decreased digestibility by three units. Van Soest and Jones (1968) found the major affect of silica confined to the cell wall carbohydrates.

Lignin depressed digestion of cell wall constituents (Deinum, 1973). It is not necessarily the total lignin content of the forage, but the location of it which affects digestibility most (Pigden, 1953). It is located almost entirely in the vascular bundles of the grass leaf (Pigden, 1953) and increases with plant maturity, thus quality of forage is important to its digestibility.

In vivo studies using the SEM were first performed by Brazle (1976) on brome, tall fescue, and alfalfa hays in the ruminant. It was observed that vascular tissue and cutinized abaxial leaf epidermis were left as end products of ruminal degradation (Brazle, 1976; Brazle and Harbers, 1977).

Digestion of forages in horses has not been observed with the SEM, but the cecal mucosa has been observed in a comparative study of the pig, domestic ruminants, and horses in which differences were thought to be due to different functional states of the cecum (Wille, 1975).

In this study we used the SEM to observe residues of the digestion of hays of Bromus inermis (smooth brome grass), Festuca arundinacea (tall fescue), Andropogon gerardi and Andropogon scoparius (big and little bluestem) in the horse.

MATERIALS AND METHODS

Samples of brome, fescue, and prairie hays were taken as they

were fed to three horses. These were cut transversely into 3 - 5 mm sections with a razor blade. They were fixed in a 4% gluteraldehyde-buffer (10 ml of 8% gluteraldehyde in 10 ml buffer containing 7 ml of .07 M $Na_2HPO_4 \cdot 2H_2O$ and 3 ml of .07 M KH_2PO_4, pH 7.168) for one hour at room temperature (Sjostrand, 1967) dried in an ethanol series (30, 60, and 80%) for 20 minutes each, and poured onto filter paper to air dry (Parsons, et al., 1973). Delco No. 93 colloidal silver (Ted Pella Co., #1603 - 2) was used to mount dry samples on aluminum stubs. Specimens were coated under vacuum with 150 Å gold paladium (Kenny Vacuum Co., Model KSE-2-A-M evaporator) and viewed with an Etec Autoscan scanning electron microscope at 10 KV (Brazle and Harbers, 1976). Polaroid PN/55 film was used to produce photomicrographs.

Fecal samples were taken from each animal for undigestible residue studies. These were well mixed before the representative samples were taken, then fixed in gluteraldehyde-buffer, dried in ethanol, and mounted the same as the hay samples, except that slurry samples from the last ethanol treatment were mounted on double edged stick tape. They were coated, photographed, and viewed in the same manner as hay samples. Stereoscopic pairs of photomicrographs were made by rotating the vertical stage of the microscope between 5° and 7° (Howell, 1975) and interpreted with a stereo viewer. Only single photomicrographs are shown.

RESULTS AND DISCUSSION

The abaxial (lower) surface of brome leaves had repeating rows of trichomes above vascular protrusions surrounded by stomates and

phytoliths (figure 1a). The phytoliths were of the Festucoid group which may be circular, rectangular, elliptical, or oblong (Twiss et al., 1969). The adaxial (upper) surface of brome was characterized by a row of trichomes directly external to the vascular tissue (Brazle, 1976). The cross section showed a large amount of mesophyll relative to vascular tissue.

Observations on the fecal material showed the brome leaves were nearly completely digested. We found remains of undigested stems, sloughed cuticle and lignified vascular tissue. The digestion of mesophyll and phloem (figures 1b and 1c) was evident. The epidermis and cuticle were beginning to slough off and a few phytoliths had been ruptured (figure 1b). It appeared to be the most digestible of the hays studied by microscopy and was determined in the digestibility study to have a dry matter digestibility coefficient of 52.19%, the highest for the hays studied.

The abaxial surface of fescue (figure 2a) was characterized by two longitudinally-oriented arrangements of cells and stomates were found on the surface of veins with phytoliths between veins. The adaxial surface of fescue (figure 2b) was characterized by the presence of stomates and phytoliths scattered on the surface. The cross section revealed relatively more vascular tissue, fiber cells, and less mesophyll than observed in brome.

The adaxial surface of fescue found in the feces (figure 2c) showed stomates intact and some phytoliths missing. The abaxial surface (figure 2d) showed more phytoliths ruptured and stomata intact. The significance of the loss of phytoliths is unknown, however they

were not digested because they were observed free in the slurries (figure 2e). The leaf cross section from feces (figure 2f) revealed the mesophyll and phloem were digested to a depth where mesophyll could still be seen by stereo viewing whereas Brazle (1976) could not find mesophyll in cattle feces using the same technique. The cells attaching the abaxial and adaxial layers to the vascular tissue were digested. The cuticle, sclerenchyma, and xylem remained undigested. Akin et al. (1973) also observed a more complete digestion of the mesophyll from exposed end views in cattle but the other plant parts seen here were undigested. Fescue hay was the least degraded of those studied with a dry matter digestibility coefficient of 41.52%.

The adaxial surfaces of big and little bluestem (figures 3a and 3b) were characterized by repeating bands of phytoliths, trichomes, and stomata (Brazle, 1976). The phytoliths are of the Panicoid group which are dumb-bell shaped (Twiss et al., 1969). The abaxial surface of both grasses had bands of trichomes, phytoliths, stomata, and cork cells (Brazle, 1976). Brazle (1976) found big bluestem to have rows of irregularly shaped waxy deposits at higher magnification and little bluestem had randomly dispersed tubular cuticular deposits. The cross section showed large bulliform cells near the adaxial surface (figure 3c) and it appeared to have more mesophyll than fescue but less than brome.

In the feces, the sloughed abaxial surface had some phytoliths missing (figure 3d). A cross section of leaf from fecal material showed the thick cuticle of the adaxial surface remaining intact (figure 3e), but the mesophyll was degraded. Leaves were compacted together

possibly from the formation of the dung ball in the small colon.

CONCLUSIONS

The differences seen in the digestion of these hays by horses compared to cattle were few. The patterns appeared to be the same as ruminal digestion, however the horse was not capable of as complete digestion of the mesophyll as the cattle. The other differences observed were the missing phytoliths and the compaction which were probably due to the mechanical actions of chewing, the formation of the dung balls in the small colon, or both.

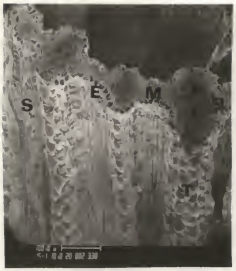
Structural differences in the hays observed contributed to the amount of digestion that took place. Brome had more mesophyll tissue and was more easily and completely digested than the other two (see part 1, this thesis). The large percentage of vascular tissue in fescue contributed to the poor digestion we observed in the metabolism trial. The thick cutin layer on bluestem was undigested and probably had an effect on rate of digestion.

BROME

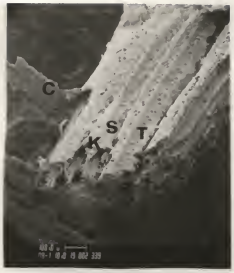
1a) Cross section and abaxial surface of brome hay. Trichomes (T) are present above vascular tissue and stomata (S) are located in parallel rows between trichomes. The cross section reveals epidermis (E), mesophyll (M), xylem (X), phloem (P), and sclerenchymal bundle sheath (B). (150 X)

1b) Degraded brome leaf from feces. The remaining tissue is cuticle (C) and fibrous bundle sheath (B). The cuticle is starting to slough off with the trichomes (T) and stomata (S) intact and some of the phytoliths missing (K). (80 X)

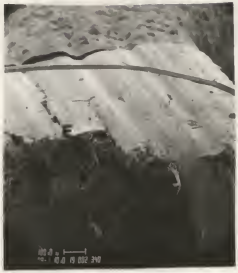
1c) Degraded brome leaf from the feces with epidermis (E), fibrous vascular tissue (V) and xylem (X) remaining while the mesophyll (M) and phloem (P) were digested. (80 X)



1a



1b



1c

FESCUE

2a) The abaxial surface of fescue with longitudinal cell pattern revealing stomata (S) and phytoliths (F). (120 X)

2b) Cross section and adaxial surface of fescue. The adaxial surface contains stomates (S) and phytoliths (F). The cross section shows the epidermis (E), mesophyll (M), xylem (X), phloem (P), and fibrous bundle sheath (B). (120 X)

2c) The adaxial leaf surface of fescue as found in the feces showed some phytoliths missing (K) while some remained (F) and stomata (S). (120 X)

2d) The abaxial leaf surface of fescue as found in the feces showing more phytoliths ruptured (K) and the stomata (S) intact. (120 X)

2e) The abaxial cuticle (C) of fescue as found sloughed off in the slurry revealing the loose silica cells (R). (500 X)

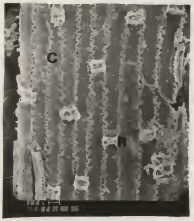
2f) Cross section of fescue leaf from the feces showing partial digestion of the mesophyll (M) and phloem (P) while the epidermis (E), fibers of the bundle sheaths (B) and xylem (X) remain undigested. (600 X)

2a

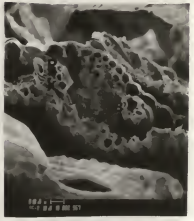
2b

2c

2d



2e



2f

BLUESTEM IN PRAIRIE HAY

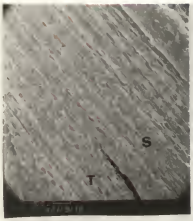
3a) The adaxial surface of big bluestem with stomata (S) and trichomes (T) on the waxy epidermis. (80 X)

3b) The adaxial surface of little bluestem revealing stomata (S) and trichomes (T). (120 X)

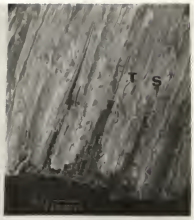
3c) Cross section of bluestem leaf showing the epidermis (E), bulliform cells (A), xylem (X), phloem (P), mesophyll (M), and in the upper right of the epidermis trichomes (T) are seen. (120 X)

3d) Sloughed adaxial epidermis of bluestem with some of the phytoliths missing (X) and some remaining (F) (dumb-bell shapes) and stomates (S). On the left side is some of the remains of the vascular tissue (V). (200 X)

3e) Cross section of bluestem leaf from the feces revealing the thick epidermis (E) pulling away from the fibers, bundle sheath (B), and xylem (X); digestion of mesophyll (M) and phloem (P). (160 X)



3a



3b

3c

3d

3e

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RATE OF PASSAGE OF KANSAS NATIVE HAYS IN THE HORSE

INTRODUCTION AND LITERATURE REVIEW

The rare-earth elements are gaining use as indigestible particulate markers in rate of passage and digestibility studies. The elements are not only indigestible but possess strong adsorptive properties for particulate matter. With the use of neutron activation analysis inert markers can be used rather than the controlled use of radioactive materials. Samples labeled with these inert markers can be stored indefinitely before analysis, there is no hazard of radioactivity to contend with, and no danger of contamination of the animals tested.

Kobt and Luckey (1972) suggested that before a substance qualified as an effective gastrointestinal marker it should: be inert with no toxic, physiological, or psychological effects; be neither absorbed nor metabolised within the alimentary tract and therefore be completely recovered from either raw or processed food; have no appreciable bulk; mix intimately with the usual food and remain uniformly distributed in the digesta; have no influence on alimentary secretion, digestion, absorption, normal motility of the digestive tract or excretion; have no influence on microflora of the alimentary tract which is of significance to the host; have qualities that allow ready, precise quantitative measurements; have physical-chemical properties which make it discernible throughout the digestive process. All criteria should be considered before accepting a marker, however few substances completely satisfy all criteria. The rare-earth metals are desirable as ingesta markers because thay are not absorbed from

the gut and they possess strong binding properties for particulate matter. Huston and Ellis (1968) and Ellis and Huston (1968) concluded that radioactive cerium was rapidly absorbed onto, and remained tenaciously bound to digesta particles during their transit through the ruminants gastrointestinal tract. Hartnell and Satter (1979) found forages to be particularly suited for use with rare earth markers because they are adsorbed onto the outer side of the cuticle or lignified plant cell wall which undergo little digestion in the gastrointestinal tract.

The rare-earths (lanthanons) comprise the 15 elements (atomic numbers 57 - 71) from lanthanum through lutetium. The solubility of their salts may be expressed as nitrates < chlorides < bromides < iodides < acetates < perchlorates, sulfates < phosphates < carbonates, flourides, hydroxides < oxides where the nitrates to the sulfates are relatively soluble and the phosphates through the oxides are relatively insoluble in water. Poor solubility confers adsorptive capacity since adsorption to some other material is inverse to the solubility function. The adsorptive effects of lanthanons occur at concentrations less than the molar solubility of hydroxides and at radiocolloidal concentration (Schweitzer and Jackson, 1952).

The toxic and pharmacodynamic effects of lanthanons are demonstrated only by subcutaneous, intravenous, intraperitoneal, or intramuscular administration (Hartnell, 1977). Distribution in the body depends on their chemical form. When given orally the absorption is so poor that the rare earth oxides may be used as fecal markers (Miller, et al., 1971, and Luckey, et al., 1975).

Several workers have used radioactive rare-earth metals as ingesta

markers (Miller and Byrnes, 1970, and Luckey et al., 1975). Sklan et al. (1975) used ^{91}Y and ^{141}Ce to follow particulate matter through the gastrointestinal tract of chicks. Padgit et al. (1966), Miller et al. (1967), Ellis and Huston (1968), and Miller et al. (1971) used either ^{141}Ce or ^{144}Ce as markers to follow movement of indigestible residues. Olbrich et al. (1971) used neutron activation analysis of cerium. Gray and Vogt (1974) described the general procedure used in the neutron activation analysis of stable rare-earth metals. Hartnell (1977) used rare-earths to measure ingesta turn over rates in dairy cattle.

Knapka et al. (1967) used ^{144}Ce as a digestibility indicator in burros but no work has been reported in horses. Some work using chromic oxide as a marker has been reported to determine the rate of passage in horses. The data of Vander Noot et al. (1967) showed the cumulative recovery of chromic oxide was maximal from 36 to 48 hours and almost complete by 72 hours. Both Alexander (1946), using colored particles, and Haenlein et al. (1966), using chromic oxide, obtained 100% recovery by 48 hours. About 95% of the food particles destined to appear in the feces pass through the digestive tract within 65 - 75 hours after ingestion. Solid particles may reach the cecum within 45 to 60 minutes after eating, however some particles remain in the stomach 4 to 7 hours before moving on to the cecum (Evans et al., 1977).

These trials were designed to determine the rate of passage of brome, fescue, and prairie hays through the horse's digestive tract using the rare-earth metal cerium. Cerium was selected as a marker since previous work had been reported with it and it was readily available.

MATERIALS AND METHODS

A cerium solution was prepared by dissolving 3.92 g of ceric ammonium nitrate, $(NH_4)_2Ce(NO_3)_6$, in 10 ml water and diluting with water to 90 ml. This 90 ml of cerium solution was sprayed onto 12.5 kg prairie hay in trial 2, 13.5 kg brome in trial 4, and only 60 ml of cerium solution was sprayed onto 10 kg fescue since only 2 horses were used in trial 6. Hay was allowed to air dry for 2 days then fed to the horses.

These trials were conducted along with digestion trials involving 3 grade geldings (defined by Spencer, 1978), 3 to 4 years old, fed prairie hay, brome and fescue. The animals were adjusted to the diet one week in a drylot. They were placed in metabolism stalls similar to those of Stillions and Nelson (1968). An adjustment period of 2 days was allowed before the Ce treated hay was fed.

The horses ranged in weight from 429 to 544 kg. They were fed 2 % of their body weight per day, $\frac{1}{2}$ in the morning and $\frac{1}{2}$ in the evening. The hay refused was weighed and subtracted from the amount fed to determine the total eaten. The cerium marked hay was fed only on the first morning. The animals were watered 4 times a day and exercised 15 minutes a day to prevent stiffness.

The feces were collected for a 5 day period (120 hours). Feces were weighed every 12 hours with a 5% sample taken each time. These samples were dried at 45° C in a draft oven and ground in a Cristy Norris mill. Samples ranging from 0.0030 g to 0.0754 g were placed in polyethylene vials and heat sealed for neutron activation analysis. The contents of the vials were analyzed similar to the procedure described by Gray and Vogt (1974). The samples were irradiated with

neutrons in Kansas State University's Research Reactor for 3 hours at a thermal flux of 10^{13} neutrons/cm^2/sec instead of the 5 x 10^{11} neutrons/cm^2/sec used by Hartnell (1977). Upon return from the reactor, the samples were set aside for 3 days to allow for the decay of interfering shorter-lived isotopes, principally ^{24}Na. This was less than the 7 to 10 days recommended by Gray and Vogt (1974). The samples were then counted on a Ge(Li) detector coupled to a 636 Northern Scientific pulse range height analyzer. Each sample was counted for 17 minutes live-time. The spectrum was analyzed for cerium at 0 - 800 keV, instead of 145 keV used by Hartnell (1977), using a nuclear engineering computer program of Kansas State University and are reported as ppm Ce.

RESULTS AND DISCUSSION

The rate of passage of these hays was determined from plots of the ppm Ce in the samples vs. time (figures 6, 7, and 8). The peaks were between 36 and 48 hours for prairie hay and brome (figures 6 and 7) and very close to 36 hours for fescue (figure 8), indicating that the majority of the hay is digested by this time. This agrees with the findings of Vander Noot et al. (1967) using Cr_2O_3. The possible explanation for the difference between the hays is in their quality. Fescue contained more stem and had a dry matter digestibility coefficient of only 41.52% while prairie hay (50.13%) and brome (52.19%) were much more leafy.

We attempted to calculate a cumulative curve for the total cerium collected based on the amount fed however the values showed

Figure 6. rate of passage of prairie hay
Ce ppm vs. time (hrs)

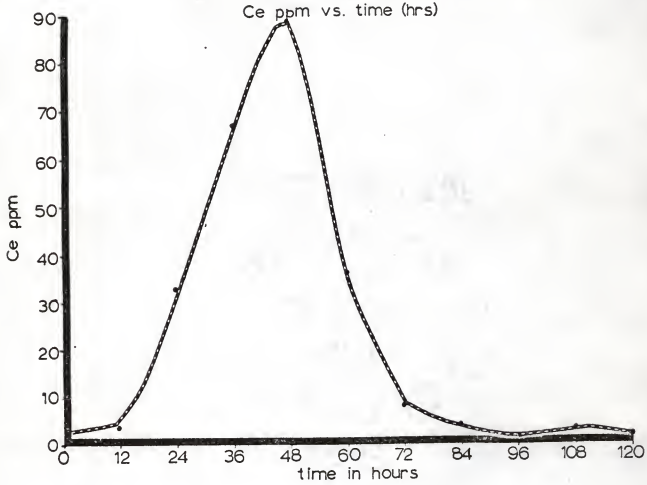


Figure 7. rate of passage of brome
Ce ppm vs. time (hrs)

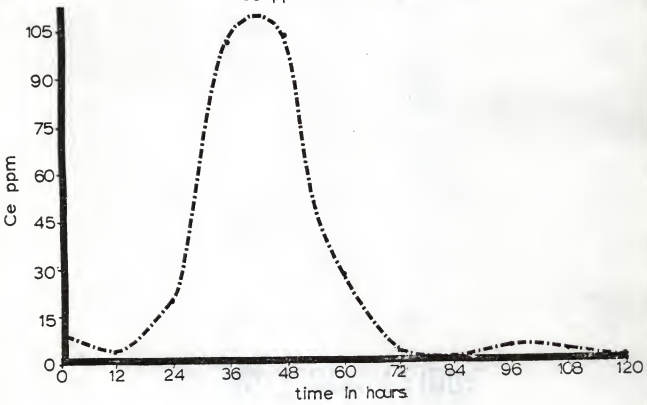
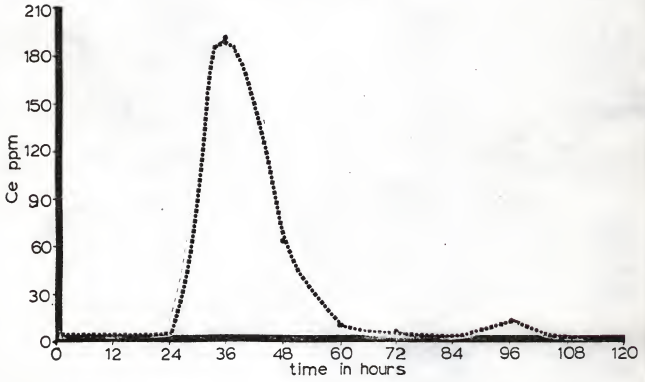


Figure 8. rate of passage of fescue
Ce ppm vs. time (hrs)



we collected much more than we fed. This problem was due to ^{24}Na interferences which could have been avoided had the samples been set aside for 7 to 10 days as recommended by Gray and Vogt (1974) instead of only 3 days. This allowed for decay of only 5 half-lives which meant that theoretically a maximum of 3.125% activated sodium could have interfered in the values for the feces. The values given for the hays were probably correct since there is generally little sodium in hay.

The cummulative curves found here are simply a plot of the percentage amount of labeled excreta by a certain time, with the total amount of labeled excreta by 120 hours set to 100% (modified from Hartnell, 1977) (figures 9, 10, and 11). Evans et al. (1977) stated that 95% of the food particles destined to appear in the feces pass through the digestive tract within 65 to 75 hours after ingestion. This data shows by 72 hours 96.47% of the prairie hay, 95.60% of the brome and 96.37% of the fescue had passed through the tract confirming this statement. In fact 100% collection was attained for fescue by 96 hours.

CONCLUSIONS

The rare-earth element cerium can be successfully used to determine the rate of passage of feedstuffs in the horse. The problems we encountered could have been avoided had the activated samples been allowed to decay for 7 - 10 days rather than 3 days. It would have been beneficial had there been another method of analysis available to confirm the correct values for the cerium without the interference problems. In the future it might be beneficial to choose lanthanum

Figure 9. cumulative % Ce collected from prairie hay

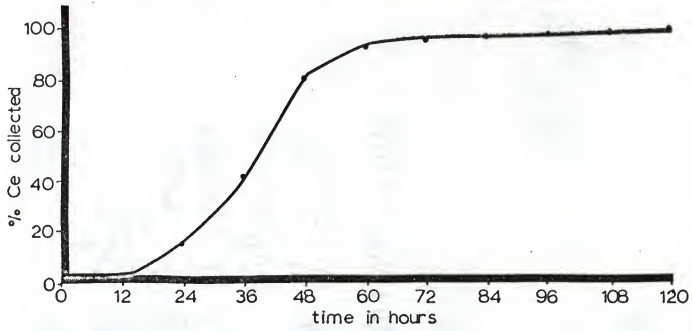


Figure 10. cumulative % Ce collected from brome

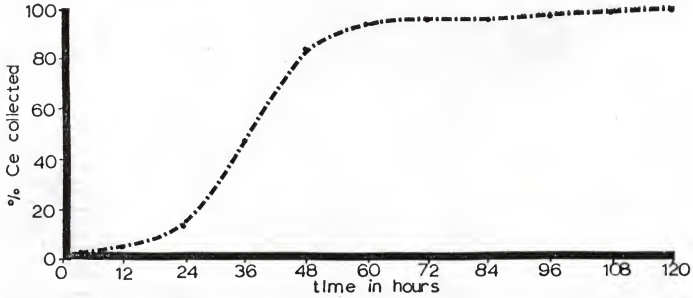
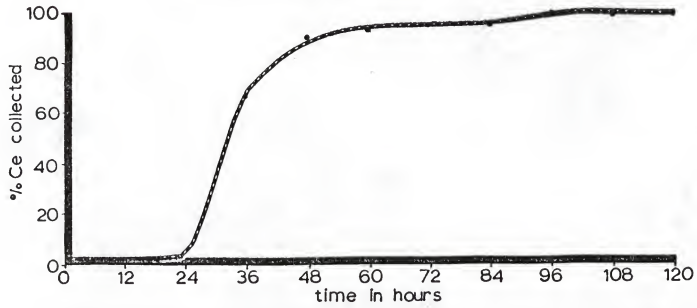


Figure 11. cumulative % Ce collected from fescue



or samarium so that both neutron activation analysis and atomic absorption spectrophotometric analysis could be correlated.

Even with the errors involved we did find the peak rate of passage to be between 36 and 48 hours for the hays. The fescue passed through more rapidly than the other two because it had more stems which were not digested. We also showed that by 72 hours 95% or more of the ingesta had passed through the tract.

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APPENDIX

TABLE A. ANIMAL WEIGHTS

	Horse	Weight Before Trial kg	Weight After Trial kg	Weight Change kg
Trial 1[a]	1	534	525	-9
	2	430	433	+3
Trial 2[a]	1	517	510	-7
	2	442	426	-16
Trial 3[b]	1	544	503	-41
	2	447	424	-23
Trial 4[b]	1	510	510	0
	2	429	433	+4
Trial 5[c]	1	528	429	-36
	2	456	438	-18
Trial 6[c]	1	536	497	-39
	2	455	435	-20

[a]prairie hay
[b]brome
[c]fescue

TABLE B. ANALYSIS OF FEEDSTUFFS FED TO HORSES

		Proximate Components					Van Soest							
Hay	Trial	DM%	EE%	CP%	CF%	Ash%	NFE%	NDF%	ADF%	Cell Solubles%	Hemicellulose%	Gross Energy%	Ca%	P%
Prairie	1	90.09	1.84	5.10	29.77	8.71	44.67	71.33	46.95	28.67	24.38	3.93	0.297	0.090
	2	89.36	1.92	4.24	28.73	7.94	46.53	67.53	44.36	32.47	23.17	3.91	0.348	0.100
Brome	3	90.62	1.69	7.71	31.70	7.03	42.49	70.51	40.91	29.49	29.60	3.95	0.213	0.208
	4	91.41	2.11	11.17	31.66	8.09	38.38	71.10	39.02	28.90	32.08	4.05	0.246	0.285
Fescue	5	88.05	1.99	7.50	36.01	10.79	31.76	75.20	45.19	24.80	30.01	3.88	0.170	0.354
	6	89.73	3.64	8.00	33.01	10.83	34.25	75.24	43.79	24.76	31.45	3.95	0.280	0.225

TABLE C. FECAL OUTPUT AND CONSTITUENTS FROM 3 HAYS

Trial	Horse	Daily Dry Feed Intake kg/day	Daily Dry Fecal Output kg/day	DM%	EE%	CP%	CF%	Ash%	NFE%	NDF%	ADF%	CS%	HI	GE%	Ca%	P%
1[a]	1	7.99	3.44	23.54	2.42	6.74	25.73	12.70	43.77	71.36	47.90	28.64	23.46	3.99	0.180	0.324
	2	6.94	3.57	32.71	2.98	5.87	28.13	12.52	44.29	71.27	47.90	28.73	23.37	4.07	0.214	0.243
2[a]	1	8.34	4.43	25.37	2.82	6.59	27.15	13.82	44.80	70.69	49.07	29.31	21.62	4.07	0.312	0.237
	2	7.60	4.01	28.54	3.08	5.67	28.19	12.37	44.44	65.57	46.78	34.34	18.79	4.16	0.256	0.171
3[b]	1	8.92	4.14	25.05	3.94	6.79	35.44	9.69	36.90	67.88	46.99	32.12	20.89	4.22	0.257	0.419
	2	7.80	3.95	26.72	3.47	6.27	35.26	8.77	39.65	72.35	49.39	27.65	22.96	4.32	0.306	0.367
4[b]	1	8.71	4.09	24.01	4.31	7.29	32.42	9.83	38.20	69.30	48.82	30.70	20.48	4.26	0.277	0.506
	2	7.79	3.67	23.46	3.87	6.92	35.90	9.68	36.35	70.93	50.11	29.07	20.82	4.30	0.315	0.495
5[c]	1	6.72	3.93	21.69	3.15	4.92	33.88	11.60	38.65	72.84	52.79	27.16	20.20	3.91	0.378	0.686
	2	7.42	4.43	23.81	3.04	4.07	36.54	13.41	33.56	75.20	51.98	24.80	23.22	3.96	0.387	0.565
6[c]	1	8.99	5.31	21.65	2.58	4.80	34.58	13.63	36.35	76.53	53.56	23.47	22.97	3.96	0.262	0.315
	2	8.06	4.58	24.08	2.26	4.69	35.67	13.88	36.38	74.45	51.76	25.55	22.69	4.01	0.386	0.426

[a]prairie hay
[b]brome
[c]fescue

TABLE D. URINARY OUTPUT AND CONSTITUENTS FROM THREE HAYS

Trial	Horse	Daily Total Output ml/day	N mg/ml	Ca %	P %
1[a]	1	2186	18.69	0.232	0.002
	2	2180	15.48	0.414	0.001
2[a]	1	2526	11.22	0.200	0.001
	2	2918	6.93	0.177	0.001
3[b]	1	5753	15.09	0.083	0.001
	2	5818	13.14	0.072	0.003
4[b]	1	6622	14.01	0.096	0.001
	2	7090	13.06	0.047	0.003
5[c]	1	3384	23.67	0.117	0.001
	2	4202	16.39	0.067	0.001
6[c]	1	5350	18.31	0.033	0.001
	2	4872	14.85	0.028	0.001

[a]prairie hay
[b]brome
[c]fescue

TABLE E. RATE OF PASSAGE OF CERIUM FED AS A PULSE DOSE TO HORSES WITH 3 HAYS

	Hours	Sample A ppm Ce		Sample B ppm Ce		Dry Feces kg	Average Mg Ce in Dry Feces	Cumulative %
	0	0		6.0538	± 3.2262	2.216	6.7	
	12	2.1989	± 2.9255	6.4748	± 3.5342	1.569	6.8	2.24
	24	6.9776	± 2.8235	24.271	± 7.5633	2.700	42.5	9.28
	36	69.722	± 5.2265	67.371	± 5.2671	2.268	155.5	35.06
	48	82.640	± 5.4533	90.210	± 5.9045	2.756	238.2	75.54
Horse 1	60	49.229	± 5.2106	52.808	± 5.6476	2.009	102.5	91.54
	72	13.443	± 2.7029	12.364	± 2.3049	2.416	31.2	96.71
	84	6.7448	± 1.9295	1.8814	± 1.5104	1.632	7.0	97.87
	96	0.0304	± 1.3634	1.9822	± 1.6134	2.381	4.8	98.67
	108	3.9483	± 1.633	0.0250	± 1.1523	1.922	3.8	99.30
	120	0.9488	± 1.0857	2.4129	± 1.2041	2.504	4.2	100.00
	Hay	78.533	± 3.7606			3.498	274.7	
Prairie Hay								
	0	4.7388	± 2.5215	0		2.003	4.8	
	12	4.5112	± 3.5275	0.0578	± 2.9145	2.309	5.3	2.07
	24	84.079	± 6.1104	15.650	± 6.1681	1.888	94.1	21.45
	36	10.358	± 5.4360	120.370	± 9.248	1.976	129.2	48.05
	48	90.432	± 8.0135	90.7400	±10.1190	2.131	188.5	86.87
Horse 2	60	26.207	± 6.4094	13.835	± 5.5162	1.835	36.7	94.43
	72	1.8620	± 2.5640	6.3022	± 2.5516	2.117	8.6	96.21
	84	2.2597	± 1.9862	3.4140	± 2.2608	1.709	4.8	97.20
	96	0.5785	± 2.0647	0.9764	± 2.0948	2.021	1.6	97.52
	108	3.2915	± 2.4430	3.6544	± 2.3421	2.371	8.2	99.22
	120	1.4595	± 2.8273	3.0860	± 2.7459	1.670	3.8	100.00
	Hay	81.455	± 7.0127	97.380	± 7.1206	3.812	340.9	

TABLE E. CONTINUED

	Hours	Sample A ppm Ce	Sample B ppm Ce	Dry Feces kg	Average Mg Ce in Dry Feces	Cumulative %
	0	17.852 ± 11.053	3.875 ± 6.5301	2.226	23.5	
	12	0.3157 ± 2.5266	9.1456 ± 6.5338	1.861	8.8	5.53
	24	8.4901 ± 5.8673	12.076 ± 7.6487	2.204	22.7	9.41
	36	95.404 ± 11.143	81.614 ± 8.8671	1.735	153.6	35.70
	48	157.57 ± 12.100	110.21 ± 11.8930	1.996	267.2	81.43
Horse 1	60	37.835 ± 7.9230	42.145 ± 8.1365	1.804	72.1	93.77
	72	9.4843 ± 5.3648	7.3986 ± 4.1220	2.634	22.2	97.57
	84	7.1135 ± 4.6821	0.4999 ± 1.0956	1.610	6.1	98.61
	96	1.2665 ± 1.3839	0.3220 ± 1.2803	2.676	2.1	98.97
	108	0	2.1741 ± 1.1085	1.565	1.7	99.26
	120	2.4384 ± 1.7808	1.1542 ± 1.3473	2.384	4.3	100.00
	Hay	67.196 ± 8.2414	72.209 ± 7.0346	4.606	321.1	
Brome						
	0	0	19.611 ± 21.863	1.649	16.2	
	12	7.8872 ± 26.525	0	1.954	7.7	5.37
	24	31.307 ± 11.253	28.141 ± 11.126	1.620	48.2	16.20
	36	142.81 ± 21.328	80.642 ± 22.537	1.747	195.2	60.10
	48	78.802 ± 9.9815	65.301 ± 12.487	1.624	117.0	86.43
Horse 2	60	34.392 ± 22.770	0	1.859	32.0	93.62
	72	0	0	1.860	0	93.62
	84	0	0	2.548	0	93.62
	96	17.975 ± 14.539	0	1.706	15.3	97.07
	108	14.723 ± 21.823	0	1.767	13.0	100.00
	120	0	0	1.677	0	100.00
	Hay	122.10 ± 28.860	102.00 ± 17.308	3.890	435.9	

TABLE E. CONTINUED

		Hours	Sample A ppm Ce	Sample B ppm Ce	Dry Feces kg	Average Mg Ce in Dry Feces	Cumulative %
		0	0	0	1.533	0	
		12	0	0	1.991	0	0
		24	0	0	2.451	0	0
		36	150.02 ± 15.168	142.35 ± 24.728	3.005	439.3	60.67
		48	54.693 ± 26.591	102.76 ± 9.5844	2.638	207.6	89.34
	Horse 1	60	30.991 ± 7.3378	0	2.412	37.4	94.50
		72	17.109 ± 9.8836	8.000 ± 7.1938	3.169	39.8	100.00
		84	0	0	2.705	0	100.00
		96	0	0	3.033	0	100.00
		108	0	0	2.349	0	100.00
		120	0	0	2.785	0	100.00
		Hay	122.59 ± 12.401	85.361 ± 9.0014	4.273	444.3	
Fescue							
		0	0	0	1.779	0	
		12	0	1.6101 ± 14.156	1.877	1.1	0.14
		24	0	0	2.086	0	0.14
		36	223.25 ± 29.428	293.62 ± 15.814	2.338	604.1	74.97
		48	79.135 ± 42.950	24.946 ± 10.632	2.614	136.1	91.82
	Horse 2	60	0	6.0584 ± 7.021	2.370	7.2	92.72
		72	0	0	2.673	0	92.72
		84	0	0	2.207	0	92.72
		96	0	46.642 ± 34.073	2.520	58.8	100.00
		108	0	0	1.875	0	100.00
		120	0	0	2.360	0	100.00
		Hay	229.19 ± 24.003	224.79 ± 23.154	4.078	925.7	

DIGESTIBILITY AND RATE OF PASSAGE OF KANSAS NATIVE HAYS FOR THE HORSE

by

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B. S., Kansas State University, 1977

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Animal Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1979

Three grade geldings, 3 to 4 years old, were fed 3 native hays (brome, fescue, and prairie) in 6 digestion trials. The trials lasted one week with both feces and urine collected during this period. Digestibility coefficients were calculated for dry matter, crude protein, ether extract, crude fiber, nitrogen free extract, energy, cell wall constituents, acid detergent fiber, cell solubles, and hemicellulose. Nitrogen, phosphorus, and calcium balances were also calculated. We found that these hays were not adequate in energy, protein, calcium, or phosphorus so they should not be fed as the sole maintenance ration. Fescue was the least valuable of the hays studied. Brome and prairie hays were nearly equivalent in value. We found it necessary to determine the nitrogenous components for brome and fescue, since they had adequate digestible crude protein but the animals were in negative nitrogen balance. We found they had about 24% to 45% nonprotein nitrogen causing error in the crude protein values. Limited energy intakes probably prevented use of this nonprotein nitrogen.

Rate of passage of these hays was determined in 3 trials: hays were sprayed with a cerium solution and fed the first feeding. Feces samples were collected twice daily for neutron activation analysis to determine the ppm Ce passed every 12 hours. We found the hays passed through between 36 and 48 hours after ingestion; fescue passed through more rapidly than the others. Within 72 hours we had 95% or more of the cerium collected. In all trials we obtained 100% collected in 120 hours.

Hay and fecal samples were prepared for analysis on the scan-

ning electron microscope. Photomicrographs were taken to determine the pattern of digestion in the horse. The patterns appeared to be the same as ruminal digestion, however the horse was not capable of as complete digestion of the mesophyll as cattle. The mesophyll and phloem were digested leaving the epidermis, xylem, and fibrous vascular bundles in the feces. The horse appeared to utilize more mechanical digestion than the ruminant since the phytoliths were missing and the samples were compacted.

These trials showed we need to analyze our feedstuffs before balancing a ration since our evaluations of the nutrients in the hays were lower than the established N. R. C. values. We also need to be sure that the hays selected for use are of high quality; i.e., a stemmy hay such as the fescue used here was of little value to the horse.