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Abstract Approved: ______________________
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This study involved three separate experiments employing a total of 29 horses and 4 rabbits. The purpose of these studies was to investigate the use of various quantities and forms of ryegrass straw in horse rations, and to determine the use of whole corn plant pellets as an alternative roughage for horses and rabbits.

In the first experiment, twenty head of mature (500 kg) mares and geldings were divided into two groups of ten fed Diet I (51% ryegrass straw and 49% concentrates), or Diet II (51% fescue hay and 49% concentrates). The rations were completely pelleted, isonitrogenous, and isocaloric containing 10.8% crude protein and 2.40 Mcal/kg digestible energy (DE). Apparent digestibilities (Mean ± SE) were calculated by utilizing an indicator ratio technique, chromic oxide. Results indicated that dry matter (DM) digestibility was less ($P < .05$) for Diet I than for Diet II (DM 56.00 ± 1.8 and 66.0 ± 1.3). There were no differences ($P > .05$) between the two diets for acid detergent fiber (ADF 18.5 ± 1.5

and 21.0 ± 1.5), or cell wall constituents (CWC 30.8 ± .5 and 36.0 ± 1.7). Apparent crude protein (CP) digestibility in Diet I (76.2 ± .8) was greater ($P < .01$) than Diet II (70.3 ± 1.0). During a 60-day maintenance trial, body appearance improved considerably. However, considerable wood chewing was noted with most horses during the initial three weeks of the feeding period. Both groups maintained body weight during the trial with average weight gains of 10kg and 1 kg, respectively, for Diet I and Diet II. However, horses fed Diet I consumed 7.9 kg of feed whereas horses on Diet II consumed 7.5 kg. The maintenance and gain in weight, improved appearance and apparent excellent health of the animals in this trial indicated that complete light horse diets can be based upon poor quality roughages such as ryegrass straw. Although the ration based on ryegrass straw was the cheaper per ton, the increased intake made daily feed costs equal.

In the second experiment, four mature (500 kg) horses were used in a 4 x 4 Latin square experiment to determine diet preference for a variety of physical forms of ryegrass straw on the basis of nutrient digestibility, consumption and side effects. All forms of straw were similar in composition, varying only in form (longstem, pelleted, cubed or briquetted). Addition of 5% molasses was used both as a binder and to aid palatability.

All horses adapted to the compressed straws, but individual horses were hindered initially by the compactness and density of the cubed and briquetted forms. Greater chewing and consumption time of these forms was necessary for splitting and ingesting the straw. Mean voluntary consumption of the densified forms of straw was greater ($P < .01$) than for longstem straw (5.5, 6.4, 6.0 and 5.9 kg for longstem, pelleted, cubed and briquetted, respectively). Considerable wood chewing was noted among all animals regardless of diet; however, horses consuming the pelleted diet tended to chew even after ingesting the diet. No digestive disturbances, health impairments or choking was noted.

Digestibility coefficients indicated that all horses digested equally the CP and ash fractions regardless of diet form. Digestibility of ADF, CWC and DM was lower for pelleted straw than longstem straw ($P < .01$) and, furthermore, was lower for the pellets than for the four other diet forms. A possible explanation for this decreased digestibility of pellets may be a faster rate of passage. Data indicate that the mature horse will accept different physical forms of straw. Straw fed as the only source of nutrients will not meet the horses' needs for maintenance over time. Additional research is necessary to determine if concentrates can be incorporated into one of the densified forms to form a complete package feedstuff that might help solve the bulkiness, storage, and transportation problems of conventional hay and grain rations.

In the third experiment, whole corn plant pellets (WCPP) contain-

ing 6.2% CP, 30.8% ADF and 64.8% CWC were fed to five mature horses (500 kg) as a completely pelleted total ration (no supplementation). Apparent digestibilities were calculated by utilizing conventional total fecal collection techniques or the acid insoluble ash (AIA) method. Results of the total collection vs. AIA techniques, respectively, were not different ($P > .05$) for CP, ADF and CWC, but were different for EE. Similar trials with rabbits indicated higher CP digestibility, but lower ADF and CWC digestibility as compared to horses. Results from total collection and AIA techniques were not different in rabbits ($P > .05$).

A three month maintenance trial indicated that mature horses could be maintained by feeding 6.2 kg per day (1.8% of body weight), but considerable appetite depravity and excessive coprophagy were observed. Supplementation of the WCPP with soybean meal to increase dietary protein content to 10% CP eliminated all coprophagy within five to seven days. Subsequent removal of the supplemental protein source initiated coprophagy again within seven to ten days. Horses fed WCPP alone, practising coprophagy, had higher ($P < .05$) CP digestibility than when coprophagy was inhibited. Similarly, when WCPP are fed and coprophagy is allowed but not practised during protein supplementation, CP digestibility is significantly higher ($P < .05$) than when coprophagy is allowed and practised with no protein supplementation. Furthermore,

when protein is supplemented to the WCPP, there is a significantly higher ($P < .01$) CP digestibility than when WCPP are fed alone with coprophagy inhibited and no protein supplemented. Irrespective of whether or not coprophagy was practiced or protein supplemented, DM, ADF and CWC digestibilities were not different ($P > .05$). Data indicate that the mature horse may be maintained on WCPP if supplemented with an adequate protein source.

Utilizing the AIA technique for determining apparent digestibilities in horses offers another indicator technique that may be more convenient and easier to use than conventional total fecal collection techniques.

Ryegrass Straw and Whole Corn Plant Pellets as Alternative Roughages for Horses

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INTRODUCTION

The horse industry has expanded greatly in the past few years and with this expansion has come significant interest in new methods, techniques, and types of feed and feeding in sound horse nutrition programs. Feeding horses is somewhat unique compared to feeding other farm animals in that horses are generally used as athletes and, therefore, must be fed for longevity and athletic performance in addition to normal health, growth and development. These factors pose some problems for which answers are limited. However, the horse is not considerably different from other animals, including man, regarding the nutrients he requires.

Considerable information is available concerning the nutrition of man and other farm animals and until recently most information regarding nutrient requirements for the horse have been extrapolated from other animals. With limited available information and the fact that horse nutrition as a science is a comparatively new field, additional research is justified.

In addition, the competitiveness of all animals to utilize available feedstuffs, including cereal grains and forages, again makes a very complex problem. It has been the attempt of many researchers to indicate new areas of alternative feedstuffs for farm animals. It is in part the objective of this research to investigate the utilization of low quality, by-product type feedstuffs for horses; attempting to help solve a critical problem of disposing solid waste by-products and at the same time utilizing a feedstuff that proves an alternative to normal equine horse feeding practices.

The objectives of these studies were: (1) to evaluate the use of various quantities and forms of ryegrass straw in rations for horses; and (2) to investigate the potential of whole corn plant pellets as an alternative roughage for horses and rabbits.

LITERATURE REVIEW

There have been increasing efforts by the horse and feed industries to develop alternative rations and feeding methods for horses. This has been a result of the ever increasing urban horse population and rising feed costs.

Low quality roughages such as grass and cereal straws represent a large potential source of feed energy if they can be utilized by livestock, including the horse.

Use of Low Quality Grass and Cereal Straws by Livestock

Low quality straws such as the ryegrass straws of the Willamette Valley in Oregon represent a tremendous source of relatively economical energy. However, these straws are generally low in total digestible nutrients, digestible protein, vitamins, and minerals, but are high in fiber and lignin in addition to extreme bulkiness. Utilization of low quality roughage and energy sources has been widely investigated in ruminants (Oh *et al.*, 1971; Anderson, 1972; Shultz and Ralston, 1973) and results indicate that both cattle and sheep are able to perform satisfactorily. To date, however, only limited information is available on the feeding value of high roughage diets of low quality to horses (Pulse, 1973; Hintz *et al.*, 1971; Leonard *et al.*, 1973). Many workers have concluded that the inability of ruminants and other livestock to utilize the energy from the carbohydrate sources of straws may be due to many factors including: (1) lignin acts as an inert barrier between the carbohydrates and the digesting enzyme (Baker and Harriss, 1947; Pigden and Heaney, 1969); (2) cellulose is too highly crystalline to be quickly available to enzyme action (Baker et al., 1959; Cowling and Brown, 1969); and (3) silica inhibits carbohydrate digestibility (VanSoest and Jones, 1968).

Guzzolz et al. (1971) indicate that following heat, water, and alkali treatments, digestibility and palatability of some grass straws can be improved. Anderson and Ralston (1973) reported that chemical treatment of ryegrass straw increases in vitro digestibility. Anderson (1972) and Shultz (1974) have indicated improved digestibility and intake of ryegrass straw when fed to ruminants. White et al. (1974) reported that as the level of untreated rice straw increased in the diet, digestibility of energy and fiber fell drastically when compared to similar levels of dehydrated bermuda grass hay.

Ralston (1973) indicates that most straws contain only 3.5 to 5.0 percent crude protein, which is well below the National Research Council's recommendations for both beef cows and horses. It has been further indicated by Ralston (1973) that this protein deficiency can be corrected by additions of supplemental protein sources (soybean meal and cotton seed meal) or non-protein nitrogen sources. Also indicated was the alteration of the physical form of the straw (i.e., pelleting, grinding, chopping) which usually increases intakes of the straws. However, pelleting many times reduces digestibility (McCrosky et al., 1970; Haenlein et al., 1962a; Haenlein et al., 1962b; Ralston et al., 1966; and Leonard et al., 1973).

Conklin (1974) has investigated the economic potential of using rye-grass straw in animal feeds and other forms. Straw in its natural form requires costly modifications to become attractive to the horseowners. A marketing study of straw as an alternative horse feed in the Pacific Northwest indicated that the urban horseowner dominates this market, and most of these horseowners utilize longstem, high quality hay and grains, along with pastures (Jacob, 1974). These horseowners are aware of market prices, high feed costs, and inflated production costs associated with the horse industry. However, their preference for attractive, high priced feedstuffs was apparently without regard to cost. Results indicated that a maintenance ration including straw could be marketed, as long as it was economically competitive with alfalfa or grass hays.

Comparative Aspects of Digestive Anatomy, Physiology and Nutrient Utilization in Ruminants and Non-Ruminants

The horse is a herbivore and has the ability to utilize high fiber diets like other herbivores. Ruminants (polygastric stomachs) and non-ruminants (simple stomachs), such as the horse (enlarged cecum and large colon) are unique in that they display an anatomical arrangement which allows retention of fiber in the digestive tract for fermentation and cellulolytic digestion.

After many years of limited horse research, Alexander (1946) published information on the digestion and physiology of the horse. Similar work with ruminants had been published nearly 20 years earlier by Schalk and Amadon (1928). The anatomical comparisons between equine and ruminant animals are similar in some respects, but quite striking in others.

The basic differences in the digestive tract of ruminants and non-ruminants has been outlined in the early work of Colin (1886) as cited by Robinson and Slade (1974). The ruminant herbivore has a specialized area in the digestive tract that is anterior to the small intestine where most all bacterial activity occurs. This specialized area consists of a multicompartmental stomach. The horse and other non-ruminants possess a simple stomach located anterior to the small intestine. They also have an enlarged cecum and large intestine which lies posterior to the small intestine. The cecum and large intestine of the horse are very well defined. Robinson and Slade (1974) indicate these comparisons between ruminants and non-ruminants: (1) There is no eructation or rumination in the non-ruminant, and (2) due to the small stomach size, rate of passage of ingesta is more rapid from the stomach to the large intestine. Dougherty (1968) indicates that ingesta passes through the small intestine twice as fast in horses as it does in ruminants. Also, fiber digestion may be up to a third less in the horse than the cow due to enzymatic digestion in the small intestine prior to cecal fermentation in the horse. However, the reverse is true for the cow.

There are some pharmacological similarities and differences between ruminants and equines. Alexander (1951) showed that adrenaline inhibits movements of the equine stomach and large intestine while raising the tone of the cecum. Similarly, Dougherty (1942) showed that adrenaline inhibits motility of the ruminant stomach. Histamine, carbachol, and posterior pituitary extract have little effect on the equine stomach (Alexander, 1951). In the bovine, they inhibit motility of the ruminoreticulum and carbachol increases the tone of the ruminoreticulum of the ovine (Dougherty, 1942).

The bacterial population of the horse is similar in comparison to that of ruminants (Smith, 1965; Kern et al., 1974). Bacteria from the horse large intestine were as efficient in the digestion of cellulose as bacteria from the rumen of cattle under in vitro conditions (Alexander, 1963). Hungate (1966) and Kern et al. (1974) indicate further that the protozoa of the cecum are somewhat different than those from the rumen. However, there still remains the need for bacterial activity present in the two animals for efficient utilization of plant fiber (Knapka et al., 1967).

Comparative digestion of feedstuffs is well established in horses and ruminants. Haenlein _et al._ (1966a) found no differences in digestibility of nutrients by horses and ruminants fed roughage diets. Olsson and Ruudvere (1955) reported that horses and ruminants fed diets low in fiber (cereal grains) digested all components equally well. When diets had high fiber content, the horses did not digest components as efficiently as cattle. In more recent investigations by VanderNoot and Gilbreath (unpublished data, cited by Fonnesbeck, 1969) digestibility was compared in horses and cattle consuming the same forage. Protein digestibility was 3.5% higher while crude fiber and cellulose were 15% lower for horses than for cattle. Also, dry matter digestibility was low for horses. Other workers indicate that the horse is as efficient as the ruminant in the digestion of crude protein (Hintz, 1969; VanderNoot and Gilbreath, 1970; VanderNoot _et al._, 1967). The horse digests fiber about 60-70% as efficiently as the ruminant (Hintz, 1969; Olsson and Ruudvere, 1955; VanderNoot and Gilbreath, 1970), although the difference between species decreases as the quality of the roughage increases. Decreases in digestibility are due to the faster rate of passage of digesta in the horse.

Several researchers have compared protein digestion in horses and ruminants (Alexander, 1951; VanderNoot and Gilbreath, 1970; Word and Breuer, 1967). Results in regard to protein digestion in the non-ruminant and the effect of fermentation in the large intestine in this function is conflicting (Reitnour, 1969, 1970; Hintz, 1971). Reitnour (1969) using ponies to study the digestion of protein supplied by either corn, oats, or barley found digestibilities of 49.5%, 41.7% and 50.8%, respectively. Data from this study indicated that most protein digestion takes place post-cecally. However, later work by Reitnour (1970) suggested that protein digestion and absorption was pre-cecal and that the horse was more similar to chicks, pigs or dogs in protein digestion than cattle. Hintz et al. (1971) and Hintz (1975) indicated that regardless of diet the major portion of protein digestion and absorption, in addition to that of soluble carbohydrates, most minerals, fats, and fat and water soluble vitamins occurs pre-cecally in the small intestine, whereas the major fiber digestion and net water absorption occurs posterior to the small intestine in the cecum and large colon. It has also been suggested by Hintz (1975) that variation in protein digestion may be due to the fact that the dietary protein is absorbed prior to the cecum. Also, in terms of energy digestion the relative importance in the lower gut increases with increased dietary fiber content and intake. Some protein sources are essential for bacteria to digest fiber.

When high grain diets are fed to horses, more carbohydrate is digested in the small intestine and absorbed as glucose. When high fiber diets are fed, glucose production decreases and an increased production of volatile fatty acids (VFA) in the lower gut is found (Crawford, 1971).

Rate of passage studies have been conducted by many workers utilizing markers, indicators, and different roughages in various forms (Alexander, 1946; Castle et al., 1956; Alexander and Benzie, 1951; Shellenberger and Kesler, 1961; Seerley et al., 1962b; Hintz and Loy, 1966; VanderNoot et al., 1967). For example, VanderNoot et al. (1967) reported that the horse passes ingesta through its system in about 96 hours, which is slower than swine and faster than ruminants. These workers suggest that a collection period of at least five days for horses is necessary from their studies.

The horse is more efficient in its ability to utilize fiber than the rabbit, even though the rabbit behaviorally practices coprophagy (Slade and Hintz, 1969; VanderNoot et al., 1967). Digestion coefficients are similar in horses and ponies (Slade and Hintz, 1969).

Conventional and Indicator Techniques for Determination of Digestibility in Livestock

The definition of "digestion" includes all the physiological activities and biochemical changes which food undergoes within the digestive tract to prepare it for absorption and utilization in the body. The "digestibility coefficient" of a substance may be defined as the percentage of a nutrient consumed in the ration which is absorbed and does not appear in the feces.

For many years the most applicable and practical method for determining digestibility coefficients of nutrients in feeds was to use the "standard" or "conventional" techniques. These procedures involved the complete record of the nutrients consumed and total collection of the feces. This method is generally accepted as the most accurate technique. It involves special metabolism stalls for collection of urine and feces separately, or fecal collection bags, and removes the animal from his natural environment. Also, these methods involve unlimited hours of labor by technicians and other workers. Many workers have developed different types of metabolism stalls for use in total collection trials with sheep, swine, cattle and horses (Bratzler, 1951; Hansard et al., 1951; Horn et al., 1954; Nelson et al., 1954; Stillions and Nelson, 1968; Tasker, 1966; VanderNoot et al., 1965).

Some digestibility trials are carried out with animals in their natural environments. For example, in grazing trials animals must adapt to fecal collection bags in order to obtain accurate results. Pulse (1973) modified a total fecal and urine collection apparatus similar to those described by Friend and Nicholson (1965) that was used with young horses producing respectable results.

Digestion trials are very time consuming, laborious and expensive to conduct. In recent years, nutritionists have identified many indirect methods of determining or estimating digestibility. An alternative to the total collection procedures is the use of inert reference substances or "indicator" substances which are naturally occurring and can be added to the feedstuffs being studied. The digestibility coefficient of a nutrient can then be found by determining the ratio of the concentration of the indicator in the dry matter of the feed to that which appeared in the feces. Maynard and Loosli (1965) indicate that the ideal indicator for digestibility studies should be:

> "totally indigestible and unabsorbable, have no pharmacological action on the digestive tract, pass through the tract at a uniform rate, be readily determined chemically, and preferably be a natural constituent of the feed under test." (p. 352)

The calculation of digestibility by an indicator method requires the use of the following formula:

$$\text{Digestibility} = 100 - 100 \left[\frac{\%\ \text{indicator in feed}}{\%\ \text{indicator in feces}} \times \frac{\%\ \text{nutrient in feces}}{\%\ \text{nutrient in feed}} \right]$$

This procedure of estimating digestibility is based upon the determination of the concentration of the nutrient(s) and indicator both in the feed and feces without measuring either total feed intake or fecal output. Digestibility studies can be determined using internal indicators that naturally occur in forages such as lignin, silica or acid insoluble ash. Also, the use of external indicators such as chromic oxide, dyes or polyethylene pellets can be added to the ration in known amounts and measured in the feces. In addition to the indicator ratio technique where both determination of indicator in feed and feces is needed, the fecal index technique can be used where the indicator does not have to be indigestible and only measured in the feces.

Following is a discussion of use of the indicators chromic oxide, lignin, and acid insoluble ash for determination of digestibility coefficients.

Chromic Oxide

Work reported by Hardison et al. (1956) indicates that Edin (1918) was the first to use chromic oxide as an indicator of nutrient digestibility by feeding a combination of chromic oxide and macaroni to dairy cattle.

Hamilton et al. (1927) used chromic oxide and ferric oxide as inert reference materials in an experiment involving sheep and steers. Nutrient digestibility calculated from a 14-day total collection was compared to the indicator technique. These workers concluded that the indicator technique was unreliable for collection of short durations, especially those covering a day or less.

Barnicoat (1945), in an experiment with lambs, pigs and calves, compared digestion coefficients obtained by the chromic oxide method and the total collection or conventional method. The chromic oxide method digestion coefficients were low due to incomplete recovery. The following were suggested as factors offsetting the recovery of chromic oxide: (1) losses through error, (2) losses of chromic oxide in food, (3) loss by solution and absorption in the digestive tract, (4) stratification of chromic oxide in the digestive tract, (5) retention in the digestive tract, and (6) lag between feeding and excretion of chromic oxide.

Kane _et al._ (1949) conducted six digestion trials involving three cows and compared conventional, chromic oxide and lignin techniques using a total collection of feces. The use of chromic oxide or lignin offered promise of saving time, labor, and expense in conducting digestion trials. Variation among the three methods utilized were not mentioned.

Clanton (1962) reported digestion coefficients calculated from the determinations of chromic oxide in the total fecal collection were lower than those calculated from the conventional method. This was attributed to a 95.1% recovery of the ingested chromic oxide. In a second experiment, animals fed low energy rations, which were principally composed of low quality hay, resulted in erroneous chromic oxide recoveries.

Putnam _et al._ (1964) ran 64 digestion trials with steers and compared the conventional and chromic oxide methods. During these studies, the plane of nutrition varied from less than maintenace to approximately two times maintenance and involved 11 different rations. The rations contained from 22 to 89% roughage and 0 to 30% molasses. The digestion coefficients determined by the use of 5-day chromic oxide grab sampling, 10-day chromic oxide total collection, and 10-day conventional total collections methods were similar. These methods were also compared by calculating the number of collection days required to have a standard error of 1.0% for the estimated digestion coefficients. Both comparisons indicated that daily estimates of digestibility were less variable when the chromic oxide grab sampling method was used. Thus, mixing chromic oxide with a complete pelleted ration and taking fecal grab samples at 9 am and 3 pm for 5 days proved to be a satisfactory technique for estimating dry matter digestion coefficients in steers.

Lassiter <u>et al.</u> (1966) conducted four trials using eight lambs and a 7-day total collection of feces. All concentrate rations were fed with chromic oxide for estimation of digestibility. Digestibility coefficients calculated by the chromic oxide method and the total collection method revealed lower ($P < .01$) coefficients of digestibility using the chromic oxide method. Seventy-eight percent of the ingested chromic oxide was recovered.

Putnam <u>et al.</u> (1967) studied rate of passage of chromic oxide with four groups containing four pregnant heifers in each group. The four groups were fed four levels of intake of a mixed pelleted ration. Rate of excretion was more rapid for heifers fed at the 150% level than at lower levels. Coprophagy confounded comparisons between the lower levels. Average percent recovery for the 150, 100, 80 and 60% levels was 82, 74, 75 and 86%, respectively.

VanderNoot <u>et al.</u> (1967) studied rate of passage of various feedstuffs through the digestive tract of the horse using chromic oxide impregnated paper. Recovery of the ingested chromic oxide required four days regardless of the ration fed. An effect from ration differences could not be determined due to the limited number of animals employed.

Kiesling et al. (1969) determined the recovery of chromic oxide from steers grazing tobosa at two stages of maturity. The indicator was administered once daily as a component of paper. Five steers were each given boluses at 7 am for eight days in three trials. The average recovery was 82.4% for days three through eight in trial one and 88.0% for days four through ten and 93.4% for days seven through ten of trial two. The indicator recovery was highly variable among steers. These workers concluded that administration of chromic oxide in paper offered no advantage over other methods and resulted in wide variation among animals and between trials.

The validity of the indicator technique for estimating nutrient digestibility depends on the degree of positive correlation of the time-concentration excretion patterns of the indicator and the nutrient being studied.

Kane et al. (1950) compared the total collection, lignin and Cr_2O_3 methods for determining nutrient digestibility. This study consisted of 18 digestion trials of 8-day duration and involved three cows. There were no significant differences between digestibility coefficients for the three methods.

Putnam et al. (1958) studied the effects of feeding schedule and various ratios of forage to concentrates upon the excretion pattern of chromic oxide. The ratios contained from 35-100% roughage. Twenty grams of chromic oxide were administered daily in the form of a gelatin capsule. Fecal grab samples were taken at 2 to 3 hour intervals. Neither the feeding schedule nor the proportion of roughage to concentrate had an influence upon the general character of the excretion curve of chromic oxide. These workers recommend a 7-day collection period with once-a-day chromic oxide administration, 12 hr. interval grab samples and four animals to get digestibility values within 5% of those obtained by the total collection procedure.

Hayes et al. (1964) proposed and tested a sampling procedure to reduce diurnal variation in the excretion of fecal components. Steers were fed twice daily at 6 am and 6 pm. Ten grams of Cr_2O_3 per steer per day were administered by way of gelatin capsule at feeding time. Two fecal samples were taken each day and composited at the end of six days for each steer. Diurnal variation was reduced using this procedure.

Diurnal variation in the excretion of Cr_2O_3 in six horses was studied by Haenlein et al. (1966b). The average recovery of Cr_2O_3 in three digestion trials was 98.4%. The intra-day variations ranged from 59.2% to 134.8% of the daily mean among defecations of individual horses. These researchers noted that there is a shift in the excretion curves

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when pellets, wafers or loose hay were fed. These results indicate that rate of passage of Cr_2O_3 varies with different physical forms of roughage.

Lignin

There is considerable conflict of opinion concerning the use of lignin as an internal indicator. Ellis et al. (1946) studied a sulfuric acid method for determining lignin. Furthermore, he observed that lignin was not digested by cattle, sheep or rabbits. Other workers have indicated reliable results using lignin as an indicator (Forbes et al., 1946; Swift et al., 1947; Kane et al., 1950). However, Crampton and Jackson (1944), Davis et al. (1947) and Bondy and Meyer (1948) did not get satisfactory results. Today most nutritionists are in agreement that chromic oxide as an external indicator is superior to other indicator methods.

Acid Insoluble Ash

McCarthy et al. (1974) have successfully used this technique in swine. They have reported that the acid insoluble ash (AIA) technique is superior to chromic oxide and conventional total fecal collection techniques for determining digestibility of swine diets. Also, it is indicated that most swine diets will contain sufficient quantities of 4N-HCl insoluble ash without additions of celite. The technique involves using 10 to 12 grams of finely ground feed or dried feces and boiling in 100 ml of

4N-HCl for 30 min., filtering through ashless filter paper, washing with boiling water until free from acid and ashed at 650 C for a minimum of six hours. One can use chromic oxide along with this method since it is insoluble in the acid. The AIA values were obtained by the difference.

Feed Processing -- Densification of Roughages

Feed processing and densification of roughages is not new to the feed industry. Use of pelleting, cubing, crumbling and wafering has offered the feed industry a revolutionized method of manufacturing feedstuffs. The use of high roughage pellets has for many years been the best densification form available. Research in agricultural engineering has indicated other processing methods such as cubing, wafering and briquetting that may compete with pelleting.

The pelleting process has been widely used in cattle, sheep, swine, poultry and horse rations (Dyer, 1958; Fontenot and Hopkins, 1965; Haenlein *et al.*, 1966a; Haenlein and Holdren, 1965; and Hintz and Loy, 1966). The use of high roughage pellets has been shown to increase gain and efficiency for beef cattle, swine and poultry.

The densification process involves first chopping or grinding the feedstuff to reduce the particle size prior to mixing. Then the chopped mixture undergoes a pressure treatment which generates heat, followed by densification, drying and cooling.

The hay used in high roughage pellets and the amount of grinding necessary to make an acceptable pellet depends on the type of roughage used. It has been suggested that this effect of grinding and subsequent densification of roughages is to increase their acceptability to the animal, thus increasing intake (Minson, 1962). Other workers have also indicated increases in forage intake by feeding cubes (Anderson et al., 1975; Hutton et al., 1964; Radloff and Allison, 1971; Ronning and Dobie, 1962; and Kercher et al., 1971).

Early reports by Kuznetsov (1942) indicated favorable results from feeding horses complete rations consisting of hay, oats, bran, beet pulp, and molasses compressed into brickettes as a means of reducing bulk problems with storage and transportation. This was a means of incorporating by-product feedstuffs into horse rations. Earle (1950) concluded that a complete pelleted horse ration had several advantages over the usual separate allowances of hay and grain. These included economy of labor, transportation and storage, convenience in feeding and opportunity for increased utilization of by-product feeds. Processing of feed has been shown to influence its digestibility. Haenlein et al. (1966a) showed that 14% more wafered and 21% more pelleted feed was eaten than loose hay but that pelleting reduced crude fiber digestibility. This may have been due to increased rate of passage since wide differences in intake have been shown not to influence the digestibility of proximate components (Hoffman et al., 1967).

Pelleted rations have been and will continue to be widely used by horsemen. Hintz and Loy (1966) and Haenlein (1969) reported substantial increases in feed intake, rate of passage, and rate of gain when pelleted rations were fed free choice to horses. Nelson and Jordan (1974) using 12 weanling ponies fed pelleted or unpelleted rations during a 168-day growth study. They indicated that ponies fed _ad libitum_ rations of pellets, based on timothy hay, had increased daily feed intake 53% (2.82 _vs._ 1.84 kg) and average daily gains by 100% (.32 _vs._ .15 kg). Pelleting a ration containing high quality alfalfa did not increase daily feed intake (pelleted, 2.44 kg _vs._ longstem, 2.48 kg). Also, average daily gain was not different (.29 _vs._ .25 kg). Johnson and Hughes (1975) suggest that the use of "packaged" roughages for horses appears to be satisfactory as a horse feeding method.

In addition to horses, much work with cattle, sheep and swine has been presented by many workers (Wallace _et al._, 1961; Baird, 1973; Woods and Rhodes, 1962; Haenlein and Holdren, 1965) and all indicate that the use of densification processes has influence the progress of all these animal nutrition programs.

Feeding Behavior of Horses and Livestock

Several researchers have observed depravity of appetite in horses fed complete pelleted diets (Breuer _et al._, 1970; Haenlein _et al._, 1966a; Pulse, 1972), but comparatively little research relating to feeding behavior with horses has been reported. Kern and Bond (1972) have reported that ponies spent the most time at feeders during the daylight hours, but frequented the feeders throughout the night. Feed consumption was 2.0 kg and 1.8 kg per head for day and night periods, respectively. A similar study with ruminants (Putnam and Davis, 1963) showed that steers spent 30% less time feeding when rations were pelleted than when ground and 21% less time feeding on low hay rations than on high-hay rations. Park et al. (1974) revealed that cattle fed pelleted hay spent less time eating (60 min.) while those fed chopped hay spent greater time eating (217 min.) per day.

Few studies have been made to determine whether horses respond similar to ruminants to compressed roughage in the ration. Wood chewing by ruminants receiving pelleted diets is often extensive, and was observed by Lindahl (1972) when sheep were maintained in metal crates but with access to pieces of wood for chewing. Wood chewing was inversely correlated with level of alfalfa pellet intake and was reversible. Mitchell and Shropshire (1959) noted a preference of Thoroughbreds for pelleted over baled red clover hay. Kuznetsov (1942) reported favorable results from feeding horses complete rations consisting of hay, corn, oats, bran, beet pulp and molasses compressed in brickettes. Haenlein et al. (1966a) have reported that horses fed three different physical forms of hay (loose, wafered, and pelleted) chewed wood when pellets were fed. Body weight gain of the horses fed the three physical forms of hay was not significantly different. When mature horses were fed complete pelleted diets, Breuer and Word (1970) observed that they chewed each other's manes and tails as well as wood.

There are limited data concerning coprophagy in horses. Kennedy (1972), when feeding a 20% CP pelleted diet made from either casein or gelatin to mature rabbits, reported that apparent nitrogen digestion, nitrogen-balance and retention of digested nitrogen were greater for the casein diet than for the gelatin diet. Corprophagy decreased but did not eliminate differences and produced a weight gain on both diets, but to a greater extent on the casein diet. A number of researchers have expressed opinions regarding coprophagy by the equine (Slade and Hintz, 1969; Slade, Robinson and Casey, 1970; Schurg et al., 1976), but limited reports of controlled research on this practice and its effects on nutrient digestibility in horses have been found.

Nutritive Requirements

Up until recently, most information regarding nutrient requirements in horses was obtained by extrapolation of data from other livestock and human nutrition. The most current information available to date is compiled by the National Research Council's Nutrient Requirements of Horses, 1973.

The primary nutrients of most interest are protein and energy (carbohydrates and fats). Vitamin and mineral work is generally lacking or quite limited. Finally, water intake and its role as a nutrient per se has had limited research investigation.

The following discussion will deal with information regarding current protein, energy and water requirements of the horse.

Hintz et al. (1969) and Slade et al. (1970) indicated that protein quality may be of lesser importance in mature equines.

The sites of protein digestion and relative digestive efficiency in equines has been studied recently. Reitnour et al. (1969) reported extensive apparent digestion of nitrogen in the lower gut of ponies and less apparent digestion in the small intestine. However, no attempt was made to account for endogenous protein availability to the animals. It was not indicated as to whether the comparatively large quantity of nitrogen absorbed from the cecum and colon was absorbed as amino acids or ammonia. More recently it has been reported that the major amount of protein digestion in equines is prececal (Reitnour et al., 1970; Hintz et al., 1971).

Up until recently, extrapolation of information from other species has been used to estimate protein digestion in horses, and several researchers have compared digestion in the horse and ruminant (Alexander, 1954a,b; VanderNoot and Gilbreath, 1970; Word and Breuer, 1967).

In 1966, NRC assumed, based on ruminant protein digestion, a 70%

apparent protein digestibility in arriving at equine dietary protein requirements.

Recent evidence indicates that values of this order are too high. Slade and Robinson (1970) reported that apparent protein digestibility in mature horses ranged from 33% to 60%, and varied with level of protein intake. At the higher levels of protein intake, the apparent digestibility tended to increase due to metabolic fecal protein making up a smaller portion of the total fecal excretion.

Based on work by Nitsche (1939), maintenance requirements for horses (NRC, 1966) were set at 60 grams of digestible protein per 100 kilograms body weight. Slade et al. (1970) also suggested that this was near the maintenance requirement. Knox et al. (1971), using idle horses in nitrogen balance studies with a 15% crude protein ration, reported that the crude protein requirements for maintenance was 5.43 grams per metabolic weight daily. This was about 95% greater than the 2.70 grams digestible protein per metabolic weight used by NRC (1966) in recommending the maintenance requirement for horses.

As previously mentioned, dietary protein level has an effect on intake of dry matter and consequently on energy intake. Protein or amino acids in an animal's diet will only be used when energy requirements are met through sufficient feed intake.

The energy requirement for maintenance as defined by Brody (1945) is "the net dietary energy required to keep the organism in a steady energetic state, i. e., the net dietary energy required to replace the energy expended while carrying on maintenance life processes." (p. 59) Under practical conditions, the maintenance energy requirement is affected by such things as environmental temperature, fatigue, diet composition, nervous disposition and animal activity. The latter two are of particular importance in the equine since there is considerable variation among individual animals (Wooden, 1970).

The energy required for maintenance of weight has been investigated by many workers (Hintz, 1969; Hoffman et al., 1967; Slade et al., 1970; Stillions et al., 1968; and Wooden et al., 1970). The equation DE(kcal/day) = 155 $W^{0.75}$, where W equals the weight of the horse in kilograms and DE is the digestible energy requirement, can be used to calculate maintenance energy requirements (NRC, 1973). Further studies are currently underway to investigate the proposed maintenance requirements discussed previously. Wolfram et al. (1976) have indicated that the NRC (1973) values are low, and have proposed this equation as an updated calculation: DE(kcal/day) = 176.42 $W^{.75}$. Also, these workers indicate the cost per gram of weight gain made by the horses to be 10.93 kilocalories.

Regarding water consumption, horses require large quantities of good, clean water. Fonnesbeck (1968) indicates water intake to be highly correlated to dry matter intake. Thus, feed intake affects water consumption and likewise water intake will alter feed intake. Temperature, activity and lactation all will affect water intake (NRC, 1973).

SECTION I

Grass Straw: An Alternative Roughage for Horses

Experiment 1

Currently there is an urgent need in the Pacific Northwest, especially in the Willamette Valley of Oregon for developing alternative means for disposal of grass straws which are by-products of the extensive grass seed industry. After harvesting ryegrass seed, it has been traditional to dispose of the residue by open field burning. It has been estimated that approximately 750,000 tons of grass straw residue from some 315,000 acres of the Willamette Valley are burned each year (Anderson, 1972). Recent activation of more stringent environment laws concerning air pollution necessitates a change in the current disposal methods. Also, straw left on the ground harbors harmful pests and diseases and interferes with future harvests. In view of these problems, an alternative means of disposal is necessary, one which might be economical and possibly profitable to the seed growers. One such alternative is using these straws as roughage or energy sources in horse rations.

Ruminants are able to perform satisfactorily on low quality rations incorporating straw as roughage and energy sources (Oh et al., 1971; Anderson, 1972; Shultz and Ralston, 1973). Similarly, horses subsist on high roughage diets of low quality (Pulse, 1973; Hintz et al., 1971;

Leonard et al., 1973).

The competition for the various feed grains and protein sources between meat animals, man, and horses is becoming greater (Pulse, 1973). Hense, there is an increasing need for development of horse rations which take advantage of economical roughages and waste products. The objective of this study was to evaluate ryegrass straw as a roughage source for horses.

Experimental Procedure

Twenty mature (500 kg) mares and geldings were divided according to body weight and sex and randomly alloted to one of two experimental diets based on ryegrass straw or fescue hay (Table 1). The rations were pelleted, isonitrogenous and isocaloric containing 5.1% Digestible Protein with 2.35 Mcal/kg and 2.53 Mcal/kg Digestible Energy (DE) in Diet I and Diet II, respectively. The horses were maintained individually in tie stalls, exercised daily, and fed and watered twice a day for 60 days to maintain body weight at light work. Trace mineralized salt was provided free choice. All horses were weighed initially and at weekly intervals to monitor body weight. During the last ten days of the feeding trial, the diets were altered to include 0.25% chromic oxide (Cr_2O_3) as an indicator. A digestion trial followed with fecal grab samples taken daily from each horse for the last three consecutive days of the trial. Representative samples of feed were

Table 1. Ingredients and comparison ofhorse rations based on ryegrass straw and fescue hay (Experiment 1).

Ingredients		Diet I	Diet II
Oats		19.3	22.5
Barley		18.3	22.5
Molasses		5.0	5.5
C. S. M.		6.0	----
Limestone		0.5	0.5
Ryegrass straw		51.0	----
Fescue hay		----	51.0
Vit. Mix		+	+
Total		100.0	100.0
	Composition		
Digestible Energy	Mcal/kg	2.4	2.5
Crude Protein	%	10.9	10.9
Calcium	%	0.4	0.4
Phosphorus	%	0.3	0.3
Vit. A	IU/lb	2,500	2,500

Cr_2O_3: 0.25% chromic oxide to be added to each diet taken at each feeding and composited. Fecal samples were composited and 50 gram aliquots were taken for analyses. Feed and feces were dried in a forced air-draft oven at 70° C for 72 hours and ground in a Wiley mill through 60 mesh screen in preparation for further analyses.

Chemical analyses for dry matter (DM), and crude protein (CP) or Kjeldahl nitrogen were carried out in accordance with A.O.A.C. (1970) procedures. Acid detergent fiber (ADF) and cell wall constituents (CWC) data were obtained by following the procedures of Goering and Van Soest (1970) and the modified micro-procedure of Waldern (1971). Apparent digestibilities were calculated using the indicator ratio techniques of Hill and Anderson (1958). Treatment differences, hereafter will be expressed as means ± standard error (SE) and were tested for by analysis of variance (Steel and Torrie, 1960).

Daily observations of feeding behavior, general body appearance, digestive disturbances, diet preference and acceptability were made.

Results and Discussion

All horses adapted from preliminary longstem hay and grain rations to the complete pelleted rations quite readily during a three-day transition period. The general health was normal; no digestive disturbances were observed among the horses during the trial. Considerable appetite depravity (wood chewing) was noted with most horses during the initial three weeks of the feeding period. However, the wood chewing was considerably reduced by trimming most exposed wood edges with metal and weekly applications of creosol to exposed wood surfaces. Moreover, there appeared to be an overall decline in appetite depravity irrespective of the metal surfacing as the horses adjusted to the all-pelleted diets.

Body appearance improved considerably during the trial with all horses losing their "hay bellies" and appearing trimmer and neater within three weeks following initiation of the trial. Both groups of horses maintained body weights during the trial with initial weights of 509.0 (kg) and 498.0 (kg) and final weights of 519.0 (kg) and 499.0 (kg), respectively, for Diet I and Diet II. There was a tendency for the ryegrass straw group to show a gain in body weight. All horses were maintained in above average condition on diets somewhat lower in digestible energy than that recommended by NRC (1973) for mature 500 kg horses at light work (Table 2).

General observation of feeding behavior indicated no differences in acceptability of either ration.

Apparent digestibilities of Diets I and II are presented in Table 3. Mean dry matter digestibility was significantly ($P < .05$) greater for Diet II than for Diet I. There was a trend for ADF and CWC digestibility to be greater in Diet II. However, there were no statistical differences between the two diets. Mean ADF and CWC for Diet I were 18.47

± 1.54 and 30.80 ± .45, respectively; whereas, for Diet II they were 21.03 ± 1.49 and 36.03 ± 1.65, respectively. These values are in agreement with ADF and CWC digestibility values for mature horses and ponies as reported by Hintz et al. (1971), Baker et al. (1973a, b), and Leonard et al. (1973). Digestibility coefficients are also presented in Figure 1.

Apparent crude protein digestion in Diet I was significantly ($P < .01$) greater than Diet II. The apparent digestibility values that were observed here for crude protein were similar to those observed by Knox et al. (1971) and Pulse et al. (1973). Although the diets were calculated to be isonitrogenous, the inclusion of the supplemental protein source, cotton seed meal, in Diet I possibly provided for an increased availability of protein in Diet I. Apparent digestible protein in Diet I was 8.3% in comparison to 7.7% for Diet II. The maintenance and gain in weight, improved appearance and apparent excellent health of the animals in this trial indicated that complete light horse rations can be based upon poor quality roughage such as ryegrass straw. Although the ration based upon ryegrass straw was the cheaper per ton, the increased intake made daily feed costs equal (Table 4). More economical formulation of horse rations based upon ryegrass straw could do much to help dispose of some of our solid waste problems. Additional research is needed to establish the extent of usefulness ryegrass straws may play in

Table 2. Mean body weights and daily feed intakes of mature horses fed ryegrass straw or fescue hay.

Item	Diet I	Diet II
Initial Body Weights (kg)	509.0	498.0
Final Body Weights (kg)	519.0	499.0
Daily Feed Intake (kg)	7.9	7.5
Digestible Energy Intake (Mcal/day)	19.6	19.3
Energy Requirements (NRC, 1973) for 500 kg mature horses (Mcal/day)	21.9	21.9
Daily Crude Protein Intake (kg)	.9	.8

Table 3. Mean apparent digestibility coefficients of horses fed rye-grass straw or fescue hay.

% ± SE

	DM*	CP*	ADF*	CWC*
Diet I	45.0 ± 1.8[a]	76.2 ± .8[c]	18.5 ± 1.5	30.8 ± .5
Diet II	66.0 ± 1.3[b]	70.3 ± 1.0[d]	21.0 ± 1.5	36.0 ± 1.6

[a, b]Means within same column with different superscripts are different ($P < .05$)

[c, d]Means within same column with different superscripts are different ($P < .01$)

*Dry matter(DM), crude protein (CP), acid detergent fiber (ADF), cell wall constituents (CWC).

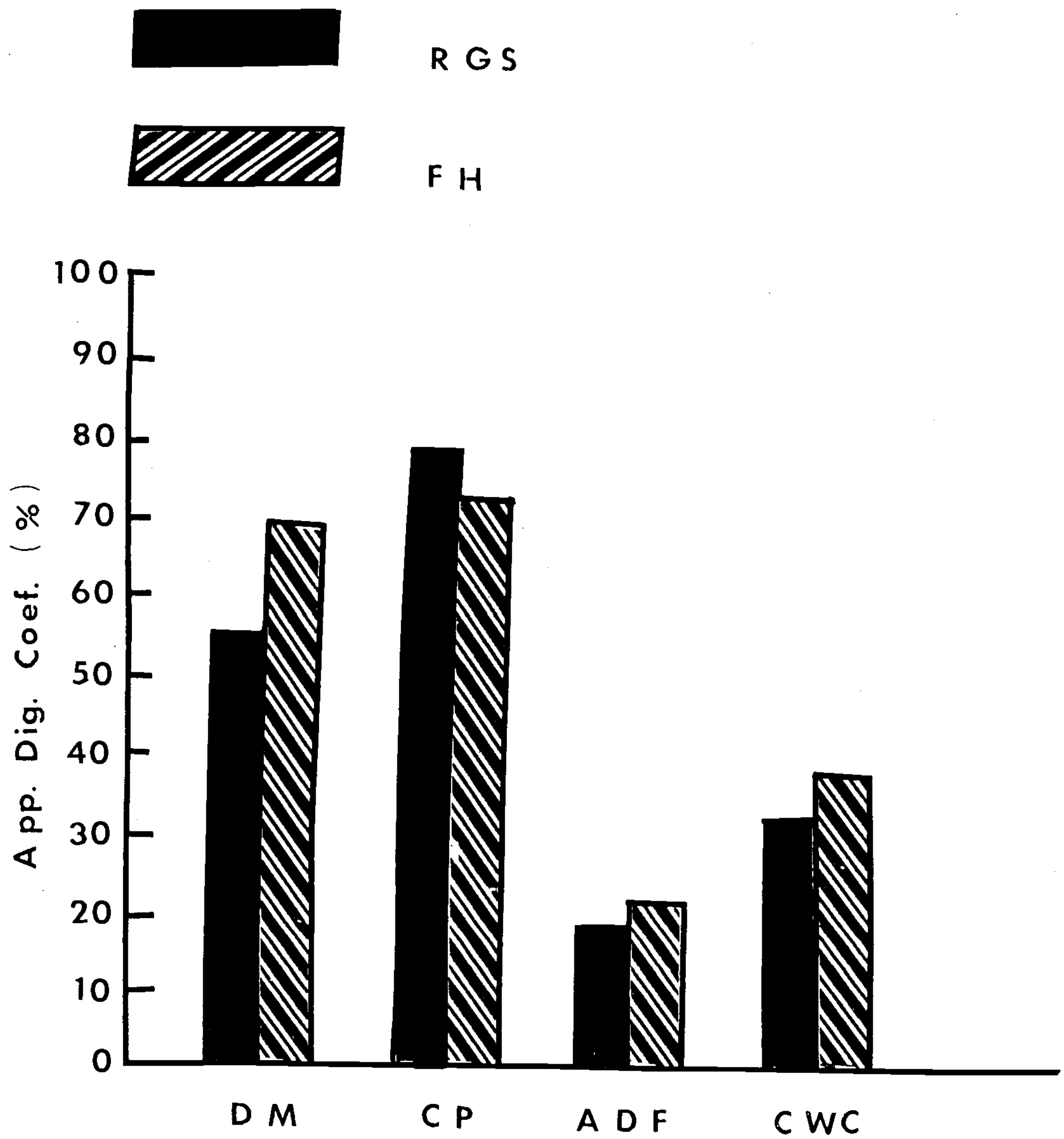

Figure 1. Ryegrass straw (RGS) and fescue hay (FH) digestibility in horses.

Table 4. Ryegrass straw vs. fescue hay -- cost comparison.

	Cost/Ton	Cost/Head/Day	Cost/45.5 kg Body Wt./Day	Cost/454.5 kg Horse/30 Days
Diet I	$85.70	73¢	6.6¢	$19.80
Diet II	$89.52	76¢	7.1¢	$21.30

equine diets.

Summary

A comparative feeding and digestibility trial was conducted using twenty mature (500 kg) mares and geldings. The animals were divided into two groups of ten according to body weight and sex. One group received a diet based on ryegrass straw and the other group received a diet based on fescue hay. Complete pelleted, balanced rations containing 51% roughage sources that were both isonitrogenous and isocaloric were fed. The objective was to evaluate ryegrass straw as a roughage source for horses. Horses adapted to the all-pelleted rations quite readily, as no differences in diet preference or acceptability were observed.

No digestive disturbances, or general health impairments were observed among horses. Considerable appetite depravity existed during initial three weeks of the trial. General body appearance improved and horses maintained body weights. Significant ($P < .05$) increases in DM digestibility were observed in Diet II over Diet I. However, CP digestibility was significantly greater ($P < .01$) for Diet I as compared with Diet II. No significant differences were observed in the fibrous fractions between the two diets.

The results indicate that ryegrass straw can be utilized in rations for light working horses as a roughage source, thus providing a potential

new energy source for equines and a new pathway of straw disposal for the grass seed industry.

SECTION II

Response of Horses Fed a Variety of Densified Physical Forms of Ryegrass Straw

Experiment 2

The increased need for research for horses and in particular the area of use of ryegrass straws as an alternative roughage for horses and livestock has been emphasized by Schurg and Pulse (1974), Anderson (1972), and Shultz (1974).

With a large percentage of horses in urban areas, Jacob (1974) indicates that there will be greater transportation problems especially in bulkiness of hays and other roughage. Modification of long stem hay by pelleting, chopping, wafering and cubing will substantially reduce bulkiness of baled hay. Haenlein and Holdren (1965) and Haenlein et al. (1962b) indicate that these modifications may influence nutritive retention time, increase consumption and increase rate of passage. However, densification processes reduce digestibility of some of the nutrients.

There have been only limited reports of studies to determine the extent horses respond to compressed roughages (Mitchell and Shropshire, 1959; Kuznetsov, 1942; and Haenlein et al., 1966a). Furthermore, there are no studies to this author's knowledge on the ability of the horse to utilize various densified physical forms of ryegrass straw.

The study reported herein was designed to determine the response of horses on the basis of nutrient digestibility, consumption and side affects, when fed ryegrass straw long stem, pelleted, cubed or briquetted.

Experimental Procedure

Diet preference and acceptability, feed intake and appetite depravity along with nutrient digestibilities for dry matter (DM), crude protein (CP), ash, acid detergent fiber (ADF), and cell wall constituents (CWC) were studied in four mature (500 kg) horses in a 4 x 4 Latin square experiment fed ryegrass straw in a variety of physical forms. All animals were maintained individually in tie stalls, fed twice daily at 12 hour intervals. A composition of the various straw diets is shown in Table 5. The diets consisted of: (1) long stem straw, (2) pelleted straw, (3) cubed straw, and (4) briquetted straw with about 5% molasses added in all cases. Water, dicalcium phosphate and trace mineralized salt were available free choice. Chromic oxide as an external indicator was administered during the digestibility trial via 20 gram gelatin capsules. Maximum voluntary consumption was measured during the experiment. During each five day collection period, fecal grab samples were taken twice a day. Representative samples of feed and feces were composited for further analysis. Digestibility of nutrients were calculated using indicator ratio techniques.

In this experiment, a 4 x 4 Latin square design was used (Steel and

Table 5. Composition of ryegrass straw fed to horses in various physical forms (Experiment 2).[a]

Physical Form of Straw	Dry Matter	Crude Protein	Acid Detergent Fiber	Cell Wall Constituents	Ash
	%	%	%	%	%
Long stem	92.2	4.2	46.0	77.2	4.5
Pelleted	91.5	4.0	44.7	75.0	4.0
Cubed	92.0	4.3	46.0	74.9	4.5
Briquetted	91.0	4.1	48.2	77.5	3.8

[a]Four composite samples taken during the trial.

Torrie, 1960). The horses were randomly allotted to the four treatments initially and followed the order described in Table 6.

Results and Discussion

Processing the straw into densified forms did not adversely alter chemical composition of the straws. Thus, at the time of feeding, all forms of straw were similar in nutritive value. Top dressing of all straw forms with a uniform amount of molasses was necessary to facilitate ingestion.

Horses adapted to the compressed straws without difficulties; however, individual horses did have problems with splitting the cubed and briquetted straw forms. This may have been due in part to the hardness of these products. The cubed and briquetted straw forms were of very high density. Pellets were chewed and ingested without any apparent problems. Mean daily consumption of the straw forms is presented in Table 7. Mean voluntary consumption of pelleted, cubed and briquetted straw was significantly ($P < .01$) higher than long stem straw.

Considerable appetite depravity (wood chewing) was noted among all individuals regardless of diet form; however, horses consuming the pelleted diet tended to continue to chew after ingesting the feed to a greater degree than when other forms were fed. These behavioral observations are similar to other worker's reports (Haenlein et al.,

Table 6. Experimental design -- Experiment 2.

Horse	Period 1	Period 2	Period 3	Period 4
1	LS	BS	CS	PS
2	PS	LS	BS	CS
3	CS	PS	LS	BS
4	BS	CS	PS	LS

Treatments: Longstem straw (LS), Pelleted straw (PS), Cubed straw (CS), and Briquetted straw (BS).

Table 7. Mean daily feed intakes by horses (kg).

Physical Form of Straw	Week 1	2	3	4	5	Ave.
Longstem[a]	5.5	5.7	5.5	5.6	5.4	5.5
Pelleted	6.5	6.4	6.3	6.4	6.2	6.4
Cubed	6.1	6.0	5.8	6.3	6.0	6.0
Briquetted	6.0	5.7	5.9	6.1	5.8	5.9

[a]All values for longstem were different ($P < .01$) from all other forms.

1966a; Breuer and Kasten, 1970; Schurg and Pulse, 1974). There were no observations of health impairment, digestive disturbances or choking.

Results of the digestibility trial is presented in Table 8 and Figure 2. Horses digested crude protein and ash to the same degree regardless of physical form. However, acid detergent fiber, cell wall constituents and dry matter were all significantly ($P < .01$) decreased when pellets were fed compared to loose hay and significantly ($P < .05$) decreased when pellets were fed compared to cubed or briquetted straw. Many workers attribute this decreased digestibility to the faster rate of passage, indicated by different excretion patterns of chromic oxide with different physical forms of roughage fed (Haenlein et al., 1966a; Haenlein et al., 1962b; and Hintz and Loy, 1966). Longstem and cubed straw were similarly digested among all horses; however, briquetted straw tended to be lower in digestibility.

Summary

Responses of mature horses to four various physical forms of ryegrass straw (longstem, pelleted, cubed and briquetted) were evaluated. Chemical composition was similar for all forms of straw, however due to processing the particle size and density of the forms was different. No digestive disturbances or impaired health was observed among the horses. Considerable appetite depravity (woodchewing) was

Table 8. Mean apparent digestibility coefficients of horses fed various physical forms of ryegrass straw.

Physical Form	Item (% ± S. E.)				
	DM	CP	ADF	CWC	ASH
Longstem	58.0 ± 1.4 [d]	60.2 ± 1.7	33.8 ± 1.6 [b]	40.4 ± .2 [d]	28.9 ± 1.5
Pelleted	44.0 ± 2.0 [a,c]	58.5 ± 1.4	25.2 ± 1.1 [a]	31.1 ± 1.8 [c]	27.4 ± 1.2
Cubed	54.2 ± 1.7 [b]	58.6 ± .8	33.5 ± .9 [b]	41.0 ± 1.2 [d]	30.1 ± 2.1
Briquetted	51.4 ± 1.3 [b]	57.7 ± 1.2	31.4 ± 1.1 [b]	38.7 ± .7 [b]	32.0 ± 1.9

[a,b] Means with different superscript in same column are different ($P < .05$).

[c,d] Means with different superscript in same column are different ($P < .01$).

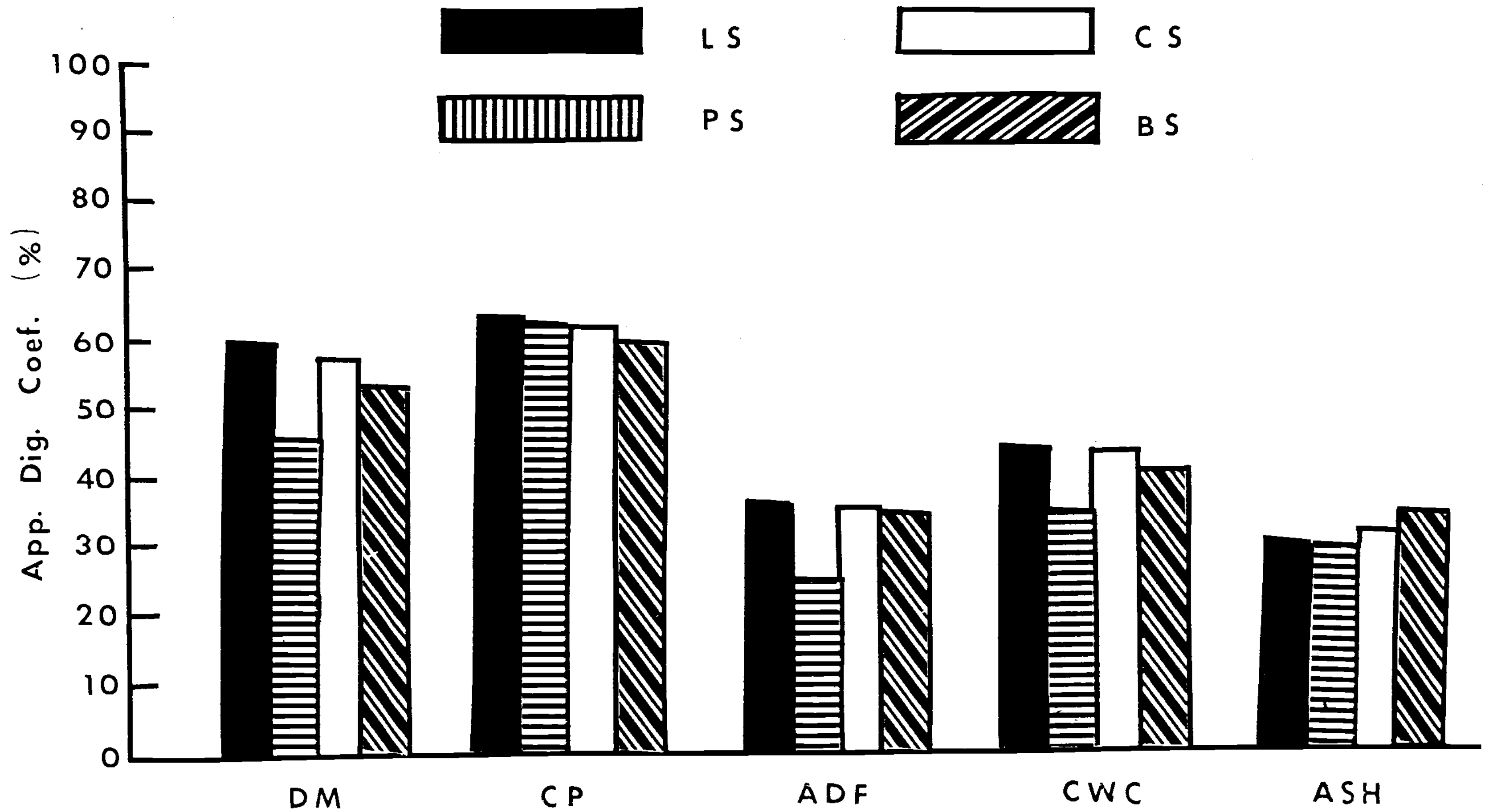

Figure 2. Digestibility of ryegrass straw in various physical forms by horses.

apparent among all horses. There was a tendency for horses fed the pelleted diet to chew wood to a greater extent than all other forms. All horses indicated some difficulty in chewing cubed and briquetted straw. This probably was due to the compactness and density of these forms. Horses fed pelleted, cubed and briquetted straw had higher ($P < .01$) mean daily feed intakes than when longstem straw was fed (6.4 kg, 6.0, 5.9, and 5.5) respectively for the four forms. All horses digested the crude protein and ash fractions equally well, however horses fed pelleted diets had significantly ($P < .01$) lower acid detergent fiber, cell wall constituents and dry matter digestibilities than when fed longstem straw and lower ($P < .05$) digestibilities than cubed or briquetted straw for the same three fractions. There were no differences ($P > .05$) among digestibility coefficients for longstem and cubed straw, but briquetted straw tended to be less digested by all horses.

Additional research in this area is needed to identify the extent densified physical forms of straw may play in horse diets. The use of ryegrass straw with incorporation of concentrates together in one of the densified forms may be a potential way to manufacture a completely densified horse feed. The product must be of lower density than those used in this experiment. A product of this nature might lend itself nicely to the increased urban horse populations by solving the bulkiness, transportation, handling and storage problems faced with baled hay and high cost concentrates.

SECTION III

Utilization of Whole Corn Plant Pellets by Horses and Rabbits

Experiment 3

The light horse industry in the United States is expanding very rapidly, and with this expansion comes a need for utilizing alternative feed sources which will provide adequate performance at reduced costs. These needs are realized at a time of shortages of traditional feedstuffs, high feed costs, and inflated production costs associated with the horse industry, which gives rise to a greater need to rely more on roughages as the energy source for horses. Processing corn forage and grain in the form of whole corn plant pellets (WCPP) provides a high roughage feedstuff that may be used by horses and other non-ruminant herbivores. Investigation of this product is relevant, as limited information is available on the feeding value of dehydrated corn plants (Beeson et al., 1959; Rumery, 1969; Lanari and Vandersall, 1971; Hendrix and Klopfenstein, 1973; and Karn et al., 1974). Whole corn plant pellets are composed of the entire corn plant finely chopped in the well-eared dent stage and processed at a dehydration plant in a similar manner as alfalfa. Subsequently, the dehydrated product is compressed into .6mm (1/4 inch) diameter pellets. Nutrient analyses and economics of such a product and its processing procedures may vary depending upon the type of corn, stage of maturity, fertilization, ear to plant ratio, and the geographical location of harvest. The objectives of this trial were: (1) to evaluate WCPP as an alternative completely pelleted supplemented and non-supplemented total ration for light horses and rabbits; (2) to investigate the nutrient composition of the WCPP; and (3) to determine apparent digestibility coefficients for the WCPP using either conventional or acid insoluble ash techniques.

Experimental Procedure

In a preliminary investigation, four mature male New Zealand White rabbits were utilized to evaluate the nutrient composition, acceptability of diet, and apparent digestibility coefficients obtained when WCPP were fed as the sole source of nutrients. Animals were housed in individual cages and fed the diet for a 14-day adaptation period prior to initiation of the digestion trial. No attempt was made to inhibit coprophagy during the rabbit trial. Conventional total fecal collection procedures and acid insoluble ash techniques (McCarthy et al., 1974) were used. Representative samples of feed and feces were taken from the total and composited for analyses and the two techniques for determination of digestibilities were compared. A similar trial was conducted using five mature (500 kg) Quarter Horse mares. Coprophagy was inhibited by keeping mares in individual tie stalls during this digestion trial. Following the digestion trial, a 90-day maintenance trial was initiated. Evidence of excessive appetite depravity and coprophagy existed during the initial weeks of the maintenance trial, thus subsequent digestibility trials were initiated to identify the effect of coprophagy and protein supplementation on nutrient digestibility and behavioral characteristics of horses fed WCPP. The diets composed of whole corn plant pellets (Table 9) contained 6.2% crude protein (CP), which is well below the 10% CP recommendations for 500 kg horses (NRC, 1973). All animals were maintained individually in tie stalls, exercised daily and fed twice a day. Water, trace mineralized salt and a Ca-P supplement were available free choice. All animals were weighed initially and at tri-weekly intervals to monitor body weight. During a 14-day adaptation period, mares were fed at 2% of their body weight; however, all animals would ingest only 1.2% of their body weight, or 6.18 kg/head/day. Again, in the first digestion trial, as with the rabbit experiment, conventional total collection and acid insoluble ash techniques for digestibility determination were compared. Representative subsamples of feed and fecal material were taken from the total on each of the five collection period days, and composited. Feed and feces were dried in a force air-draft oven at 70° C for 72 hours and ground in a Wiley mill through 60 mesh screen in preparation for further analyses. During each of the three digestibility trials, blood samples were taken and serum collected and frozen until future analysis could be done.

Chemical analyses for dry matter (DM), crude protein (CP) and

Table 9. Composition of whole corn plant pellets.[1,2]

Nutrients	%
Dry Matter (DM)	92.5
Crude Protein (CP)	6.2
Acid Detergent Fiber (ADF)	30.8
Cell Wall Constituents (CWC)	64.9
Ether Extract (EE)	1.8
Ash	6.7
Acid Insoluble Ash (AIA)	2.8
Gross Energy (Mcal/kg)	3.8

[1] Supplemental Ca-P and trace mineralized salt were available free choice.

[2] Digestion trial 3, SBM @ .5 kg/head/day was added to the WCPP to modify diet to contain 10% CP.

ether extract (EE) were carried out in accordance with A.O.A.C. (1970) procedures. Acid detergent fiber (ADF) and cell wall constituents (CWC) were obtained by following the procedures of Goering and Van Soest (1970) and the modified micro-procedure of Waldern (1971). Gross energy was measured with a Parr oxygen bomb calorimeter. Apparent digestibilities were calculated using either conventional total collection techniques or the HCl insoluble ash technique of McCarthy et al. (1974). Data was subjected to t-test analyses (Steel and Torrie, 1960).

Results and Discussion

Results of the rabbit digestibility trial using either conventional total fecal collection or the acid insoluble ash (AIA) techniques are presented in Table 10 and Figure 3. Data indicate no differences ($P > .05$) between the total or AIA techniques. Digestibility coefficients follow a similar trend as reported by Slade and Hintz (1969), who observed that rabbits digest the CP fraction very adequately, but have a reduced fiber fraction and energy digestibility when fed a pelleted alfalfa ration. Similar trials with mature Quarter Horse mares indicated no differences ($P > .05$) between the two techniques, except for EE fraction, which was higher ($P < .05$) with the total collection method (Table 10 and Figure 4). The trial with rabbits indicated higher CP, but lower ADF, CWC, and DE digestibilities as compared to horses (Figure

Table 10. Mean apparent digestibility coefficients for rabbits and horses using either total collection or acid insoluble ash techniques

Item	Rabbits		Horses	
	Total Collection	AIA	Total Collection	AIA
Dry Matter (% ± SE)	47.4 ± 2.1 [a]	42.7 ± .8 [a]	70.0 ± 4.5 [b]	72.8 ± 1.7 [b]
Crude Protein	80.2 ± 1.0 [a]	78.3 ± 2.5 [a]	53.0 ± 6.1 [b]	56.9 ± 2.5 [b]
Acid Detergent Fiber	25.0 ± 3.3 [a]	18.2 ± 3.5 [a]	47.5 ± 8.2 [b]	52.5 ± 2.7 [b]
Cell Wall Constituents	36.7 ± 2.6 [a]	31.1 ± 1.3 [a]	68.9 ± 5.2 [b]	72.0 ± 1.7 [b]
Ether Extract	93.9 ± .2 [a]	93.2 ± .2 [a]	99.2 ± .1 [a]	88.0 ± 1.7 [b]
Ash	36.4 ± 4.4	31.0 ± 2.5	31.0 ± 4.1	28.9 ± 1.4
Digestible Energy	49.3 ± 3.9 [a]	44.9 ± 3.3 [a]	79.9 ± 5.3 [b]	82.0 ± 4.8 [b]

[a,b] Means in same row with different superscripts are different ($P < .05$).

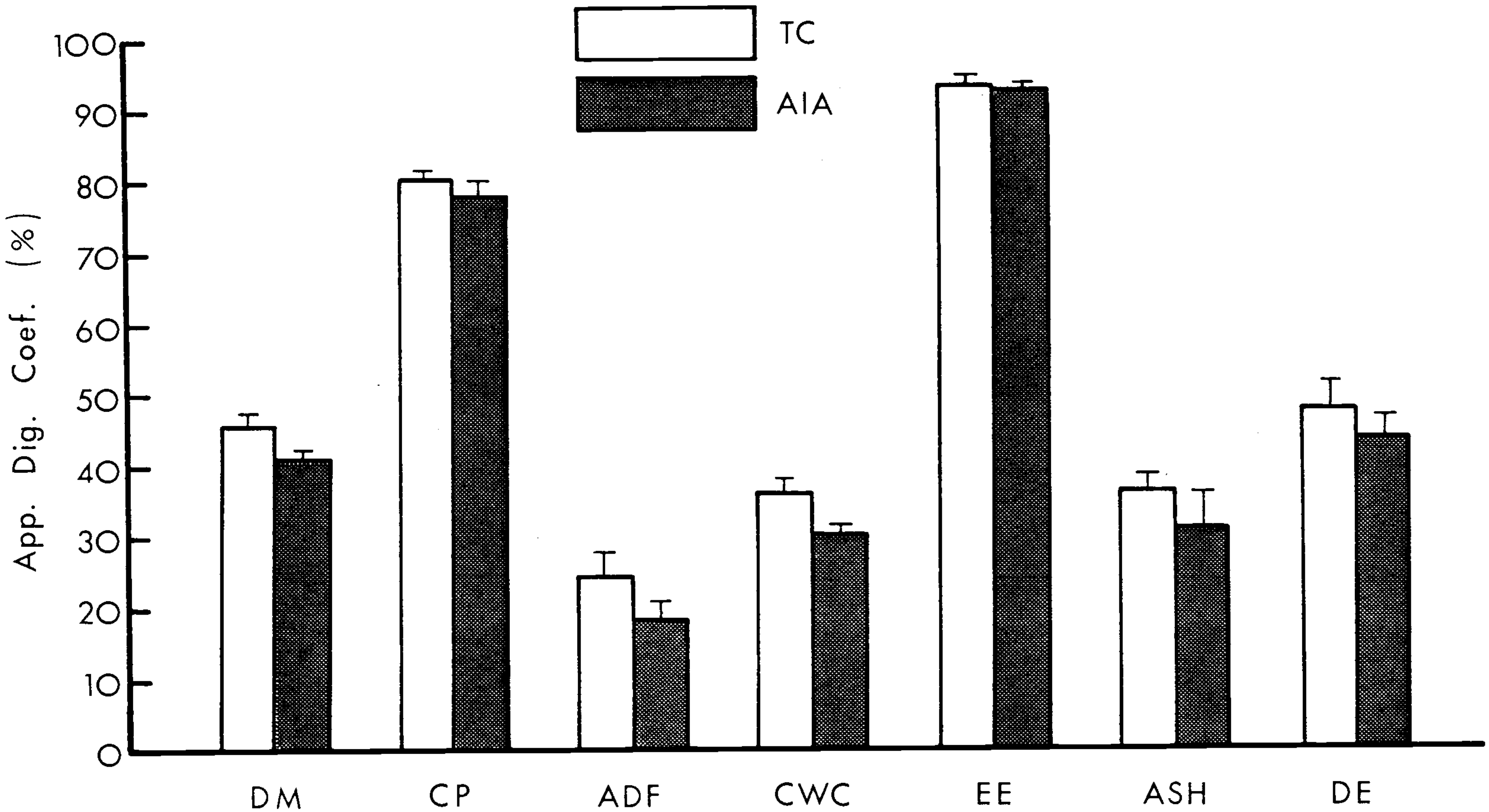

Figure 3. Digestibility of WCPP in rabbits (total collection vs. acid insoluble ash).

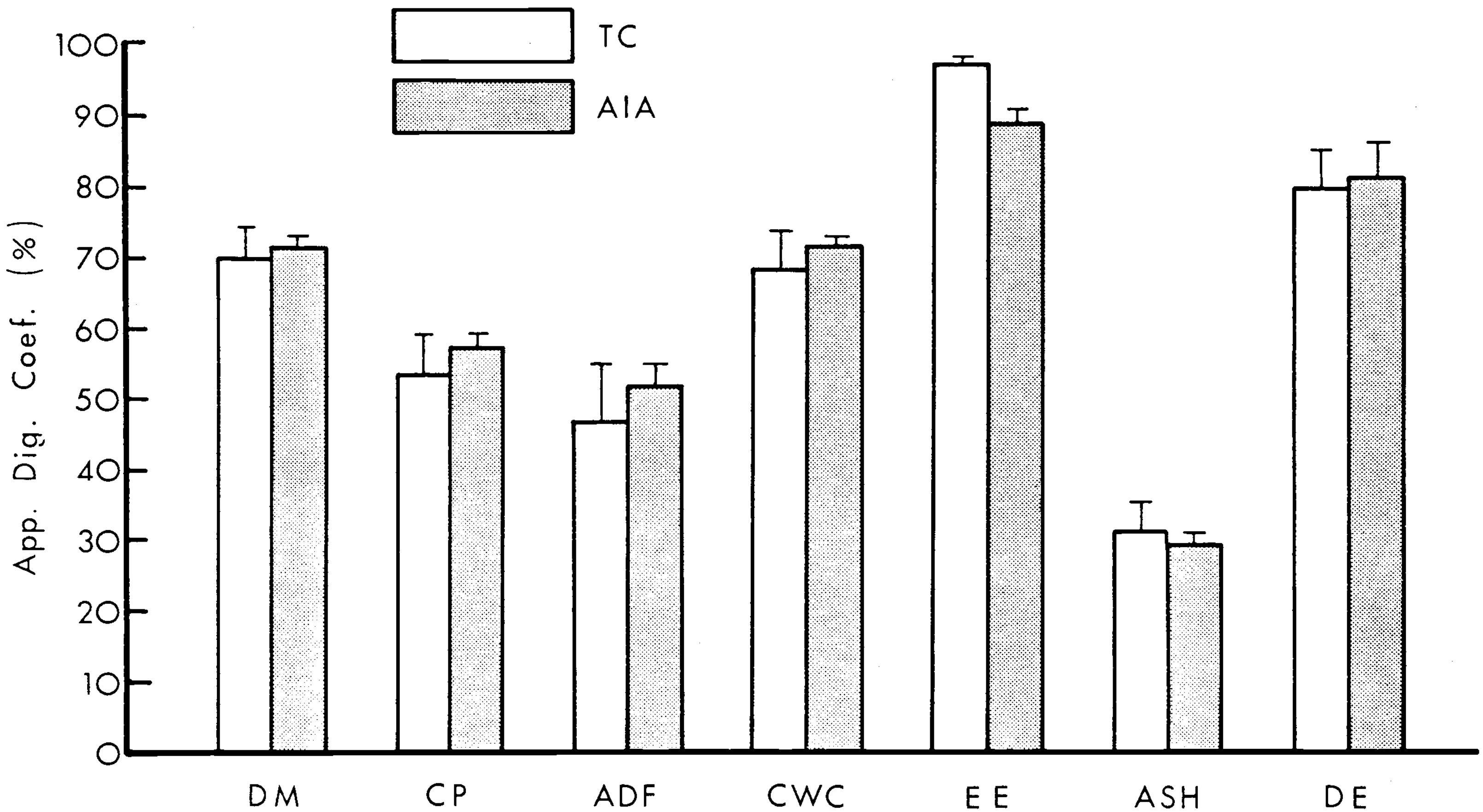

Figure 4. Digestibility of WCPP in horses (total collection vs. acid insoluble ash).

5). This may be due to the fact that rabbits practice coprophagy (Thacker and Brandt, 1955; Slade and Hintz, 1969).

During a 90-day maintenance trial all horses adequately maintained body weight on 6.2 kg/head/day (1.2% of body weight) which agrees with recommendations for 500 kg horses at maintenance (NRC, 1973). Mean body weight data and daily feed intakes are presented in Table 11. Considerable appetite depravity and excessive coprophagy was observed among all animals. Behaviorally all animals would ingest the WCPP, walk outside the feeding area and defecate. Then each animal would back up to, or circle, his own feces and ingest the total defecation. These observations are similar to those reported by Pulse (1973) who noted that colts fed a low protein high fiber diet practiced coprophagy. It may be a mechanism for the utilization of bacterial protein as a means of nitrogen conservation on a low protein diet (Slade _et al._, 1970; Slade and Robinson, 1970). Supplementation of the WCPP with soybean meal to increase the dietary protein content to 10% CP eliminated all coprophagy within 5 to 7 days. Digestibility trials were initiated both during the feeding of WCPP where coprophagy was allowed and with or without protein supplementation. Results are presented in Table 12 and Figure 6. The mean apparent digestibility coefficients indicate that horses practicing coprophagy had increased ($P < .05$) CP digestibilities. Supplementation with soybean meal resulted

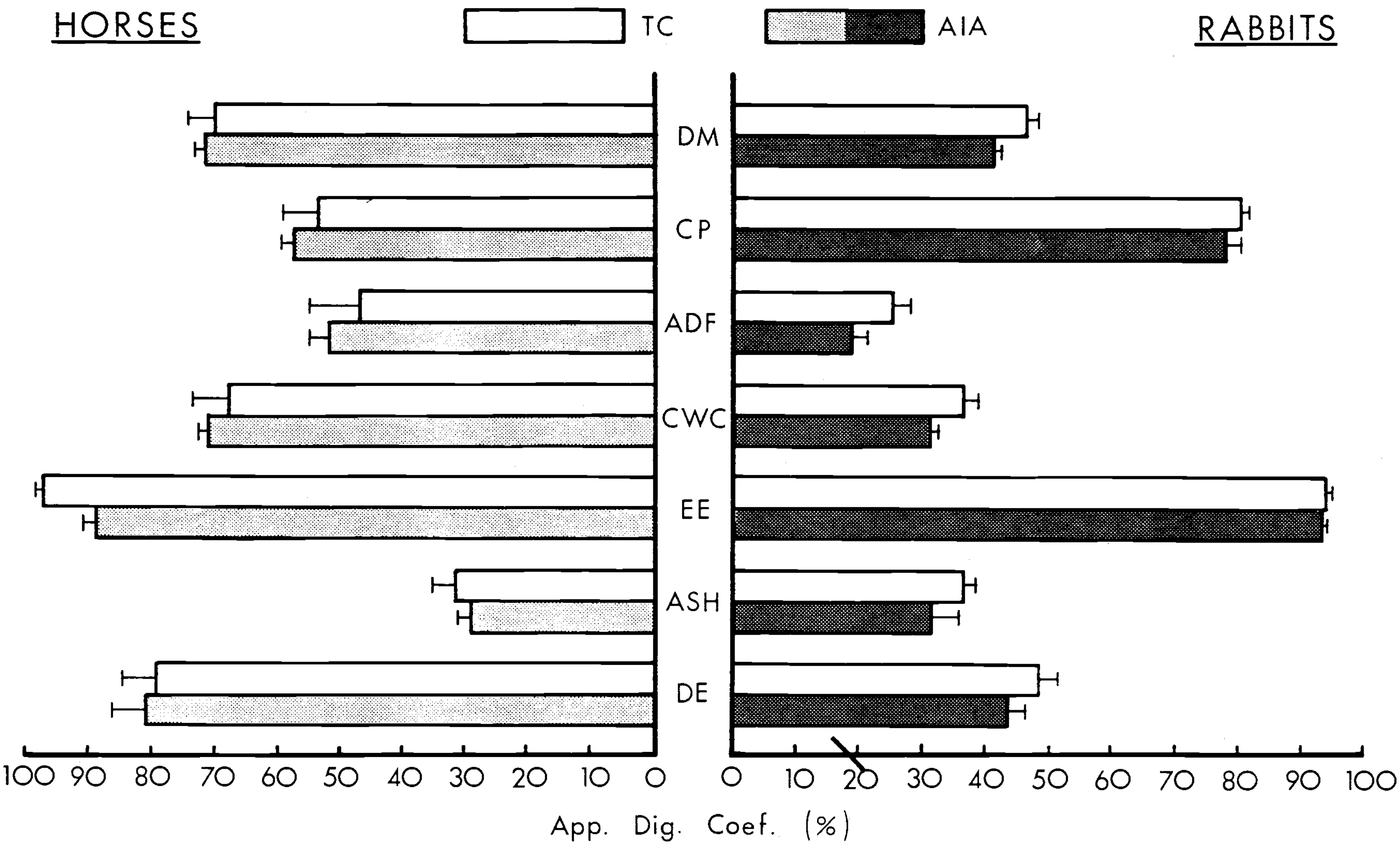

Figure 5. Digestibility of WCPP (total collection vs. acid insoluble ash in a rabbit and horse comparison).

Table 11. Mean body weights and feed intakes of mature horses fed whole corn plant pellets.[1]

Item	Means ± S. E.
Initial body weights (kg)	509.6 ± 24.1
Final body weights (kg)	503.6 ± 22.6
Daily feed intake (kg)	6.2
Digestible energy intake (Mcal/day)	22.5
Energy requirements (NCR, 1973) for 500 kg mature horses at rest (Mcal/day)	16.4

[1]Means of five animals.

Table 12. Mean apparent digestibility coefficients when horses fed WCPP with or without coprophagy and/or protein supplementation.

Digestion Trial Type	Items (% + S. E.)			
	DM	CP	ADF	CWC
WCPP, no coprophagy, no protein supplement	72.7 ± 1.7	56.9 ± 2.5[a,d]	52.5 ± 2.7	72.0 ± 1.7
WCPP, coprophagy allowed, no protein supplement	74.4 ± 1.7	64.1 ± 1.8[b]	57.3 ± 3.4	73.4 ± 1.7
WCPP, protein supplement allowed, coprophagy allowed, but not practiced	73.7 ± 1.9	70.4 ± 1.5[c,e]	55.9 ± 2.9	72.8 ± 1.8

[a,b,c] Means in the same column with different superscripts are different ($P < .05$)

[d,e] Means in the same column with different superscripts are different ($P < .01$)

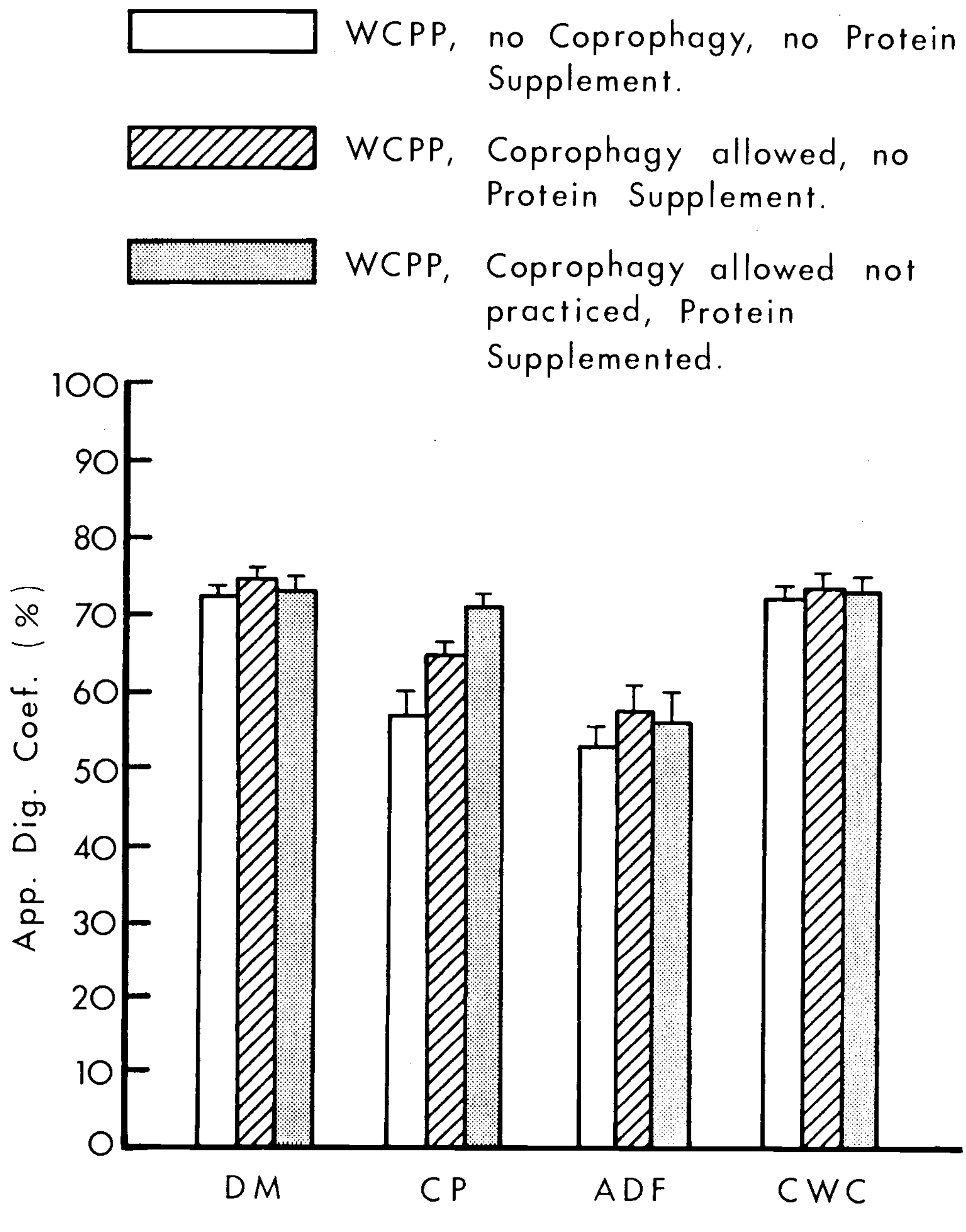

Figure 6. Digestibility of WCPP in horses with/without Coprophagy and/or protein supplementation.

in higher ($P < .05$) CP digestibilities than those obtained with WCPP alone with coprophagy allowed, and higher ($P < .01$) CP digestibilities than when WCPP was fed alone with coprophagy inhibited. Subsequently, removal of the supplemental protein source resulted in coprophagy again within 7 to 10 days.

It is apparent from these results that the mature horse can be maintained adequately on WCPP alone; however, one must realize that appetite depravity problems and coprophagy may result. Adequately supplementing with a protein source such as soybean meal as a top dressing to the WCPP eliminates the abnormal behavioral observations, while maintaining the light horse, thus making WCPP a possible economical source of feed for horses. Utilizing the AIA technique for determining apparent digestibilities in horses offers another indicator method that may be both more convenient and easier to use than calculating digestibility values for horses using either conventional total fecal collection or chromic oxide techniques. More economical formulation of horse rations using WCPP could do much to help solve an ever increasing and costly problem in feeding horses. Additional research is needed to establish the extent of usefulness WCPP may play in equine diets.

Summary

Whole corn plant pellets (WCPP) containing 6.2% crude protein

(CP) were fed to five mature horses (500 kg) and to mature rabbits as a completely pelleted total ration (with and without protein supplementation). Apparent digestibility coefficients (%) were calculated by utilizing conventional total fecal collection or the acid insoluble ash (AIA) method. Apparent digestibility coefficients utilizing the total collection vs. AIA techniques were not different ($P > .05$) for dry matter, crude protein, acid detergent fiber, cell wall constituents, digestible energy, or ash for either horses or rabbits; however, ether extract was different ($P < .05$) in horses. Digestion coefficients for horses and rabbits were respectively: DM (72.8, 42.7); CP (56.9, 78.3); ADF (52.5, 18.2) CWC (72.0, 31.1); EE (88.0, 93.2); Ash (28.0, 31.0); and DE (82.0, 44.9). A three month maintenance trial indicated that mature horses could be maintained by feeding 6.2 kg/head/day (1.2% of body weight), but considerable appetite depravity and excessive coprophagy was observed among all animals. Supplementation of the WCPP with soybean meal to increase dietary protein content to 10% CP eliminated all coprophagy within 5 to 7 days. Crude protein digestibility coefficients were increased ($P < .01$), although no significant increases in the other fractions were observed. Subsequently, removal of the supplemental protein source resulted in coprophagy again within 7 to 10 days. No digestive disturbances or general health impairments were observed among horses. General body appearance and body weights were maintained. All mares maintained normal estrous cycles.

The results indicate that the mature horse may be maintained on WCPP if it is supplemented with an adequate protein source; thus, making WCPP a possible economical source of feed for horses. Also, utilizing the AIA technique for determining apparent digestibilities in horses indicates a more convenient method for calculating digestibility coefficients for horses without using conventional total collection techniques.

SUMMARY

Twenty-nine horses and four rabbits were used in three separate experiments to evaluate various alternative feedstuffs and processing methods when diets were composed of various quantities and forms of ryegrass straw and whole corn plant pellets separately.

All experiments involved digestibility trials where a variety of techniques were used for determination of digestibility coefficients (chromic oxide mixed in the feed and given via gelatin capsule with fecal grab sampling, conventional total fecal collection, and an acid insoluble ash technique). It is the conclusion of this worker that using external or internal indicator methods offers a more convenient, accurate, and easier process for calculating and determining digestibility coefficients when compared to the laborious, time consuming, conventional total fecal collection techniques.

Diets incorporating ryegrass straw in them offers both a potential new roughage source for the horse industry and a possible alternative solution to open field burning in part. Using densified physical forms of straws may help solve the urban horse owners problem of storage, handling, transportation, bulkiness and cost of traditional baled hay and grain feeding practices for horses. The use of ryegrass straw incorporated with supplemental protein and other essential nutrients offers unlimited potential to the economical ration formulator. Also, the in-

corporation of whole corn plant pellets with straws and supplemental protein, minerals and vitamins has possibilities.

Additional research incorporating these low quality feedstuffs into practical light horse diets is needed, and may help to solve a critical disposal problem of solid waste by producing alternative feedstuffs for horses.

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BIOGRAPHICAL SKETCH

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