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PART I. EVALUATION FOR YIELD AND QUALITY OF SIX SUMMER ANNUAL GRASSES

PART II. COMPARATIVE FEEDING VALUE OF SUMMER ANNUAL GRASS HAYS AND SILAGES FOR LAMBS

by

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B.S., University of Liberia, 1975

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1979

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DEDICATION

This work is dedicated to my beloved mother, Lorpu Mawah.

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ACKNOWLEDGMENTS

I wish to express deep gratitude to Dr. Gerry L. Posler, my major professor, for the cordial, informal and respectable relationship that he encouraged between us. Also, sincere thanks are due to him for assistance with the planning and execution of the study discussed in Part One of this thesis and for the preparation of the entire manuscript. His patience, advice and emphasis on excellence are acknowledged as important guideposts for my successful completion of the M.S. degree.

My appreciation also goes to the other committee members, Dr. Keith Bolsen and Dr. Jack Riley, for their helpfulness and encouragement in all phases of my M.S. degree program. Part Two of this thesis was designed and carried out under the guidance of Dr. Bolsen.

I am also indebted to Steve Sears, Jerry McLaughlin, Harvey Ilg, Jim Oltjen, and the staff of the forage evaluation and nutrition laboratories for their assistance in the field and laboratory aspects of both studies. The work of preparing this manuscript was also greatly assisted by Dr. Dallas Johnson and Mrs. Karen Lynch, the statistical consultant and typist, respectively.

Grateful acknowledgment is made to the Government of Liberia and the African-American Institute for financing my study and affording me the opportunity to participate in educational tours and professional meetings in various parts of the United States. Sincere thanks are also bestowed upon Ms. Patricia A. Green, faculty, staff and students of the Departments of Agronomy and Animal Science, who in diverse ways, contributed to the successful completion of this degree program. Last, but not least, thanks are due to my parents, relatives and friends for their prayers, love, and endurance during my absence from home.

CHAPTER I

INTRODUCTION

The availability of forages on a year-round basis is an important component of livestock operations where efficiency and profitability are the primary goals. With increasing costs of grain and the continuing expansion of the livestock industry, there is a growing need for well-planned forage programs designed to provide good seasonal distribution of forages of high quality and yield. Because feeds comprise 50-85% of the production cost of most livestock operations, use of forages with high nutritional value can reduce animal production costs significantly.

However, one of the primary limitations to profitable livestock production on many farms is the lack of a well-planned forage program. Knowledgeable and profit-conscious farmers plan flexible, year-round forage programs that, among other things, consider the seasonal changes in climatic conditions and their resulting effects on the growth and development of forage plants.

One of these climate-related forage distribution patterns recurs annually during the summer months throughout much of the continental United States. The hot, dry weather conditions usually associated with this season depress both the nutritive value and the yield of perennial cool-season forages and native pastures. If adequate plans are not made to provide supplemental or emergency forages during the summer, this depression may severely reduce the efficiency of livestock production.

Summer annuals can provide dependable, high-quality animal feeds at a time when other forages are in short supply. They can be used for pasture, greenchop, hay or silage production. Although closely related genetically, summer annual sorghums have different morphological and physiological characteristics, i.e., growth rate, recovery after clipping, forage quality, plant height, stem diameter, and panicle density (1,2,18,31,38,53,93,95,96). Because of these differences in growth habits, proper management practices should be designed that are suitable to these plants individually.

Workers generally agree that fine-stemmed, leafy cultivars recover rapidly after clipping or grazing and are best suited for pasture production. Because of their growth habits, sudangrass varieties, under intensive grazing or frequent clipping, are generally superior in total herbage production to forage sorghum. However, when harvested for hay or silage, the sudangrass varieties are generally inferior to forage sorghum and the sorghumsudan hybrids. This inferiority is sometimes due to their greater susceptibility to certain leaf diseases, which reduce both forage quality and yield (2,10,12), and shading of tillers by neighboring plants. Hybrid sudangrass is leafier and has smaller stems than forage sorghum and the sorghumsudan hybrids. It is higher in prussic acid than sudangrass, but lower than the sudan-sorghum hybrids and forage sorghum. Haying or greenchopping have been reported as suitable managements for hybrid sudangrass. However, like sudangrass, trudan has been found most suitable for pasturing.

Like sudangrass, pearl millet is also extremely leafy and is best suited for pasture. But unlike sudangrass, it is generally not affected by many leaf diseases, and therefore is also very productive under hay and silage managements. In addition, it is devoid of prussic acid potential (2,10,12,38).

The hybrid sudansorghums are the most abundant of the four types of summer annuals. They grow very tall with large stems which often contribute more than 50% of the forage weight. Because of the lower percentage of leaves, these grasses are most often recommended for hay or silage production than for pasturing. Hybrid forage sorghum produces extremely large stems, is least tolerant to frequent harvesting, and is highest in prussic acid potential. Therefore, it is most suited to harvesting once for greenchop or silage.

Differences in time of maturity and the others previously mentioned greatly complicate management studies with these summer annual grasses. In the past, the vast majority of research studies to determine the optimum harvest stages for these crops have focused on forage yield as the primary variable. But with the ever decreasing margin between feed costs and the value of farm animal products, it has become increasingly important to make management recommendations on the basis of both yield and nutritive value. Towards this goal, a study was conducted in the summer of 1977 at the Kansas State University experimental fields at Manhattan and Hutchinson to evaluate six summer annual grasses currently available to farmers. It was anticipated that the results of this research will help livestock producers, especially those in Kansas, to improve their management practices of summer annuals.

CHAPTER II

LITERATURE REVIEW

Optimum Stage of Maturity for Pasture, Hay and Silage Production

Like all other plants, the growth and development of summer annual grasses are greatly influenced by the additive effects of environmental conditions and management practices, with the latter probably being more important (7,25,28,38). One of these management decisions is the stage of maturity at which to harvest these forages for pasture, hay or silage. Several research studies have been directed towards this goal (2,8,10,18,38,42,45,53,95). These studies generally showed that when grown for pasture, the hydrocyanic acid content of these plants, except pearl millet, becomes a primary factor determining the grazing management, and that cutting the plants at heights of 18 to 24 inches may alleviate the possibility of the prussic acid poisoning. Summer annuals grown for hay production should be harvested before heading, preferably at the flagleaf stage, while the preferred stage for cutting for silage is at the dough stage, although few have suggested cutting at anthesis or when the crops are fully headed (41,45).

Effects of Cutting Height on Yield and Quality

A second management practice that determines the performance of summer annuals is the height of defoliation. Being grasses, regrowth of summer annual forages depends upon the amount of photosynthetic area left on the stubbles and the presence and growth of terminal, axillary and basal meristems. The number of apical meristems left in the stubble increases with greater stubble heights (38,41). Holt and Alston (41), while referring to work done by A. C. Leophold, indicated that tillering is under apical dominance. Therefore, greater tillering is associated with reasonably short stubbles because of the removal of primary growth meristems and the subsequent elimination of growth hormones, especially auxin, which prevents tiller development. With the removal of primary meristems, the buds at the basal nodes then begin to produce auxin which, in turn, stimulates growth.

Therefore, as the height of defoliation is raised, regrowth from terminal meristems increases, while that from axillary and basal tillers is lessened. But since regrowth must come from all growth primordia, leaving fairly high stubbles generally leads to more vigorous and leafier regrowth. The height of stubble materials that would permit optimum regrowth has been widely studied (6,7,10,11,18, 28,38,41,42), and varying results have been published. For example, Broyles and Fribourg (10) recommended 10-inch stubbles, while workers at Kansas State University (18) suggested cutting at 6 to 8 inches. In a Florida experiment, Howland and McCloud (42) demonstrated that for the best yield and quality, Starr millet should be cut to 18-inch stubbles, while Beaty et al. (6) recommended 4 to 6 inches.

While not agreeing on the exact length of stubble material to leave in the field, these workers demonstrated that close clipping removes immature panicles and terminal or axillary meristems, and thus produces poor regrowth and low, late-season production or death. For example, Heath et al. (38) emphasized that stubbles lower than 10-15 cm would result in drastic reduction in regrowth or even death. However, because of differences in tillering ability, low clipping heights are more detrimental to some cultivars of summer annual forages than to others.

Effects of Harvest Frequency on Yield and Quality

Yield and quality of summer annuals are also a function of harvesting frequency. Irrespective of variety or hybrid, frequent removal of topgrowth regularly produces forage of high quality for a limited period of time, after which the depletion in recovery potential of the plants may limit dry matter production to the point of being an uneconomical practice. Allowing plants to advance in maturity before harvesting results in higher dry matter production, but decreased feeding value. Therefore, the optimum clipping frequency varies, depending upon whether quality or yield is the primary objective.

For example, Broyles and Fribourg (10) pointed out that the yields of all sudangrasses and millets harvested three times a year were superior to those cut four times, the average difference being about 3.64 metric tons/hectare. On the contrary, an average of 2.6% more crude protein was associated with herbage cut four times than three times. Burger et al. (12) studied four varieties of sudangrass under the pasture and hay systems of management and reported average yields of the varieties of 3.80 tons/acre and 5.76 tons/acre under the pasture and hay cuttings respectively. Burton *et al*. (14) compared the quality of bermudagrass cut once every three weeks with those cut every 24 weeks. They found that increasing the cutting interval from 3 to 24 weeks decreased crude protein from 18.5 to 8.4% and IVDDM from 73.6 to 48.1%, and increased fiber from 27.0 to 33.9%. Edwards *et al*. (28) indicated that when Sudax SX-11 matured from 37 cm to 275 cm, IVDDM decreased from 89.0 to 57.0%. While studying sorghum forages under various management schemes, Wedin (91) reported that when these grasses were cut five times or just once a year, dry matter yields increased from 4.95 to 13.46 metric tons/hectare, crude protein decreased from 18.4 to 5.8%, and IVDDM decreased from 70.1 to 57.0%. Van Soest (79) analyzed 18 legume and grass samples and reported ADF values ranging from 24.8 to 54.0%, the values increasing with forage maturity.

Forage Evaluation

Definition and Objectives

Estimates of forage nutritive value such as those cited above have been obtained through a wide range of forage evaluation techniques. Forage evaluation is the method of testing a given forage or feed in light of its intended use. The objectives, as outlined by Heath *et al*. (38) are: (1) to provide a basis for estimating the feeding value of available feedstuffs, (2) to allow more efficient use of feeds in formulating rations for year-round feeding programs, (3) to enable specialists to make more accurate diagnosis of nutritional problems associated with overfeeding and underfeeding various nutrients, and

(4) to assist farmers in making management decisions to maintain forage quality appropriate for a given livestock operation.

The first of the four objectives listed above formed the centerpiece of forage evaluation in the research reported herein. Nutritional value of forages is very important and depends on four interrelated characteristics--chemical composition or nutrient content, digestibility or nutrient availability, voluntary intake, and non-nutritive constituents (38). Thus, the basis for forage testing in agricultural research is to predict accurately the availability to and utilization of various ration constituents by a given class of livestock.

The voluntary consumption of forage plants by ruminants is a crucial determinant of forage quality. Laboratory techniques consisting of both chemical and biological assays have been developed and used successfully to provide reasonable estimates of intake potential of forages. The major requirements of such laboratory methods are threefold; namely, that they must be relatively simple in order to allow the rapid analysis of a large number of samples, they must produce results with a high degree of precision, and they must give accurate, unbiased estimates of forage quality (4).

Three Current Methods of Forage Evaluation

Three of the laboratory techniques that have tremendously advanced progress in agricultural research are the Tilley and Terry two-stage *in vitro* rumen fermentation (76), the Spectrophotometric crude protein determination (22,48,62,67), and the Van Soest acid-detergent fiber (82) procedures.

The T-T two-stage in vitro method. Prior to the development of in vitro ruminant digestion techniques, the estimation of digestibility of forages was based solely on conventional digestion trials with sheep or cattle. While they provide the best estimates of the nutritive value of forages, these animal trials are tedious, expensive, time-consuming, and require large quantities of herbage, which are usually not available from small plot-agronomic experiments (4). To alleviate these problems, numerous in vitro digestibility techniques have been developed.

One of these, which is extensively used internationally in agricultural research is that proposed by Tilley and Terry (76). By using 130 samples of grasses and legumes of known in vivo digestibility, these workers developed a procedure by which forage digestible dry matter was obtained from a 48-hour incubation of the forage material with rumen liquor inoculum and another 48 hours of incubation with acid-pepsin solution. These two stages were designed to simulate the digestive processes in the rumen and abomasum by which structural carbohydrates are digested and converted into soluble products. Therefore, the procedure accounts for the activities occurring in the entire digestive tracts of ruminant animals. It considers the fact that although the process of fiber digestion is complete by the end of 48 hours, the conversion of herbage proteins into soluble, digestible products is not. Thus the greater the content of protein in a forage plant, the smaller the proportion that can be converted into soluble products (94). The insoluble portions consist of unchanged feed protein and microbial protein, and the second stage of the Tilley-Terry procedure was included to remove these undigested proteins (77).

The technique was evolved to give high herbage digestive efficiencies. For example, Tilley and Terry (76,77) reported correlation coefficients between _in vivo_ and _in vitro_ dry matter digestibilities of 0.99 and 0.98 respectively. In evaluating various biological assays for predicting forage digestibility of corn and sorghum silages, Schmid _et al_. (66) found that the two-stage rumen fluid fermentation and acid-pepsin technique gave the highest correlation with _in vivo_ digestible dry matter. They reported correlation coefficients of 0.83 for corn silage and 0.91 for sorghum silage. Other investigators have also found high correlations between _in vitro_ and _in vivo_ dry matter disappearance--Ademosum _et al_. (1), 0.96; Oh _et al_. (58), 0.88; Reid _et al_. (63), 0.81; and Marten _et al_. (51), 0.64.

Photometric crude protein analysis. Crude protein is also a good indicator of forage digestibility, as amplified by Forbes (32). Numerous techniques have been developed for the determination of the nitrogen concentration in forages and other feedstuffs. One of these is the use of colorimetry as a rapid and fairly sensitive test. These photometric procedures have generally been found to be less time-consuming, less expensive, less laborious, and freer from noxious fumes and dangerous reagents than the standard Kjeldahl method (9). In addition, these rapid colorimetric schemes are highly correlated with the standard Kjeldahl method, as demonstrated by Linder and Harley (48). They reported a correlation coefficient between the Kjeldahl procedure and their colorimetric technique of 0.99. However, the chief disadvantage of most of the spectrophotometric techniques is their inability to analyze mixed rations, since nitrogen determinations must be standardized against a forage of known protein content.

Commonly used colorimetric methods are based on the Bertholet reaction (49). Because of the strongly alkaline and toxic phenolate-hypochlorite reagent used, colorimetric procedures using standard Bertholet reagents have been severely criticized (22,24,62). Overcoming the drawback of these hazardous reagents became possible with the discovery of a sensitive color reaction between dilute solutions of ammonia and a mixture of sodium salicylate, sodium nitroprusside, and alkaline dichloroisocyanurate (as chlorine source) (62). The brilliant emerald-green color formed from this reaction has been found to be stable, reproducible, and to obey Beer's law (22,62,67). The proposed salicylate-dichloroisocyanurate method, because of the addition of sodium nitroferricyanide (sodium nitroprusside), is about two hundred times more sensitive than the phenolate methods (22,67), and its high sensitivity allows the use of very small aliquots of tissue digests.

With spectrophotometry, if the absorbancy index at a specific wavelength is known, the concentration of a compound can be readily determined by measuring the optical density at that wavelength (64). For the salicylate-cyanurate procedure, Reardon et al. (62) have proposed the maximum absorption peak and the optimal conditions for color production between the new reactants and ammonia, with regards to time, temperature and reactant concentrations.

The value of chemical assays for crude protein in predicting voluntary intake has been well established. Some correlation coefficients reported in the literature between crude protein and animal intake potential include those of Oh et al. (58), 0.37; Marten et al. (51), 0.81; and Tinnimit and Thomas (78), 0.70-0.86.

Van Soest acid-detergent fiber procedure. Perhaps the greatest problem in feed analysis has been the separation of the digestible and indigestible fractions of carbohydrates. The Weende proximate scheme of analysis attempts this by dividing the carbohydrates into crude fiber and nitrogen-free extract (NFE). Crude fiber can be nutritionally defined as the insoluble organic matter which is indigestible by animal enzymes and which cannot be utilized except by microbial fermentation in the digestive tracts of ruminants. It therefore denotes a residue which is closely associated with indigestibility. Chemically, it is composed largely (97%) of lignin and cellulose (29).

Early chemists thought that fiber obtained by extraction with alcohol, dilute acid and alkali represented the indigestible part of feeds and therefore used this as a basis for estimating nutritive value of feeds (39,74). But the discovery, in 1860, of the digestibility of fiber and cellulose in herbivores (39) disproved the theoretical model upon which the proximate analysis was based and underscored the fact that this system of fractionating carbohydrates is unrealistic.

Furthermore, several investigations (71,79,80,82) have shown that the digestibility of crude fiber is not as low as is claimed by the proximate scheme. This is because the imperfect Weende fiber methodology allows some of the lignin to be extracted into the nitrogen-free extract (79,80,82).

The crude fiber analysis consists basically of treating a forage material with both acid and alkali. The sample is boiled in 1.25%

H_2SO_4 for 30 minutes. The residue is recovered and boiled in 1.25% NaOH for another 30 minutes and filtered through a Gooch crucible. The final residue is dried and weighed and subsequently ashed and weighed. The difference between the dried weight and ashed weight equals the amount of crude fiber present (36).

But the sodium hydroxide, which is intended to dissolve protein, also dissolves a major part of the lignin, the indigestible fraction. The net result is that in many grass samples, crude fiber and nitrogen-free extract have similar digestibilities, and there are numerous cases in which the digestibility of fiber exceeds that of the nitrogen-free extract (39,61,70,79,80). These criticisms are not as severe in the case of legumes, where the cellulose component is smaller but more lignified. Therefore the digestion coefficient of crude fiber is relatively low and always lower than that of the nitrogen-free extract (70,79).

The limitations of the widely used Weende proximate system have been recognized since the time it was first proposed more than one and one-half centuries ago. Finding a suitable replacement for this nutritionally invalid determination has long been a major goal of forage analytical chemists. Entwhistle and Hunter (29) have published an excellent review of the efforts made in this direction and given reasons for their failure.

One of the more recent and successful scientific efforts to replace the crude fiber methodology was reported in 1963 by Van Soest (80). This procedure, known as acid-detergent fiber (ADF), was developed after the discovery of the capacity of detergents to dissolve proteins in acid solution, and thereby separate the proteins from the other feed constituents. The procedure consists basically of digesting a small amount of forage sample in cetyl trimethylammonium bromide (CTAB), the detergent, and 1 N H_2SO_4 to produce a feed residue that consists mainly of cellulose and lignin (80).

This detergent technique is not only a fiber determination procedure, but the major preparatory step in the determination of lignin. Treatment of the ADF residue with 72% H_2SO_4 dissolves the cellulose and leaves a residue containing mainly lignin. The new fiber procedure has greatly increased the accuracy and rapidity of lignin analysis in forage plants and other animal feeds.

As Van Soest (85) has reported, conventional analysis for lignin is tedious and time-consuming, a major part of the labor being devoted to removing proteinacious material. This has been accomplished with several different procedures. For example, Sullivan (70) proposed an enzyme digestion method using pepsin in dilute hydrochloric acid, Thacker (75) used sodium carbonate, and Armitage et al. (3) employed trypsin in sodium carbonate buffer.

In 1967 Van Soest and Wine (86) proposed another detergent system that further advanced the determination of the structural components in forages. This system, called the neutral-detergent fiber (NDF) method, was designed to isolate plant cell-wall constituents--lignin, cellulose and hemicellulose. Thus the difference between the NDF and ADF components is a measure of the amount of hemicellulose present (79,80,85,86).

Using these two detergent systems, Van Soest (84) proposed a comprehensive system of analysis by which the digestible and indigestible parts of feedstuffs could be distinguished, the non-accomplishable goal of the proximate system. The new system makes a fundamental distinction between chemical fractions in feedstuffs, based on their nutrient availability to animals, by dividing forage organic matter into two categories. One category consists of those fractions found within the metabolic parts of plants (cellular contents) which, being unaffected by the degree of lignification, are completely available or digestible without the aid of microbial fermentation. The other category consists of the cell-wall constituents, the digestibility of which is a function of the degree of lignification.

In light of the preceding, it can easily be seen that the ADF procedure provides a better estimate of forage digestibility *in vivo* than the Weende crude fiber method. Van Soest (80), in a comprehensive evaluation of 18 forage samples, compared the two methods and reported correlation coefficients of -0.79 and -0.73 between *in vivo* dry matter digestibility and the ADF and crude fiber procedures respectively. The rapidity and accuracy of the ADF technique has increased its popularity as a tool in scientific research, and its *in vivo* predictive value has further been well established. For example, some r values that have been reported in the literature include those of Oh *et al*. (58), -0.53 and Marten *et al*. (51), -0.86.

Based upon their ability to predict relative intake of forages, none of the three laboratory schemes discussed above is significantly superior within a given forage species (51,58,78). But where the intent is to have one method that can be used to predict the digestibility of all forage species and mixtures of species, the results of several investigations clearly indicate that the method of choice is the two-stage *in vitro* procedure (51,58,63,76,78).

Effects of Forage Handling and Drying on Laboratory Analyses

Oven-drying. In order to enhance the usefulness of laboratory techniques in determining forage quality, forage samples submitted for laboratory analysis must be properly handled. One method of forage handling is preservation of forage material. Two techniques of sample preservation are quick-freezing of fresh material in liquid nitrogen and oven drying. Nutritional evaluation of fresh forages is difficult because of problems involved in handling and analysis. Consequently, the tendency in forage research has been to analyze oven-dried forage material. Conventional heat-drying of forage is done at various temperatures, usually 50, 65, 80, or 100°C.

However, if not properly controlled, oven-drying adversely affects the determinations of lignin, crude fiber, hemicellulose, sugars, and *in vitro* dry matter digestibility (35,44,56,76,79), although the optimum temperatures for drying have not been agreed upon. For example, Goering and Van Soest (35) warned that drying samples above 65°C produces a non-enzymic browning reaction in which condensation of carbohydrate degradation products, such as furfurals, are bound with proteins or amino acids to form a dark-colored insoluble polymer called artifact lignin, which consequently overestimates the lignin concentration in the forage (35,81,82,85). Thus, if samples are to be dried at temperatures above 65°C, correction factors must be applied (80,82).

Van Soest also found that oven-drying above 65°C decreased *in vitro* dry matter digestibility (82). This finding was contrary to those of other researchers (56,76). While studying the changes in chemical composition and digestibility of alfalfa and maize forage and silage, Noller *et al*. (56) found that oven-drying forage samples depleted the forage of the more readily soluble carbohydrates and consequently reduced its digestibility *in vitro*. However, when drying temperatures were compared, they noted no significant differences in the digestibility of forages dried at 65°C and those dried at 80°C.

Tilley and Terry (76) indicated that forage samples could be dried at 100°C for 1 or 2 days without markedly decreasing their digestibilities. They found that *in vitro* dry matter digestibility of forages decreased severely only when drying was continued at 100°C for more than 4 days.

Grinding. Another preparatory procedure which affects the results of laboratory forage analysis is grinding. Herbage samples submitted for analysis differ considerably in their fineness of grind, depending on the type of mill or mill sieve used and on the moisture content of the sample at the time of grinding. Samples need only be ground finely enough to ensure good sampling of the small weights of herbage used (76). Extremely fine grinding (ball-milling) forage samples greatly increases the *in vitro* digestibility because it disrupts the cell walls of the plant structure and thereby enables enzymes to penetrate into regions from which they are normally excluded by the protective effect of lignin or the crystals in cellulose (35,76). In light of these findings, it has been suggested that grinding dried samples through a 1-mm screen appears suitable for most analytical work (35).

CHAPTER III

MATERIALS AND METHODS

Field Procedures

To detect possible variety by location interactions, two experimental fields about two hundred miles apart and differing in climatic conditions (Table 1) were selected for this investigation. The Manhattan experimental site was seeded on June 3 on Smolan silty-clay loam of the fine-silty montmorillonitic, mesic family of the Pachic Argiustolls. The trial at Hutchinson was planted on June 8 on a Clark-Ost complex of the fine-loamy, mixed, thermic family of the Typic Calciustolls and Argiustolls. Prior to planting, the plot areas were fertilized, disked, and harrowed.

Plants included in the study were five cultivars of the *Sorghum* genus and one of the *Pennisetum* genus. The sorghum plants were: 'Piper' sudangrass (*Sorghum bicolor* (Stapf); DeKalb 'FS 25A' hybrid forage sorghum (*Sorghum bicolor* (L.) Monech); DeKalb 'Sudax SX-11' and Ring Around 'Super Chow Maker 235' sorghumsudan hybrids; and Northrup King 'Trudan 6' hybrid sudangrass. The Pennisetum cultivar evaluated was Northrup King 'Millex 23' hybrid pearl millet (*Pennisetum typhoides* (Burm) Stapf and C. E. Hubb). The field data were collected

Table 1. Average Temperatures (^{o}F) and

Total Precipitation (Inches)

Month (1977)	Temperatures			
	Manhattan	Departure from Normal	Hutchinson	Departure from Normal
June	76.5	2.2	77.1	1.7
July	82.0	2.9	83.4	3.2
August	76.6	-1.8	77.3	-2.0
September	70.5	1.4	72.1	2.0
October	58.2	-0.4	59.9	0.6
March	49.5	7.5	49.7	6.9
April	60.3	4.8	58.3	2.6
May	70.5	5.3	68.1	2.7

Month (1977)	Precipitation			
	Manhattan	Departure from Normal	Hutchinson	Departure from Normal
June	11.55	5.71	8.15	3.13
July	1.30	-3.08	1.86	-2.23
August	7.25	3.65	9.55	6.38
September	5.95	1.99	8.02	4.52
October	2.07	-0.65	2.37	-0.06
March	2.38	0.53	3.13	1.53
April	3.85	0.85	3.86	1.15
May	9.86	5.51	7.63	3.77

from June through October and forage samples from each harvest were subsequently processed and analyzed for nutritional value.

At each experimental site, all combinations of the six summer annuals and three cutting treatments were arranged in a randomized complete block design with four replications. Even though summer annuals grow in almost any kind of soil, they produce more when soils are fertile (38). Therefore, to enhance soil fertility, each site received a fertilizer treatment which consisted of 80 lbs/acre of actual nitrogen, applied by broadcasting and disking prior to seeding. Considering the pattern of rainfall in Kansas, all the fertilizer was applied at the time of planting, instead of in split applications as is often recommended for sustaining forage yield and quality throughout the growing season (2,10,14,38,45,73). Split application works best under irrigation or where there is heavy, regular rainfall. Therefore, the single fertilizer application method was considered appropriate for this study. Moreover, the investigations just sited emphasized that the total seasonal yields under the two methods are usually about the same.

Treated, certified seeds with high germination rates ($\geq$75%) were planted with a Planet Junior seeder in plots of 5 feet x 20 feet for each of the cultivars, except the hybrid forage sorghum, which was planted in 10 feet x 20 feet plots. The seeding rates were: 'Millex 23', 10 lbs/acre; 'Piper' and 'Trudan', 12 lbs/acre; 'Sudax' and 'Super Chow Maker', 25 lbs/acre; and 'FS 25A', 8 lbs/acre. All seeds were planted at a depth of 1½ inches.

The hybrid forage sorghum was planted in rows spaced thirty inches apart, while rows of each of the other grasses were spaced six inches apart. Twelve foot wide alleys were seeded for border protection, and weeds were controlled by hand hoeing. A more severe weed infestation occurred at Manhattan than at Hutchinson, and efforts to subdue weeds were distributed accordingly.

Like all other plants, the growth and development of summer annuals are greatly affected by soil and climatic conditions. They grow best under warm conditions and require a soil temperature between 20 and 30°C for seed germination. Growth can occur even when the annual precipitation is lower than 400-650 mm, though more moisture or irrigation enhances forage production (38). Therefore, the unseasonably high precipitation during the course of this experiment favored excellent growth and development of these plants. Cumulative meteorological data for the 1977 growing season were obtained from the Weather Data Library at Kansas State University and are presented in Table 1.

The six forages were compared for agronomic characteristics (percent and yield of dry matter, silage production at 60% moisture, and plant height), and quality components (percentages and yields of crude protein and *in vitro* dry matter digestibility, and percentages of acid-detergent fiber). These comparisons were made under harvesting managements designed to simulate pasture, hay, and silage production.

Cultivars were cut when they reached 30 to 50 inches in height (for grazing or pasture), boot stage (for hay), and soft-dough (for silage). Thus, harvests were made only when plants reached a desired stage of development and were not based on calendar dates (Table 2).

Table 2. Cutting Dates: Treatments and Localiona

Variety	Location												
	Manhattan							Hutchinaon					
	Grazing				Boot		Soft-Dough	Grazing			Boot		Soft-Dough
	C_1*	C_2	C_3	C_4	C_1	C_2	-	C_1	C_2	C_3	C_1	C_2	-
Piper	Jul 8	Aug 3	Aug 26	Sep 22	Jul 22	Aug 26	Sep 22	Jul 19	Aug 8	Sep 8	Aug 8	Oct 22	Sep 8
Trudan	Jul 8	Aug 3	Aug 26	Sep 22	Jul 22	Aug 26	Sep 22	Jul 19	Aug 8	Sep 8	Aug 8	Oct 22	Sep 8
Sudax	Jul 8	Aug 3	Aug 26	Sep 22	Aug 3	Aug 26 Sep 7	Sep 22	Jul 19	Aug 8	Sep 8	Aug 8	Oct 22	Sep 8
Super Chow	Jul 8	Aug 3	Aug 26	Sep 22	Aug 3	Sep 7	Sep 22 Oct 13	Jul 19	Aug 8	Sep 8	Aug 8	Oct 22	Oct 22
Millex	Jul 8	Aug 3	Aug 26	Sep 22	Aug 3	Aug 26 Sep 7	Sep 22 Oct 13	Jul 19	Aug 8	Sep 8	Aug 22	Oct 22	Oct 22
Forage Sorghum	Jul 8	Aug 3	Aug 26	Sep 22	Aug 3	Sep 7	Sep 22 Oct 13	Jul 19	Aug 8	Sep 8	Sep 8	-	Oct 22

*C = cut; subscripts = cut number; only one cut at soft-dough atage.

Three harvests at the grazing stage were made at Hutchinson and four at Manhattan. Two harvests at the flag-leaf stage and one at the soft-dough stage were made at each location.

A self-propelled Carter flail harvester was used to cut the grasses. Before each harvest, six extended plant-height measurements were taken at random in each plot, and the average was recorded as "plant height." The harvester was set to cut at a six-inch stubble height to allow optimum regrowth.

Forage production was determined by harvesting the center three feet of each plot. The harvested forage material was bagged and weighed immediately. The outside rows in each plot were then mowed and discarded. A "grab" sample was taken from the harvested forage for moisture and quality determinations. These samples were oven-dried under forced ventilation at 65°C (150°F) for five days. At the end of the drying period, the samples were weighed immediately after removal from the oven and later ground for quality analyses. The samples were finely ground in a Wiley mill to pass through a screen with openings 1 mm in diameter (40-mesh). The ground samples were bottled, properly labelled and stored at room temperature until analyzed.

Laboratory Procedures

Quality determinations were made for crude protein, acid-detergent fiber and *in vitro* dry matter digestibility.

Crude Protein

Crude protein was determined colorimetrically, following the procedure worked out by the Division of Soils, Department of Agronomy, Kansas State University (unpublished) for ammonia nitrogen analysis, and those of Reardon et al. (62). The former techniques were employed primarily in digesting the sample material. To do this, 4.0 ml concentrated sulfuric acid and 1.0 ml 30% hydrogen peroxide were added to 0.25 g of plant tissue in 25 x 200 mm ignition tubes. The mixture was then heated over hotplates until it became clear.

As reported by Linder and Harley (48), the use of 30% H_2O_2 in the presence of concentrated H_2SO_4 is a remarkably fast and thorough method for digesting relatively small quantities of plant material. During the digestion process, which usually took 1-2 hours, the sample was periodically removed from the hotplates for the addition of more H_2O_2, after a 5-10 minute cooling period. About 50 ml of deionized distilled water was added to the digested sample and the resulting solution was bottled until analyzed for ammonia nitrogen.

Two color development reagents were prepared and added to the digested plant tissue before absorpmetric determinations were made. The two reagents, Salicylate (Reagent A) and Cyanurate (Reagent B), were prepared from analytical grade reagents, following the Kansas State procedures and using reagent concentrations as established by Reardon et al. (62). About 0.5 ml of diluted, well-mixed aliquot of the digest was treated with 2.0 ml of the salicylate reagent followed by 2.0 ml of the alkaline dichloroisocyanurate solution. One and one-half to two hours were allowed for full color development, after which the absorbance of the test solution was measured at 660 nm in a Bausch and Lomb Spectrophotometer against a reagent blank.

The 660 nm setting was chosen because Reardon et al. (62) indicated that at this wavelength and under the optimal conditions of temperature, reactant concentrations and time for color formation with ammonia, color was produced in accordance with Beer's law over a wide range of ammonia nitrogen concentrations. Beer's law states that the amount of light absorbed at a given wavelength is directly proportional to the concentration of the solute in solution, i.e., amount of organic nitrogen in plant tissues.

Deionized distilled water (ammonia-free) was also used to dissolve dry $(NH_4)_2SO_4$ to give stock solutions containing 50 ppm N, 100 ppm N, 150 ppm N, 200 ppm N, and 250 ppm N. One hundred ml of each of these standards and one containing 0 ppm N were prepared from these dilutions. Prior to measuring the absorbance of the digested sample, the spectrophotometer was warmed for 30 minutes and then zeroed with the 0 ppm N standard. The optical densities of the other standards were averaged. The absorbance of the digest was converted into % N by multiplying the reading of the unknown by the average of the five standards (50 ppm - 250 ppm N). Since feed proteins are generally assumed to contain 16% N, the crude protein content of the digested sample was obtained by multiplying the percent colorimetrically determined nitrogen by the factor 6.25 (100/16).

Acid-Detergent Fiber

The Van Soest acid-detergent fiber (ADF) technique (82) was used to estimate the percentage of the indigestible fraction of plant material. Two modifications were made in the procedure. One of these was the reduction of the amount of tissue sample and reagents recommended by one-half. Odland (57) has reasoned that correspondingly decreasing the amounts of forage material and chemicals will not adversely affect the results. Moreover, this approach was considered more economical in terms of reagent costs. The other modification was the use of Whatman No. 41 ashless filter paper (11 cm) instead of Gooch glass crucibles during the filtering and drying steps. The extreme care, time and chemical costs required for cleaning the crucibles, as well as cost of crucibles, encouraged the adoption of the filter paper technique. The determination of percent acid-detergent fiber with filter paper followed the procedures outlined by Goering and Van Soest (35). Work at the Department of Animal Sciences and Industry, Kansas State University (unpublished) has shown that the precision obtained with filter paper is about the same as obtained with crucibles.

In Vitro Dry Matter Digestibility

Percent dry matter digestibility was determined following the two-stage *in vitro* rumen fermentation technique proposed by Tilley and Terry (76), with some slight modifications. Approximately 0.4 g of forage material was incubated with 35 ml of rumen liquor-nutrient buffer solution in 50 ml polycarbonate centrifuge tubes fitted with rubber stoppers and bunsen valves. The rumen fluid was removed through a permanent fistula from a dairy steer maintained on an alfalfa-prairie hay ration. The inoculum was strained through four layers of cheesecloth and its pH determined in the lab before subsequent procedures were undertaken. The acceptable pH range was 6.7 - 6.9.

The buffer solution (735 g $NaHCO_3$, 277.5 g Na_2HPO_4, 35.25 g NaCl, 42.75 g KCl, 4 g $CaCl_2$, and 6 g $MgCl_2$ per liter) was added to the rumen liquor and the solution then bubbled with CO_2 and incubated at 39°C for 48 hours. After then, the tubes were centrifuged and the supernatant discarded. Then 25 ml of acid-pepsin solution (containing 8.33 ml HCl and 2 g Pepsin/liter) was added for the second stage incubation. Percent in vitro digestible dry matter was determined following the procedure proposed by Tilley and Terry (76).

All data collected were statistically analyzed at the Kansas State University Computing Center and Department of Statistics. Standard analysis of variance procedures were followed as outlined by Snedecor and Cochran (69), while the Waller-Duncan test (88) was utilized at the .05 probability level to test differences between treatment means. Because of the unequal number of harvests within managements, all statistical analyses were made separately for each management. Since the location X variety interaction was significant, computations were made on a within-location basis.

CHAPTER IV

RESULTS: HUTCHINSON DATA

Agronomic Characteristics

Dry Matter Content

As shown in Table 3, delayed cutting significantly increased the dry matter percentages of all entries in a linear fashion from the pasture to the silage stages of maturity. The three harvest stages were significantly different for this trait ($P<.05$), and the variety by stage interaction was significant (Appendix Table 5a).

Under the three-cut management, Piper sudangrass was significantly higher in dry matter content than forage sorghum. The dry matter percentage of forage sorghum was lowest while those of the remaining cultivars were intermediate. Under the two-cut system, the dry matter percentage of Piper was again highest, though not statistically different than those of Trudan and Sudax. Hybrid forage sorghum contained the least dry matter, while Millex and Super Chow Maker were intermediate.

When harvested under the single-cut scheme, cultivar rankings differed considerably than were noted under the pasture and hay systems. Under this management, the dry matter percentage of Super Chow Maker was highest, but not statistically higher than those of Trudan and

Table 3. Mean Dry Matter Percentages of Six Summer Annuala When Harvested at Three Growth Stages Hutchinson

Variety	Grazing				Boot			Soft-Dough	
	C_1	C_2	C_3	$\overline{X}$	C_1	C_2	$\overline{X}$		Seasonal Means
Piper	25.26^{*a}	23.11^{a}	21.37^{a}	23.25^{a}	28.85^{a}	38.08^{a}	33.46^{a}	34.09^{bc}	30.27^{a}
Trudan	23.56^{b}	23.31^{a}	19.58^{ab}	22.15^{ab}	24.05^{b}	35.47^{ab}	29.76^{ab}	35.54^{ab}	29.15^{a}
S. C. Maker	23.18^{b}	20.25^{b}	16.83^{bc}	20.09^{ab}	21.67^{b}	28.50^{b}	25.09^{cd}	38.70^{a}	27.96^{ab}
Sudax	22.40^{b}	20.42^{b}	17.08^{bc}	19.97^{ab}	24.27^{b}	33.84^{ab}	29.05^{ab}	30.24^{c}	26.42^{b}
Millex	23.09^{b}	20.95^{b}	16.88^{bc}	20.30^{ab}	18.33^{c}	37.54^{a}	27.33^{bc}	37.44^{ab}	28.56^{ab}
F. Sorghum	20.03^{c}	18.45^{c}	15.16^{c}	17.88^{b}	22.49^{b}	-	22.49^{d}	30.51^{c}	23.62^{c}
$LSD_{.05}$	1.50	1.70	3.87	4.45	2.86	7.26	4.45	4.45	2.49
$\overline{X}$	22.92	21.08	17.82	20.61^{c}	23.28	34.69	27.96^{b}	34.42^{a}	-

* Means within a column followed by the same letter or letters are not significantly different at the 0.05 level, according to the Waller-Duncan multiple comparison test.

Millex. Sudax and Forage Sorghum ranked last, but were not significantly lower than Piper.

Cultivar responses to changes in dry matter percentage were probably a reflection of differences in maturity. At a given morphological stage of development, earlier maturing forages would be more advanced in growth and therefore would contain greater dry matter than the late-maturing ones.

Dry Matter Yields

Table 4 and Figure 1 show that as with dry matter percentages, total forage production of all varieties generally increased with longer intervals between harvests. It can also be seen that all cultivars increased markedly in yield between the pasture and boot stages of maturity. However, Piper and Sudax declined markedly, Trudan slightly, and the others increased between the boot and soft-dough stages.

Within managements, dry matter production generally decreased as the number of uniform clippings was increased. This trend was consistent under the hay management, whereas under the pasture system, cultivars responded somewhat erratically. Similar to dry matter content, the data on forage yield also show a significant variety * stage interaction (see Appendix Table 5a).

The data for grazing management show that Forage Sorghum did not tolerate frequent clipping and was lowest in dry matter production. Trudan, Super Chow Maker, and Sudax were similar in yield, and exceeded Piper and Millex, though not significantly.

Table 4. Total Dry Matter Yields (Tons/Acre) of Six Summer Annuals When Harvested at Three Growth Stages Hutchinson

Variety	Grazing				Boot			Soft-Dough	
	C_1	C_2	C_3	Total	C_1	C_2	Total		Seasonal Means
Piper	$1.88*^{b}$	1.48	1.74^{ab}	5.08^{ab}	4.59^{c}	3.18^{c}	7.77^{c}	5.41^{e}	6.03^{d}
Trudan	1.90^{b}	1.77	2.06^{a}	5.73^{a}	5.05^{c}	3.21^{c}	8.26^{c}	8.08^{d}	7.36^{c}
S. C. Maker	2.04^{ab}	1.72	2.08^{a}	5.83^{a}	5.61^{bc}	4.43^{b}	10.04^{b}	15.66^{a}	10.51^{a}
Sudax	2.40^{a}	1.45	2.00^{a}	5.85^{a}	6.72^{b}	5.64^{a}	12.36^{a}	10.96^{b}	9.73^{a}
Millex	0.77^{d}	1.82	1.83^{ab}	4.41^{ab}	5.36^{c}	1.65^{d}	7.01^{c}	8.38^{cd}	6.60^{dc}
F. Sorghum	1.15^{c}	1.62	1.13^{b}	3.89^{b}	9.94^{a}	-	9.94^{b}	11.98^{b}	8.60^{b}
$LSD_{.05}$	0.37	ns	0.72	1.61	1.28	0.86	1.61	1.61	0.84
$\overline{X}$	1.69	1.64	1.81	5.13^{c}	6.21	3.62	9.23^{b}	10.08^{a}	-

* Means within a column followed by the same letter or letters are not significantly different at the 0.05 level, according to the Waller-Duncan multiple comparison test.

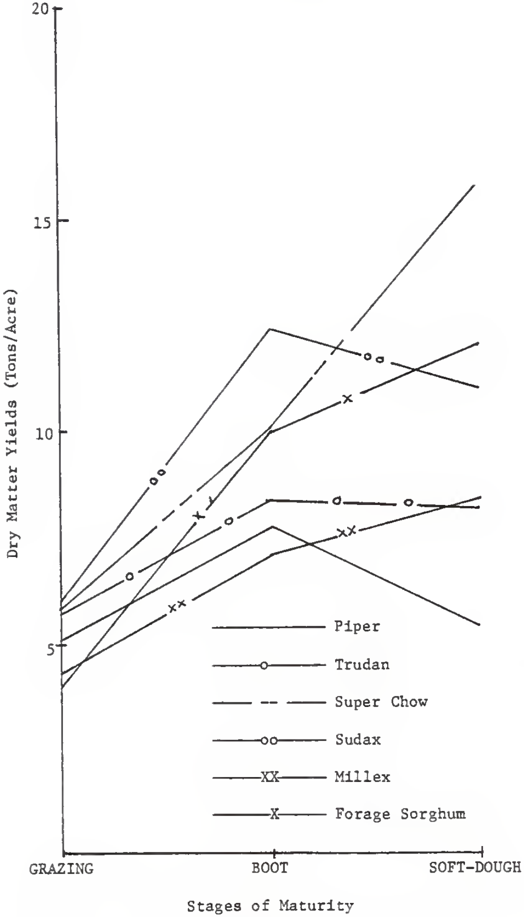

Figure 1. Dry matter yields of six summer annual forages as affected by stages of maturity, Hutchinson.

When harvested at the boot stage, Millex, Piper and Trudan were the lowest producers. Sudax was significantly superior than the other five forages, while Super Chow Maker and Forage Sorghum were intermediate.

At the soft-dough stage of maturity, Super Chow Maker significantly outyielded the other five cultivars. Piper ranked last, and its inferiority for silage production was clearly evident. The yields of Sudax and Forage Sorghum were statistically similar and better than those of Trudan and Millex.

Other Agronomic Characteristics

The comparative production of herbage determined on a 60% moisture basis, i.e., wilted silage, and plant height data, are presented in Appendix Tables 1 and 2. Similar data from Manhattan are presented in Appendix Tables 3 and 4.

Plant height increased progressively throughout the three growth stages, with Forage Sorghum making the largest increase at the soft-dough stage. Although not measured in this study, stem thickness seemed to have increased concurrently with plant height. Such rapid increases in stem height and thickness with advancing maturity increase the proportion of stems to leaves, thus leading to the quality versus yield relationships described throughout this paper.

Quality Components

In Vitro Dry Matter Digestibility

As with agronomic traits, forage quality, including the percentages of *in vitro* digestible dry matter, was a function of advancing maturity. Table 5 shows that IVDDM declined from approximately 67% in plants harvested at the vegetative stage to about 54% in those cut at the silage stage. Forage digestibilities among growth stages were significantly different. The greatest decrease in this component occurred when the two- and three-cut schemes were compared with the single-cut management.

Significant variety * growth stage interactions for IVDDM percentages were noted (Appendix Table 5b). Under the pasture management, Millex was highest and Forage Sorghum lowest in percent IVDDM. Though the lowest in percent IVDDM, Forage Sorghum was not statistically lower than Piper sudangrass. Trudan, Super Chow Maker and Sudax were similar in the percentage of *in vitro* digestible dry matter contained, and significantly lower than Millex.

The rankings of cultivars under the two-cut system were quite similar to those of the pasture management. Millex was significantly superior followed by Trudan, Super Chow Maker, and Sudax. The digestible dry matter percentages among the latter three forages decreased in this order, but the differences were not significant. Forage Sorghum contained the lowest IVDDM percentage, but was not significantly lower than Piper.

Table 5. Mean <u>In Vitro</u> Digestible Dry Matter Percentages of Six Summer Annuals When Harvested at Three Growth Stages
Hutchinson

Variety	Grazing				Boot			Soft-Dough	
	C_1	C_2	C_3	$\overline{X}$	C_1	C_2	$\overline{X}$		Seasonal Means
Piper	69.33*[b]	67.80[ab]	61.12[c]	66.16[bc]	63.17[c]	54.91[c]	59.83[cd]	50.93[d]	58.97[c]
Trudan	70.81[ab]	68.16[ab]	63.06[bc]	68.15[b]	65.90[ab]	58.16[ab]	62.94[b]	51.32[d]	60.47[b]
S. C. Maker	70.49[ab]	66.98[b]	64.68[b]	67.39[b]	66.36[ab]	57.10[bc]	62.34[b]	53.86[c]	61.93[b]
Sudax	69.76[ab]	66.98[b]	62.32[c]	66.59[b]	65.41[b]	55.63[bc]	60.95[bc]	56.34[ab]	61.29[b]
Millex	72.17[a]	70.73[a]	70.23[a]	70.79[a]	67.36[ab]	60.84[a]	65.78[a]	55.29[bc]	63.95[a]
F. Sorghum	66.45[c]	63.11[c]	64.92[b]	64.61[c]	53.29[d]	-	58.29[d]	58.64[a]	60.51[b]
$LSD_{.05}$	2.59	3.42	2.12	2.37	1.86	2.74	2.37	2.37	1.27
$\overline{X}$	69.83	67.29	64.39	67.11[a]	64.42	57.33	61.69[b]	54.39[c]	-

* Means within a column followed by the same letter or letters are not significantly different at the 0.05 level, according to the Waller-Duncan multiple comparison test.

Contrary to its performance under the multiple harvest frequencies, Forage Sorghum contained the highest percent IVDDM under the one-cut management. Its digestible dry matter percentage was higher than that of Sudax, but not significantly. Sudax performed better than Millex, but not significantly so. Trudan and Piper ranked last, while Super Chow Maker was intermediate between the Piper-Trudan grouping and Millex.

The data indicate that varieties were generally inferior to hybrids, irrespective of cutting management. This was evident when Piper sudangrass and Trudan hybrid sudangrass were compared. Furthermore, the data indicate that digestible dry matter differences existed between hybrids within a cultivar. Though not consistently, Super Chow Maker was more digestible than Sudax under multiple harvest frequencies, while the reverse was true under the single-cut system.

There were good indications that the ability to tolerate frequent clipping was positively correlated with IVDDM percentage contained. This was demonstrated by the low percentages in Forage Sorghum under two or three cuttings, whereas its percentage was highest when the grasses were cut only once per season.

Within managements, there appeared to be a consistent trend whereby previously uncut plants were more digestible than regrowths. Under the pasture management, previously uncut plants averaged 2.54 percentage units more digestible than their regrowth counterparts. Successive cuttings were also generally slightly less digestible than the preceding ones. These trends were upheld, but more significantly, when plants were harvested twice a year. Here, previously unharvested forages averaged 7.09% more digestible than regrowth grasses. Figure 2 illustrates these varietal changes in *in vitro* dry matter percent as the forages progressed towards maturity.

Crude Protein Content

The percentages of crude protein are shown in Table 6. Here, as in Figure 3, it is evident that crude protein decreased greatly with progressing maturity. Of the three quality components considered, crude protein showed the most reduction with advancing maturity. It dropped from about 15% in plants harvested three times to about 5% under the one-cut system of management, i.e., a 67% drop. This was opposed to a decrease of 19% in IVDDM and an increase of 18% in ADF, under the same conditions.

Appendix Table 5b indicates that the interaction between varieties and stages of growth was significant for percent crude protein. Within the pasture-stage management, Forage Sorghum was significantly higher than the other five grasses. The crude protein contents of the remaining forages were similar.

When cut for hay, the crude protein percentage of Millex was highest, but not significantly greater than Sudax. The crude protein percentages in Piper and Trudan were lower than in Sudax, but not statistically different. Super Chow Maker and Forage Sorghum percentages were lowest, but not significantly lower than those of Piper and Trudan.

Under the silage system of management, Piper, Trudan and Sudax were significantly superior to the others in percent crude protein.

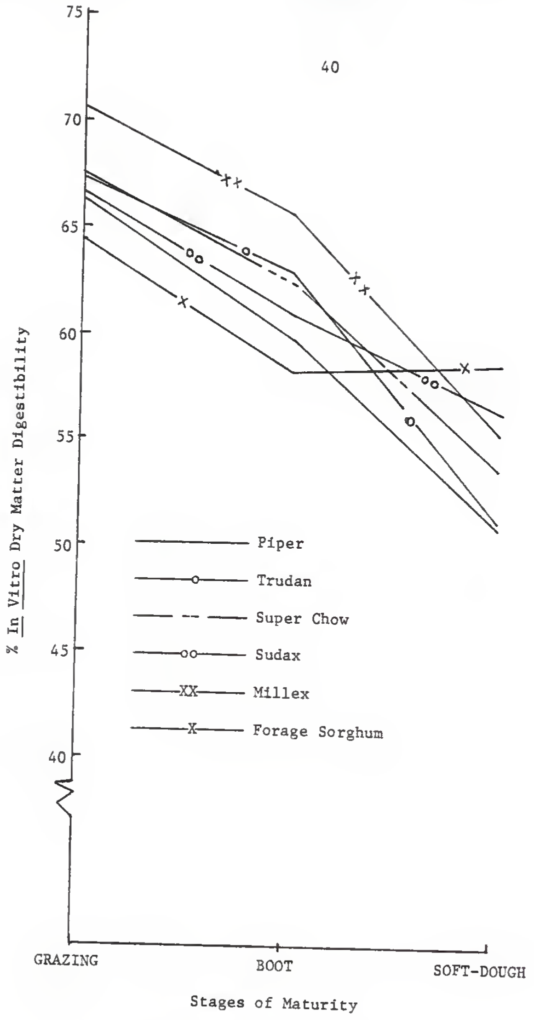

Figure 2. *In vitro* digestible dry matter percentages of six summer annual forages as affected by stages of maturity, Hutchinson.

Table 6. Mean Crude Protein Percentages of Six Summer Annuals When Harvested at Three Growth Stages Hutchinson

Variety	Grazing				Boot			Soft-Dough	
	C_1	C_2	C_3	$\overline{X}$	C_1	C_2	$\overline{X}$	.	Seasonal Means
Piper	14.79*[d]	16.29	10.90[b]	13.84[b]	10.21[b]	7.41[ab]	9.07[bc]	6.57[a]	9.83[a]
Trudan	16.06[c]	15.61	11.67[ab]	14.28[b]	10.02[bc]	6.23[bc]	8.54[bc]	5.96[a]	9.59[a]
S. C. Maker	15.93[cd]	15.69	10.24[b]	13.81[b]	10.79[ab]	4.88[c]	8.32[c]	3.31[b]	8.48[b]
Sudax	15.37[cd]	16.57	13.55[ab]	14.86[b]	11.81[ab]	8.44[a]	10.26[ab]	5.71[a]	10.28[a]
Millex	20.69[a]	17.23	10.11[b]	14.84[b]	12.62[a]	5.99[bc]	11.05[a]	3.92[b]	9.94[a]
F. Sorghum	18.77[b]	17.29	15.64[a]	17.32[a]	7.81[c]	-	7.81[c]	3.95[b]	9.70[a]
$LSD_{.05}$	1.23	ns	4.09	1.71	2.30	1.52	1.71	1.71	1.09
$\overline{X}$	16.93	16.45	12.01	14.83[a]	10.54	6.59	9.17[b]	4.90[c]	-

* Means within a column followed by the same letter or letters are not significantly different at the 0.05 level, according to the Waller-Duncan multiple comparison test.

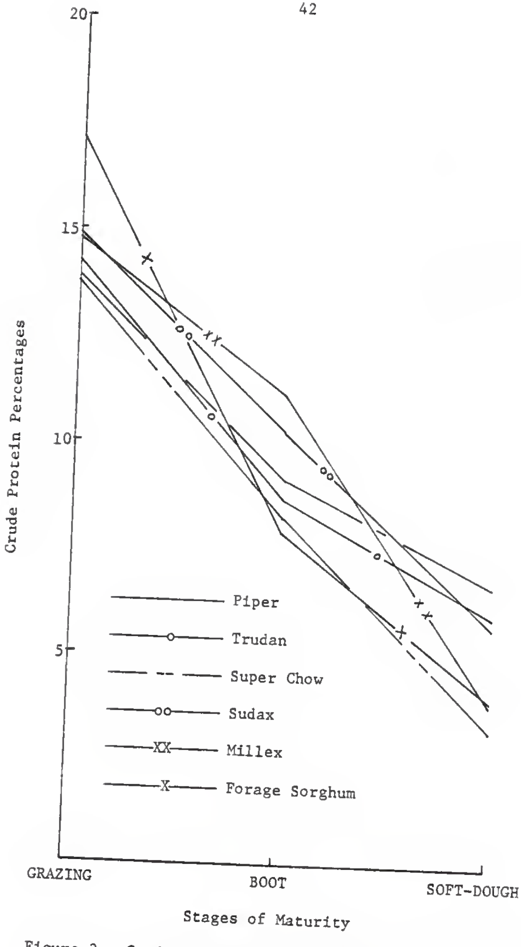

Figure 3. Crude protein percentages of six summer annual forages as affected by stages of maturity, Hutchinson.

Super Chow Maker contained the least crude protein percentage, but was not significantly different than Millex and Forage Sorghum.

Similar to IVDDM percentages, crude protein percentages tended to decrease with successive cuttings, and the differences were less dramatic under the three-cut management than the two-cut scheme. When harvested for hay, previously uncut grasses averaged about 4 percentage units more than their regrowth counterparts.

Acid-Detergent Fiber

As shown in Table 7, the structural components in all cultivars increased significantly with maturity. The three growth stages differed significantly in fiber concentration. With the exception of Forage Sorghum, which declined slightly at the soft-dough stage, all cultivars increased in percent ADF from the pasture to the silage stages of maturity.

Of the three quality predictors examined in this study, the response of cultivars to changes in fiber were generally most consistent. The data suggest that within managements, previously uncut grasses were generally slightly lower in fiber content than regrowth plants, and that regrowth plants were related similarly to their successors. As shown in Appendix Table 5b, the entries responded similarly at the three growth stages, as demonstrated by the non-significant variety by stage interaction. In general, it was therefore difficult to identify any one grass as being statistically high or low in fiber concentration.

Table 7. Mean Acid-Detergent Fiber Percentages of Six Summer Annuals When Harvested at Three Growth Stages Hutchinson

Variety	Grazing				Boot			Soft-Dough	
	C_1	C_2	C_3	$\overline{X}$	C_1	C_2	$\overline{X}$		Seasonal Means
Piper	28.39*[a]	30.76	35.14	31.39	33.72[b]	41.75[a]	36.96[a]	38.06	35.47
Trudan	29.11[a]	30.93	34.94	31.79	33.57[b]	38.82[ab]	35.36[ab]	38.76	35.30
S. C. Maker	29.60[a]	31.96	35.73	32.49	30.51[c]	39.52[ab]	34.24[b]	38.39	35.04
Sudax	30.28[a]	32.66	34.09	32.25	30.13[c]	36.34[b]	33.02[b]	36.39	33.89
Millex	25.27[b]	30.56	34.41	31.11	31.87[bc]	39.33[ab]	33.47[b]	37.76	34.11
F. Sorghum	30.49[a]	32.80	34.00	32.44	37.48[a]	-	37.48[a]	36.40	35.44
$LSD_{.05}$	2.77	ns	ns	ns	2.54	3.94	2.27	ns	na
$\overline{X}$	28.57	31.61	34.72	31.91[c]	32.84	39.15	35.09[b]	37.62[a]	-

* Means within a column followed by the same letter or letters are not significantly different at the 0.05 level, according to the Waller-Duncan multiple comparison test.

Relationship Between Forage Yield and Quality

As the dry matter yield of a forage increased (Table 8), the yield of IVDDM also increased, although not in the same proportion. Thus the forage that produced the highest dry matter also generally tended to produce the largest *in vitro* digestible dry matter yield.

Because of the positive correlation between the yields of dry matter and digestible dry matter with advancing maturity, lower yields of IVDDM were obtained under the pasture management. Thus, frequent harvesting did not increase total IVDDM yields, although such cutting practices increased forage digestibility.

Total crude protein production increased slightly between the pasture and boot stages. It dropped sharply after the boot stage so that forages cut only once per season produced only about half as much as at the grazing stage. Figure 4 graphically describes these yield and quality relationships. In addition, it shows that percentages of crude protein and IVDDM are inversely related to dry matter yield, while the correlation between dry matter yield and percent ADF is positive.

Table 8. Total Dry Matter, Crude Protein and *In Vitro* Digestible Dry Matter Yields (Tons/Acre)
Hutchinson

Variety	Grazing			Boot			Soft-Dough		
	D.M.	C.P.	IVDDM	D.M.	C.P.	IVDDM	D.M.	C.P.	IVDDM
Piper	5.08^{*ab}	0.71	3.36^{ab}	7.77^{c}	0.71^{b}	4.65^{d}	5.41^{e}	0.35	2.75^{d}
Trudan	5.73^{a}	0.82	3.85^{a}	8.26^{c}	0.70^{b}	5.21^{cd}	8.08^{d}	0.49	4.13^{c}
S. C. Maker	5.83^{a}	0.80	3.93^{a}	10.04^{b}	0.83^{b}	6.24^{b}	15.66^{a}	0.53	8.45^{a}
Sudax	5.85^{a}	0.87	3.89^{a}	12.36^{a}	1.28^{a}	7.52^{a}	10.96^{b}	0.52	5.53^{b}
Millex	4.41^{ab}	0.65	3.11^{ab}	7.01^{c}	0.78^{b}	4.61^{d}	8.38^{cd}	0.33	4.63^{c}
F. Sorghum	3.89^{b}	0.67	2.51^{b}	9.94^{b}	0.79^{b}	5.81^{bc}	11.98^{b}	0.47	7.02^{b}
$LSD_{.05}$	1.61	ns	0.99	1.61	0.23	0.99	1.61	ns	0.99
$\overline{X}$	5.13	0.75	3.44	9.23	0.85	5.67	10.08	0.45	5.42

* Means within a column followed by the same letter or letters are not significantly different at the 0.05 level, according to the Waller-Duncan multiple comparison test.

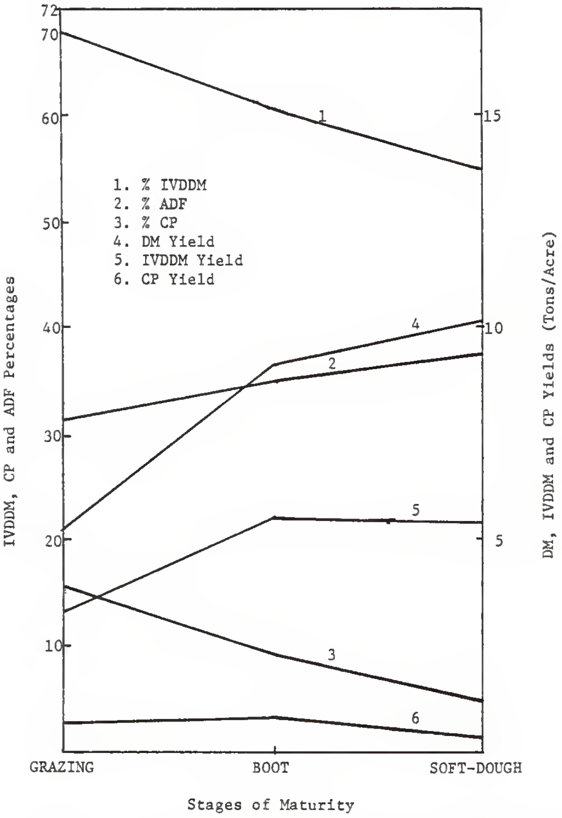

Figure 4. Effects of maturity on dry matter yield and quality components of six summer annual forages, Hutchinson.

CHAPTER V

RESULTS: MANHATTAN DATA

Agronomic Characteristics

Dry Matter Content

Cultivars displayed large fluctuations in dry matter percentages with advancing maturity (Table 9). Some entries were lower in dry matter content at the boot stage than at the pasture stage. Scrutiny of the data shows that unexpected drops occurred in the third cutting of the grazing stage and in the second of the boot stage, both of which were made on the same day, and may have caused the seasonal mean dry matter percentages of the two growth stages to be equal.

The nonsignificant variety * stage interaction which resulted (Appendix Table 6a) could have been caused by the responses noted above. Across the three managements, mean seasonal dry matter percentage of Piper ranked first but was not significantly different than those of Trudan and Super Chow Maker. Sudax, Millex and Forage Sorghum dry matter percentages were similar and significantly inferior to those named previously.

Table 9. Mean Dry Matter Percentages of Six Summer Annuals When Harvested at Three Growth Stages Manhattan

Variety	Grazing					Boot			Soft-Dough	
	C_1	C_2	C_3	C_4	$\overline{X}$	C_1	C_2	$\overline{X}$		Seaaonal Means
Piper	23.03*[a]	25.16[a]	17.44[a]	28.89[a]	23.30[a]	26.10	16.11	21.10	38.87[a]	28.09[a]
Trudan	23.81[a]	23.55[ab]	14.27[ab]	25.57[ab]	21.80[ab]	24.94	15.14	20.04	38.93[a]	26.92[a]
S. C. Maker	22.18[a]	21.65[b]	14.25[ab]	24.41[ab]	20.34[ab]	26.26	16.57	21.42	39.34[a]	27.03[a]
Sudax	22.78[a]	22.48[b]	14.01[b]	25.33[ab]	21.15[ab]	25.69	15.64	20.66	31.60[b]	24.47[b]
Millex	19.97[b]	21.66[b]	10.66[c]	16.79[b]	17.27[b]	23.38	15.58	19.48	31.43[b]	22.73[b]
F. Sorghum	19.96[b]	17.66[c]	14.35[ab]	22.89[ab]	18.52[ab]	22.26	-	19.72	31.98[b]	23.41[b]
$LSD_{.05}$	1.92	1.96	3.32	3.38	4.29	ns	na	ns	4.29	2.41
$\overline{X}$	21.95	22.03	14.16	23.98	20.40[c]	24.77	15.81	20.40[b]	35.52[a]	-

* Means within a column followed by the same letter or letters are not significantly different at the 0.05 level, according to the Waller-Duncan multiple comparison test.

Dry Matter Yield

The data in Table 10 show that dry matter accumulation (tons/acre) consistently increased as plants were harvested at more mature stages. Forage production was about three times as great at the soft-dough stage as at the pasture stage. The variety * stage interaction for dry matter yields was highly significant, as shown in Appendix Table 6a.

Within managements, the decrease in dry matter production with successive cuttings was more consistent here than was observed at Hutchinson. With the exception of the third cutting of the grazing stage, the growth rates of regrowth plants decreased as the number of uniform cuttings increased under the pasture management and to a greater degree under the hay system. However, no attempts were made to draw direct comparisons between regrowths under the two systems since "regrowth 1" of the vegetative stage began about two weeks before that of the boot stage. Rate of regrowth was considerably slower as the season progressed, the slowest occurring in last-cut plants.

Significant differences were obtained among forages within managements in dry matter yield. When they were managed for pasture production, Millex was the highest dry matter producer, although its yield was not significantly greater than those of Sudax, Super Chow Maker, Piper and Trudan (these four are listed in the order of decreasing values). As was noted at Hutchinson, Forage Sorghum was highly sensitive to frequent clipping and therefore produced the least pasture-stage dry matter.

Table 10. Total Dry Matter Yields (Tons/Acre) of Six Summer Annuals When Harvested at Three Growth Stages Manhattan

Variety	Grazing					Boot			Soft-Dough	
	C_1	C_2	C_3	C_4	Total	C_1	C_2	Total		Seasonal Means
Piper	1.34^{*bc}	1.50^{ab}	1.46^{ab}	0.93^{a}	5.01^{ab}	3.13	3.40	6.53^{ab}	7.58^{d}	6.37^{b}
Trudan	1.22^{bc}	1.56^{a}	1.48^{ab}	0.66^{ab}	4.91^{ab}	3.69	2.63	6.32^{ab}	8.40^{d}	6.54^{b}
S. C. Maker	1.79^{b}	1.14^{bc}	1.80^{a}	0.54^{b}	5.13^{ab}	4.43	3.76	8.20^{a}	16.57^{a}	9.66^{a}
Sudax	1.69^{b}	1.22^{abc}	1.78^{a}	0.75^{ab}	5.44^{a}	4.50	2.36	6.86^{ab}	9.11^{dc}	7.14^{b}
Millex	2.47^{a}	1.18^{abc}	1.72^{a}	0.75^{ab}	6.11^{a}	4.18	3.26	7.44^{a}	13.38^{ab}	8.97^{a}
F. Sorghum	0.95^{c}	0.88^{c}	0.96^{b}	0.52^{b}	2.93^{b}	3.59	-	4.98^{b}	12.17^{bc}	6.69^{b}
$LSD_{.05}$	0.64	0.39	0.67	0.38	2.29	ns	ns	2.29	2.29	1.24
$\overline{X}$	1.58	1.25	1.48	0.69	4.92^{c}	3.92	3.08	6.72^{b}	11.20^{a}	-

* Means within a column followed by the same letter or letters are not significantly different at the 0.05 level, according to the Waller-Duncan multiple comparison test.

For dry matter production, cultivars ranked in the same order as at Hutchinson, when the forages were harvested for hay. Here, Super Chow Maker produced the largest yield, although not significantly more than Millex. The dry matter yields of Sudax, Piper and Trudan were lower than those of Super Chow Maker and Millex, but were not significantly different. Similar to the pasture management, Forage Sorghum yielded least under the two-cut scheme, again an indication of the susceptibility of this grass to frequent cutting.

When harvested at the soft-dough stage, Super Chow Maker produced the most dry matter, but was not statistically superior to Millex. The silage dry matter yield of Forage Sorghum was lower, but not significantly different than that of Millex. Piper and Trudan were at the lower end of the scale, and the extremely low dry matter yields indicated their undesirability for silage production. The yield of Sudax was intermediate between those of Forage Sorghum and Trudan. A graph of these yield relationships is presented in Figure 5.

Quality Components

In Vitro Dry Matter Digestibility

Table 11 readily shows that the decrease in forage digestibility with advancing maturity followed the same pattern as was noted at Hutchinson. *In vitro* dry matter digestibility of the forages averaged about 67%, 62%, and 51% respectively at the pasture, boot and soft-dough stages of maturity. These decreases were significant among the growth stages. It can be seen that the greatest decrease occurred when the pasture and hay managements were compared with the silage management.

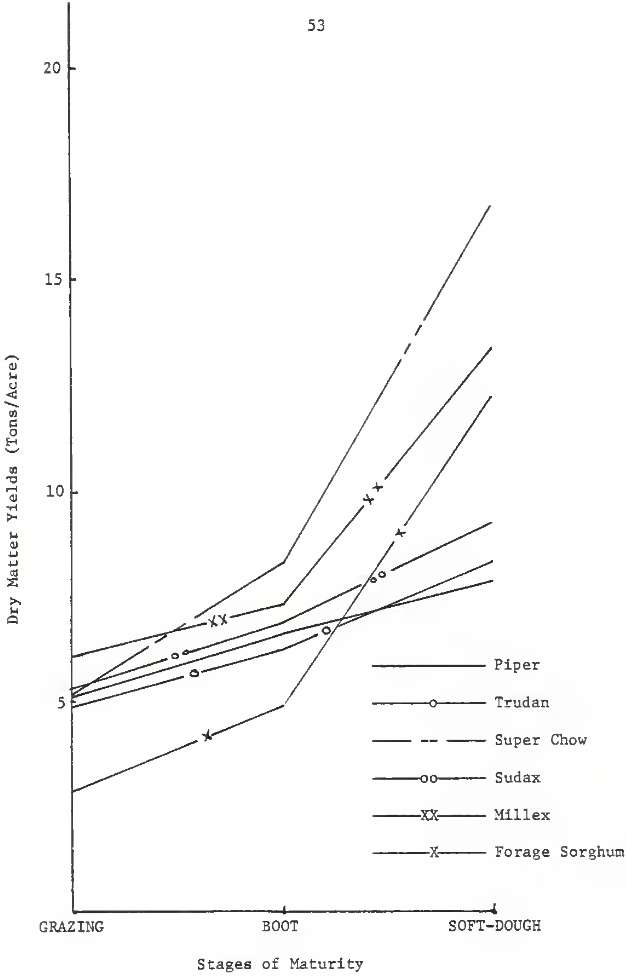

Figure 5. Dry matter yields of six summer annual forages as affected by stages of maturity, Manhattan.

Table 11. Mean *In Vitro* Digestible Dry Matter Percentages of Six Summer Annuals When Harvested at Three Growth Stages
Manhattan

Variety	Grazing					Boot			Soft-Dough	
	C_1	C_2	C_3	C_4	$\overline{X}$	C_1	C_2	$\overline{X}$		Seasonal Means
Piper	71.51*^{ab}	66.04^{ab}	66.55^{a}	64.81	67.32	65.92^{a}	60.83^{b}	63.13^{ab}	49.77^{b}	60.03^{ab}
Trudan	72.98^{a}	65.52^{abc}	66.48^{a}	65.19	67.61	62.92^{ab}	60.31^{b}	61.82^{ab}	51.49^{ab}	60.31^{ab}
S. C. Maker	70.67^{abc}	63.68^{bc}	63.87^{b}	64.15	66.14	60.94^{b}	64.51^{a}	62.56^{ab}	50.88^{ab}	59.85^{ab}
Sudax	68.80^{c}	63.18^{c}	63.84^{b}	64.59	65.13	59.98^{b}	64.54^{a}	60.99^{b}	50.27^{b}	58.79^{b}
Millex	68.28^{c}	67.18^{a}	67.32^{a}	66.12	67.38	62.11^{ab}	66.38^{a}	63.88^{a}	52.79^{a}	61.35^{a}
F. Sorghum	69.31^{bc}	59.16^{d}	68.37^{a}	67.26	65.60	58.56^{b}	-	58.56^{b}	53.07^{a}	59.88^{ab}
$LSD_{.05}$	2.49	2.61	2.68	ns	ns	4.75	2.88	2.51	2.51	1.68
$\overline{X}$	70.26	64.12	66.07	65.35	66.53^{a}	61.64	63.31	62.21^{b}	51.38^{c}	-

* Means within a column followed by the same letter or letters are not significantly different at the 0.05 level, according to the Waller-Duncan multiple comparison test.

Contrary to the Hutchinson situation, the interaction of variety by stage of maturity was nonsignificant (Appendix Table 6b). With respect to the mean yearly IVDDM percentages, the order of decreasing values was Millex, Trudan, Piper, Forage Sorghum, Super Chow Maker and Sudax. Millex was significantly superior only to Sudax. The rest of the cultivars were similar.

As has been stated elsewhere, dry matter yield and percentages of crude protein and of IVDDM are inversely proportional. The dry matter percentages of the third cutting of the vegetative stage and the second of the boot were surprisingly lower than their preceding cuttings. This tended to have a concentrating effect on the IVDDM and crude protein percentages of these cuttings. The ultimate result of these changes was to upset the general pattern in which previously uncut plants were more digestible or contained higher percentages of crude protein than forages harvested in successive cuttings.

Crude Protein Content

The relationships among the percentages of crude protein, *in vitro* digestible dry matter and acid-detergent fiber were comparable to that described in the Hutchinson results. From the vegetative stage to the soft-dough stage, crude protein dropped approximately from 20 to 9% (a 55% decline). During the same period, IVDDM decreased from 67 to 51% (a 24% decrease) and ADF increased from 29 to 37% (an increase of 24%).

Management * variety interaction was significant, as shown in Appendix Table 6b. The data in Table 12 reveal that at the vegetative

Table 12. Mean Crude Protein Percentages of Six Summer Annuals When Harvested at Three Growth Stages Manhattan

Variety	Grazing					Boot			Soft-Dough	Seasonal Means
	C_1	C_2	C_3	C_4	$\overline{X}$	C_1	C_2	$\overline{X}$		
Piper	21.18*	16.25^{bc}	20.74^{ce}	19.97^{a}	19.17^{b}	13.67^{b}	15.06	14.26^{c}	10.22^{a}	14.55^{b}
Trudan	19.51	15.02^{c}	19.19^{de}	18.08^{b}	17.83^{c}	14.29^{b}	17.56	15.64^{ab}	8.88^{bc}	14.12^{bc}
S. C. Maker	20.40	17.03^{b}	19.68^{de}	19.28^{a}	19.17^{b}	13.05^{bc}	16.16	14.48^{bc}	8.33^{c}	13.99^{bc}
Sudax	20.17	17.64^{b}	22.01^{ab}	20.11^{a}	20.09^{b}	11.39^{c}	16.43	12.61^{d}	9.86^{ab}	14.19^{bc}
Millex	21.54	21.83^{a}	22.60^{a}	18.60^{b}	21.52^{a}	17.12^{a}	16.66	16.61^{a}	10.23^{a}	16.12^{a}
F. Sorghum	21.07	16.55^{bc}	21.30^{bc}	21.15^{a}	19.65^{b}	11.31^{c}	-	12.52^{d}	8.68^{bc}	13.62^{c}
$LSD_{.05}$	ns	1.62	1.23	2.22	1.24	1.79	ns	1.24	1.24	0.67
$\overline{X}$	20.56	17.38	20.92	19.53	19.57^{a}	13.47	16.37	14.35^{b}	9.37^{c}	-

* Means within a column followed by the same letter or letters are not significantly different at the 0.05 level, according to the Waller-Duncan multiple comparison test.

stage, Millex was significantly superior, while Trudan was significantly inferior to the other cultivars. The remaining four grasses were similar, and intermediate between Trudan and Millex.

When cut twice a year, Millex retained its superiority, although it was not significantly different than Trudan. Piper was significantly lower than Millex, but similar to Super Chow Maker. Sudax and Forage Sorghum were similar and significantly lower than the other cultivars.

Under the silage system, Millex and Piper were similar in crude protein percentage, and were significantly superior to Trudan, Super Chow Maker and Forage Sorghum. Sudax was intermediate between Trudan and Forage Sorghum on the one hand and Millex and Piper on the other. Super Chow Maker was the lowest, although statistically similar to Trudan and Forage Sorghum. Figure 6 presents these relationships graphically.

Acid-Detergent Fiber

All cultivars increased in fiber concentration throughout the three growth stages, and significant differences were noted among growth stages in this trait. Table 6b of the Appendix shows that the variety by stage interaction was highly significant ($P<.05$).

At the pasture stage, Millex was significantly lower than the others in this component. Piper, Super Chow Maker and Sudax were similar. Although it contained a relatively high acid-detergent fiber content, Forage Sorghum was not significantly different than

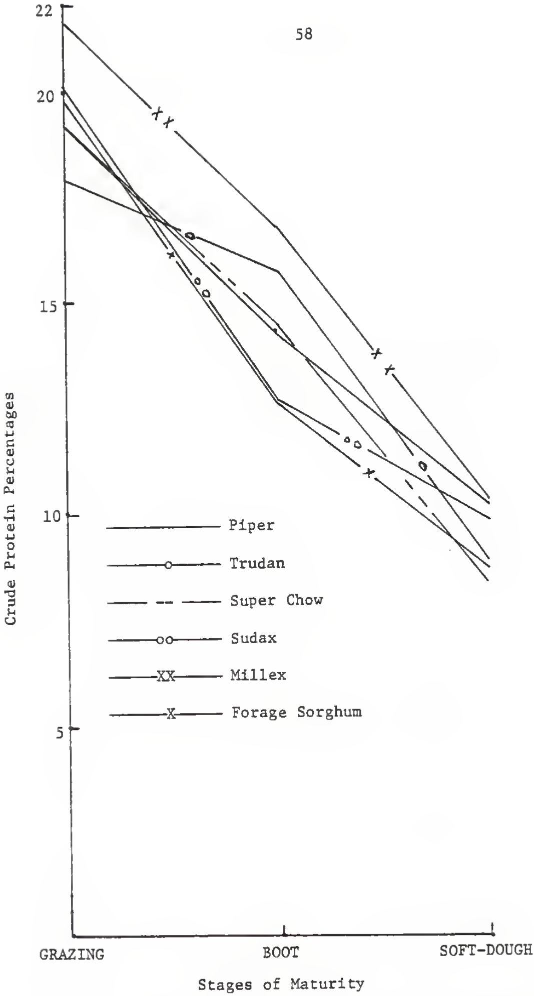

Figure 6. Crude protein percentages of six summer annual forages as affected by stages of maturity, Manhattan.

the preceding three forages. Trudan was not significantly lower than Piper, Super Chow Maker or Sudax.

The data in Table 13 show that no differences existed among the cultivars when cut at the boot stage. However, under the silage management, the ADF percentages of Millex and Forage Sorghum were lower than that of Super Chow Maker. Super Chow Maker, Piper, Trudan and Sudax were not statistically different.

The mean ADF contents for all varieties within individual cuts suggested that within managements, previously unharvested plants contained less fiber than regrowths. This trend was more pronounced under the hay system of management than under the pasture scheme.

Relationship Between Forage Yield and Quality

Changes in IVDDM contents and yields with those in dry matter yields were similar to those previously described for the Hutchinson data. As shown in Table 14, total crude protein was slightly higher at the silage than at the pssture stage. Unlike total IVDDM yields, the differences in total crude protein yields among growth stages were nonsignificant, although there was a gradual increase in this trait as maturity progressed. The maximum crude protein production in Trudan occurred at the boot stage and then decreased as harvest was delayed. For the other forages, except Piper and Sudax, protein yields steadily increased throughout the growth stages. The yields of crude protein in Piper and Sudax slightly decreased at the boot stage, but were highest at the soft-dough stage. These relationships are shown graphically in Figure 7.

Table 13. Mean Acid-Detergent Fiber Percentages of Six Summer Annuals When Harvested at Three Growth Stages
Manhattan

Variety	Grazing					Boot			Soft-Dough	
	C_1	C_2	C_3	C_4	$\overline{X}$	C_1	C_2	$\overline{X}$		Seasonal Means
Piper	25.43*	24.47[b]	31.20[a]	31.20	28.88[ab]	26.22[c]	34.35	30.65	36.69[ab]	32.07[a]
Trudan	24.72	28.12[ab]	30.67[a]	28.68	28.11[b]	29.48[b]	35.22	31.88	36.53[ab]	32.17[a]
S. C. Maker	26.35	29.45[ab]	33.20[a]	31.51	30.39[ab]	30.88[ab]	32.38	31.64	38.69[a]	33.57[a]
Sudax	27.32	28.12[ab]	30.36[a]	29.92	28.82[ab]	30.68[ab]	31.58	31.08	36.39[ab]	32.10[a]
Millex	24.23	25.53[b]	23.19[b]	26.19	24.49[c]	29.73[b]	30.95	30.38	35.59[b]	30.15[b]
F. Sorghum	28.20	33.98[a]	31.21[a]	30.42	30.83[a]	32.83[a]	-	32.19	34.38[b]	32.47[a]
$LSD_{.05}$	ns	6.18	4.89	ns	2.19	2.41	ns	ns	2.19	1.52
$\overline{X}$	26.02	28.78	29.97	29.65	28.59[c]	29.97	32.90	31.30[b]	36.38[a]	-

* Means within a column followed by the same letter or letters are not significantly different at the 0.05 level, according to the Waller-Duncan multiple comparison test.

Table 14. Total Dry Matter, Crude Protein and <u>In Vitro</u> Digestible Dry Matter Yields (Tons/Acre) Manhattan

Variety	Grazing			Boot			Soft-Dough		
	D.M.	C.P.	IVDDM	D.M.	C.P.	IVDDM	D.M.	C.P.	IVDDM
Piper	5.01^{*ab}	0.96^{b}	3.38^{a}	6.53^{ab}	0.93^{b}	4.12^{ab}	7.58^{c}	0.78^{bc}	3.78^{c}
Trudan	4.91^{ab}	0.87^{b}	3.32^{a}	6.32^{ab}	0.98^{ab}	3.91^{ab}	8.40^{c}	0.74^{c}	4.32^{c}
S. C. Maker	5.13^{ab}	0.99^{b}	3.39^{a}	8.20^{a}	1.19^{ab}	5.14^{a}	16.57^{a}	1.39^{a}	8.47^{a}
Sudax	5.44^{a}	1.09^{ab}	3.54^{a}	6.86^{ab}	0.87^{bc}	4.17^{ab}	9.11^{c}	0.89^{bc}	4.57^{c}
Millex	6.11^{a}	1.23^{a}	4.12^{a}	7.44^{a}	1.23^{a}	4.75^{a}	13.38^{b}	1.38^{a}	7.08^{b}
F. Sorghum	2.93^{b}	0.58^{c}	1.93^{b}	4.98^{b}	0.62^{c}	3.02^{b}	12.17^{b}	1.06^{b}	6.47^{b}
$LSD_{.05}$	2.29	0.30	1.34	2.29	0.30	1.34	2.29	0.30	1.34
$\overline{X}$	4.92	0.97	3.28	6.72	0.97	4.18	11.20	1.04	5.78

* Means within a column followed by the same letter or letters are not significantly different at the 0.05 level, according to the Waller-Duncan multiple comparison test.

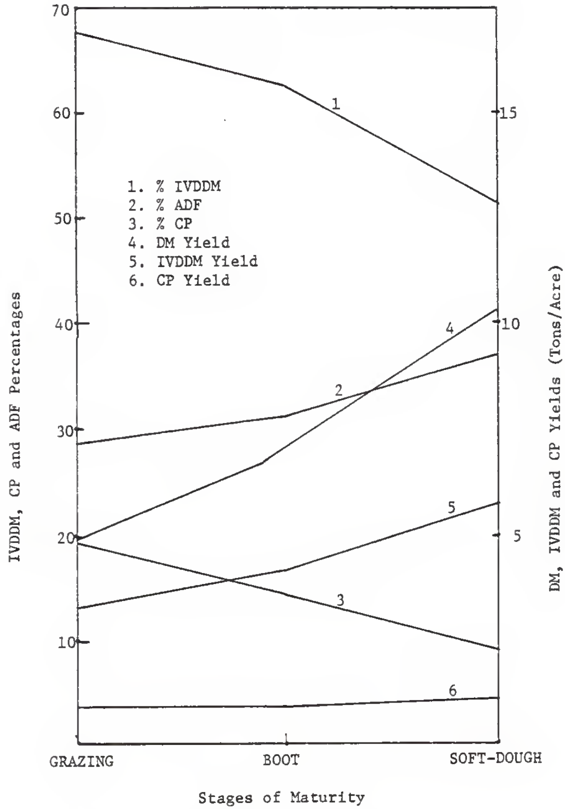

Figure 7. Effects of maturity on dry matter yield and quality components of six summer annual forages, Manhattan.

CHAPTER VI

DISCUSSION

Introduction

In the production and management of forage crops, it is important to understand the seasonal distribution and the forms in which they can be utilized in order to yield the maximum benefit to a given livestock operation. In this study, six summer annual grasses were harvested to simulate field practices for pasture, hay and silage production and hopefully to bring into clearer perspective the yield and quality implications associated with managing summer annuals in these ways. By way of initiating these discussions, the roles of pasture, hay and silage in farm stock production are highlighted herein.

As regards pasture, it can be said that for all classes of farm stock (poultry and swine to a lesser extent) good quality pasture is the foundation for efficient production. Since it is harvested directly by the animal itself, pasture is the most economical way of utilizing forage plants. Hay also plays an important role in livestock production. It is included in rations for ruminants mainly as an energy source and in monogastric rations to supply vitamins, minerals and protein (38). A well-made and well-preserved hay can be stored for longer periods than other forms of harvested forage. Silage is also an important type of livestock feed. It has several advantages over hay. One of these is that crops may be ensiled when climatic conditions disallow curing them into hay. Also, good silage, even from plants with coarse stalks, is eaten practically without waste, while a considerable loss of stems and leaves is incurred even in a good hay-making or hay-feeding operation. Like hay, silage is also used mainly as a source of energy.

Efficient use of pasture, hay and silage can only be made if the producer understands the relationship between dry matter yield and forage quality. However, as Morrison (54) has pointed out, many stockmen do not fully realize the great differences in nutritive value that exist between young forage crops and the same plants at later stages of maturity. Frequently farmers are only concerned about dry matter production. However, for an efficient livestock feeding program, both yield and quality must be kept in proper perspective.

Perhaps the most important factor that determines the relationship between the opposing attributes of yield and quality is the stage of maturity at which the harvest is made. For example, to make good quality silage, crops must have solid stems, which after being chopped will pack well and consequently facilitate the ensiling process, by eliminating oxygen. They must also contain high levels of carbohydrates which provide the raw materials for the fermentation process, which in turn preserves the silage via the production of organic acids, especially lactic. These two requirements indicate that plants intended for silage production must be harvested at more advanced stages of maturity.

On the other hand, high quality pastures can be achieved only if plants are harvested at the vegetative stage. Vegetative plants are much richer in protein (dry matter basis) than the same plants at more mature growth stages. They also are more digestible and richer in other nutritional attributes than the more mature ones. The stages of maturity recommended for utilizing summer annuals are: vegetative (for pasture), boot (for hay) and soft-dough (for silage). The dry matter yield and quality relationships associated with these will be carefully examined here.

Agronomic Characteristics

Dry Matter Yield

The effect of harvesting frequency on dry matter production of summer annuals has been well studied. Despite the varieties of forages, environmental conditions, etc. considered, there is general agreement that frequent removal of topgrowth decreases herbage production. For example, in this study, the yield of summer annuals cut two times a year was on the average about 1.8 tons/acre and 4.1 tons/acre greater than those of forages harvested three and four times, respectively. Single-cut plants produced 4.95 tons/acre and 6.28 tons/acre more dry matter than those subjected to three and four-cut harvest frequencies, respectively. The yield superiority of forages cut only once per season over those cut twice was more dramatized at Manhattan than at Hutchinson. At Manhattan, plants subjected to the former management scheme yielded 4.48 tons/acre more dry matter than those subjected to the latter.

The data indicate that even within a given cutting management, increasing the harvesting frequency depressed dry matter accumulation. For example, when the grasses were cut four times during the season (Manhattan), they produced 4.92 tons/acre as opposed to 5.13 tons/acre under a three-cut system (Hutchinson).

Plants depend on carbohydrates stored in their stems and/or roots for the initiation of growth after cutting or for winter-hardiness. Frequent harvesting reduces the total carbohydrate reserves of plants, the degree of reduction depending greatly on the origin of growth primordia. Harvesting removes a large percentage of the active primary meristems. Grasses have basal nodes below or near the soil surface from which tillers develop. Therefore, after clipping, these forage species begin to replenish their food reserves quickly because of these basal leaves which are not removed. Rate of regrowth and survival of grasses after cutting depends largely on the ability to produce tillers. Since frequent harvesting removes most of the active photosynthetic leaf area and depletes the total storage carbohydrate reserves, the dry matter yield of forages decreases as the cutting intervals are shortened, hence the yield relationships mentioned earlier among the pasture, boot and soft-dough stages of maturity.

However, the degree of response to cutting frequencies varies with cultivars or hybrids within cultivars, depending on tillering ability and consequently the ability to tolerate frequent clipping (2,41,68,93,96). The ability of a grass to tiller after removal of apical meristems is influenced by genotype and environmental factors such as ridging and shading, with some varieties being influenced more by environment than others (68). Differences in tillering therefore account for many of the yield relationships and adaptations of grasses. As will be shown subsequently, adapted summer annual grasses with high tillering abilities and fast recovery after clipping produced the highest dry matter yields under multiple harvest schemes. Grasses producing less tillers were more susceptible to frequent cutting and consequently produced less dry matter.

As shown in this study and supported by many experiments, especially (2,18,96), Forage Sorghum produced the lowest dry matter yields under pasture management. However, the response of this grass was less consistent than has been reported when harvested for hay. It has been generally shown that under hay management, the forage yield of this plant exceeds that of sudangrass, but less than that of the sorghum X sudangrass hybrids (2,96); but in the present study, this response was true only under high moisture conditions. Under drier climatic conditions during the months in which hay harvest was made, the yield of Forage Sorghum was found to be inferior to those of other grasses (Manhattan data). This was a good example of the tremendous influence of environmental conditions on forage production and adaptation.

Silage-dry matter production of Forage Sorghum was in agreement with published results. When harvested at the soft-dough stage, Forage Sorghum significantly outyielded the sudangrass varieties. However, at Manhattan, the yield of Forage Sorghum was inferior to that of Millex at the dough stage. This was probably due to drier environmental conditions to which Forage Sorghum appeared more susceptible than the other grasses considered in this study.

Piper Sudangrass and the hybrid, 'Trudan 6' were very similar in dry matter production at both the pasture and hay stages. However, when harvested for silage, Trudan yielded more dry matter than Piper, though not significantly. The data also indicate that the sudangrasses were generally inferior to the other cultivars in silage production. The hay-stage dry matter yields of the sudangrass varieties were significantly inferior to those of Forage Sorghum and the sorghumsudangrass hybrids, as was reported by Worker and Marble (96) and of Millex, as shown by other investigators (2,16).

This was, however, not true at Hutchinson, where the forage production of Millex was lower, but not significantly, than those of the sudangrass varieties. This was probably due to the greater tolerance of the latter to limited moisture supplies and low temperatures. The precipitation and temperature records (Table 1) reveal that the months preceding and during the early growth of grasses were drier and cooler at Hutchinson than corresponding months at Manhattan. These climatic conditions probably caused Millex to get off to a slow start, and ultimately affected its boot-stage dry matter yield. On the contrary, under the wetter and warmer Manhattan conditions, the herbage production of Millex was significantly higher than those of the sudangrasses throughout the three growth stages.

It appears, therefore, that under adequate moisture conditions and warmer temperatures, Millex is a better dry matter-yielding forage than the sudangrass cultivars under the three management stages. The findings of researchers at the United States Department of Agriculture (2) confirmed the conclusions reached above. They emphasized that Pearl Millet is less tolerant to lower temperatures and limited moisture supplies than Piper Sudangrass.

Much has been written about the causes of low forage yields of sudangrass at the hay or silage stage of maturity. Greater susceptibility to leaf diseases than Millex and sorghumsudan hybrids has been cited as the chief cause (2,10,12). However, in the research now being reported, there were no visual indications of damage caused by leaf diseases. Therefore, the lower dry matter production of these grasses at the flag-leaf and silage stages was probably due to factors other than noted above.

It should be remembered that tiller production is governed by apical dominance (41). Therefore, the rapid recovery and production of leaves after close grazing or intense clipping seems to indicate that a good proportion of the tissue growth of sudangrass originates from tillers. These tillers can easily be overshaded by neighboring plants. For example, Holt and Alston (41), in reference to work done by Shen and Harrison, reported that reduced light delayed the tillering process in sudangrass. Furthermore, they remarked that where plants were excessively shaded by neighboring grasses, tillers usually stopped growing. That such a stoppage in tiller production can reduce the total herbage production of affected species cannot be overemphasized.

Thus where reduction in forage production due to shading interacts with that due to leaf damage, total dry matter yields of sudangrass can be much more severely depressed. Depending on the extent of damage caused by either or both of these factors, silage-dry matter production of sudangrass varieties could even fall below that at the boot stage. The reasoning behind this is that since grasses grown for silage remain longest in the field, continued insect infestation and/or increased shading could depress yield as described above. Thus, the decline in dry matter yield of Piper and Trudan at the soft-dough stage at Hutchinson was probably due to shading. However, no acceptable explanations could be found for that in Sudax.

Commercially available Sorghumsudan hybrids have a characteristically high-yielding potential. The data in this study show that these grasses also recovered fast after cutting, so that their total dry matter production under frequent cutting was, in general, very similar to those of the sudangrass varieties and Millex. However, evidence contradicting this high-yielding potential of sorghumsudans at all growth stages have been reported. For example, Wedin (92) and Worker (95) indicated that Sudangrass was superior to Sudansorghum hybrids when the forages were managed for pasture production. Under hay and silage managements, the Sorghumsudans were generally either equal or superior to the other forages considered in the study. This yield relationship of Sudax and Super Chow Maker to the other sorghum types has been investigated, and excellent reports such as (2,16,46,96) have been published, all of which are in agreement with the present findings.

Important morphological and physiological differences exist among summer annuals. As has been emphasized elsewhere, these differences exist not only between cultivars, but also between hybrids within cultivars. A good example is the yield relationship between the Sorghumsudan hybrids--Sudax and Super Chow Maker. The results of this experiment appeared to favor Super Chow Maker as the choice for silage production (because of higher dry matter yield), but that neither grass was truly better than the other for pasture and hay production.

In the preceding chapter, it was pointed out that as the number of uniform cuttings increased, there was a general reduction in dry matter yield. It was further stressed that these reductions were more severe at the boot stage than at the pasture stage. These findings agreed with those of Holt and Alston (41), who demonstrated a sharp reduction in total carbohydrate reserves in sudangrass hybrids following clipping at all stages and heights. However, the different growth stages differed in the pattern of carbohydrate loss and recovery.

In vegetative plants, restorage of carbohydrates started shortly after clipping because of rapid regrowth coming mainly from apical meristems. However, under frequent harvesting practices, only partial restorage was attained between cuttings. Thus, as found also in other investigations (25,28), frequent cutting reduced the reserved carbohydrates of plants and thereby curtailed stand vigor. Consequently, the dry matter yields decreased in successive cuttings.

Holt and Alston (41) also found that as plants advanced towards maturity, the carbohydrate contents of their lower portions increased, prior to initial harvest. Therefore, the reduction of reserved foods was more severe in older plants than those in the vegetative stage. Furthermore, they showed that boot-stage plants were very slow in replenishing their carbohydrate reserves after clipping, since regrowth was mainly from the slower-growing basal buds. It was this slow carbohydrate restorage characteristic that caused successive boot-stage cuttings to produce less dry matter than those obtained in previous cuttings. It was also observed in the present research that some of the stubbles of boot-stage grasses dried after the first cutting. This was probably due to the slow restorage of stored foods, and definitely led to reduced dry matter yields.

Quality Components

It has been discussed earlier that harvesting forages at advanced stages of maturity enhanced yields of dry matter, but at the expense of high quality. In the present study, three quality components--*in vitro* dry matter digestibility, crude protein and fiber were evaluated as plants progressed through the vegetative, boot and soft-dough stages of growth.

The results of this experiment are in good agreement with those reported in the literature regarding changes in forage quality with advancing maturity. *In vitro* digestible dry matter content declined because of the increase in lignin and its protective encrustation on cell wall constituents. The increasing values of acid-detergent fiber indicated the positive relationship between forage indigestibility and advancing maturity. Crude protein percentages declined much more rapidly than those of IVDDM and ADF. This greater sensitivity of protein to progression in maturity is due mainly to the diluting effects of corresponding increases in carbohydrates (54).

Similar to agronomic traits, the extent to which these quality changes occurred varied with cultivars. Therefore, it is important to examine the responses of individual forages to the effects of maturity and cutting frequencies on nutrient composition.

In Vitro Dry Matter Digestibility

The study indicated that under pasture and hay managements, the percent dry matter digestibility of Forage Sorghum was generally inferior to those of the other five grasses. Forage Sorghum is thick-culmed and has a poor tillering ability. Therefore, under frequent harvesting practices a larger proportion of the plant consists of stems rather than leaves. Consequently, its digestibility is much lower than the other grasses. Therefore, on the basis of its dry matter digestibility, Forage Sorghum is a poor crop for pasture or hay production.

However, the suitability of this plant for silage production becomes very evident partly because of its high dry matter digestibility. As indicated by the Hutchinson data, the dough-stage digestibility of Forage Sorghum may even exceed that at the boot stage. This increase in dry matter digestibility is related to the high grain-producing ability of this grass, as explained by Worker (96).

Grain production from a random sample of two plots of each of the six forages indicated that Forage Sorghum was a superior grain-yielder. Grains from the middle two rows of each plot were dried, threshed and weighed. The results, in pounds, were: Piper, 1.15; Trudan, 1.45; Super Chow Maker, 1.75; Sudax, 2.60; Millex, 1.10; and Forage Sorghum, 6.80.

Because of the significant impact of grain on improving the overall digestibility of a forage, one may be led to believe that Forage Sorghum should always be significantly more digestible at the soft-dough stage than the other forages. However, one must be reminded of the extreme stemminess of this grass. Therefore, depending on the degree to which the increase in highly digestible grains offsets the effects of lignification, Forage Sorghum may or may not be significantly more digestible than the other cultivars (see Table 11).

The IVDDM of Piper and Trudan were statistically similar throughout all growth stages. However, if a forage that is nearer to a highly digestible grass like Millex is desired, then the choice should be Trudan hybrid sudangrass. The work reported by Faix _et al_. (30) contradicts the conclusion just made between the dry matter digestibilities of Piper and Trudan. In that investigation, it was found that Piper sudangrass significantly exceeded Millex in _in vitro_ dry matter disappearance under grazing conditions. The present conclusion also disagreed with Wedin's work (93), in which Piper and Trudan were found to be less digestible under all growth stages, than the Sudangrass X Sorghum hybrids.

In pre-dough maturity stages, the data in this study appear to indicate that Super Chow Maker was higher than Sudax in digestibility, although not significantly. The hybrids were related to Millex in digestibility at all maturity stages in the same way as were the Sudangrass varieties.

In discussing the dry matter digestibilities of the six summer annuals, much reference has been made to Millex, as if it were the standard forage. This was done to underscore the fact that of the six plants studied, Millex was generally higher in digestibility in pre-silage maturity stages than the other cultivars (Hutchinson data). At Manhattan, Millex was generally similar to the other grasses, although its dry matter digestibility was about 1 to 2 percentage units higher.

Crude Protein

Under the pasture management, Piper, Trudan, Super Chow Maker and Sudax were similar in crude protein content and generally tended to be statistically equal to or less in this trait than Forage Sorghum and Millex. Not much work has been done to compare all six of these forages in one study. However, evidence supporting the above conclusion has been published. In evaluating changes in composition of Sudangrass and Forage Sorghum with maturity, Farhoomand and Wedin (31) showed that under the pasture system of management, Forage Sorghum was significantly superior to Piper. Under the same management scheme, Clark *et al*. (16) reported that Millex contained significantly more crude protein than Piper. While evaluating yield and quality components of several types of sorghums, Wedin (93) concluded that there were no significant differences among the sudangrass varieties and Sudansorghum hybrids in crude protein content.

As regards percentages of crude protein at the flag-leaf stage, the data indicated that Millex was significantly superior to the rest of the remaining grasses. However, Forage Sorghum, which was very high in this component at the vegetative stage, dropped significantly to the extent that it was generally the most inferior among the five cultivars just described. This decline was probably due to the great disparity between stalks and leaves as this grass matures, although Farhoomand and Wedin (31) reported to the contrary. They found that with advancing maturity, Piper Sudangrass dropped more drastically in crude protein content than Forage Sorghum. Their conclusion might not be contested where there is an outbreak of leaf diseases, which reduce both forage yield and quality.

At the boot stage, Piper, Trudan, Sudax and Super Chow Maker were generally similar in crude protein content. There was a considerable fluctuation in the crude protein contents of these forages between the two experimental sites. But from an average-effect standpoint, there is validity to the conclusion stated above, which is contrary to the findings of Koller and Scholl (47), but in conformity with those of Wedin (93). The former workers stated that under hay management, Piper was higher in protein than Sudax, while the latter showed that under the two-cut management, there was no significant differences among Piper, Trudan and Sudax.

Under the single harvest system, Piper Sudangrass was highest in crude protein content. The other five forages were more sensitive to location variations, as was indicated by fluctuations in their protein contents. Piper's ability to produce silage of high protein content was also reported by Wedin (93), who said that Piper was significantly higher in crude protein than Sudax and other sorghumsudan hybrids.

Fiber

At the vegetative and boot stages, the cultivars were statistically similar in acid-detergent fiber. However, if a forage with lower fiber concentration at these stages is to be singled out, then the choice would be Millex. The same remarks can be made about the six grasses at the soft-dough stage, except that it was Forage Sorghum that tended to be lower in this component. As indicated in the Hutchinson data, the fiber content of Forage Sorghum at the boot stage exceeded that at the soft-dough stage. The rapid increase in highly digestible grains and the resulting dilution of the effect of lignification of stalks and leaves can be identified as the cause of the decline in fiber concentration.

Crude Protein and IVDDM Yields

Frequent harvesting practices (e.g., 3 and 4 cuts) produced forage materials of very high digestibility, but at the expense of dry matter yield. Therefore, the acre yield of IVDDM of such cutting frequencies was depressed. As the frequency of harvesting decreased, IVDDM yields increased and were maximized at the soft-dough stage. On the other hand, the yield of crude protein increased gradually, but was maximized at the boot stage, after which it dropped drastically (Hutchinson data).

These yield (yield = % X dry matter yield) relationships can be explained as follows. At Hutchinson, the increase in dry matter yield between the boot and soft-dough stages of maturity was less than that between the pasture and boot stages. Considering the precipitous drop in crude protein with advancing maturity, it is easy to see why the acre yield of crude protein at the soft-dough stage was so low, almost half as large as at the pasture stage. However at Manhattan, because of the changes in dry matter yields between the pasture and boot stages and between the boot and soft-dough stages, there was a gradual increase in crude protein yield from the pasture to the soft-dough maturity stages.

With respect to cultivar rankings in crude protein yields, it was observed that in general, cultivars higher in crude protein percentages were lower in protein yields. It should be understood that high percent crude protein is indicative of low dry matter yields. Therefore, on dry matter basis, the higher the percent crude protein in a forage, the lower its acre yield in protein will be. On the other hand, cultivars high in IVDDM contents were also high in IVDDM yields. Since IVDDM estimates the digestible portion of the carbohydrates in forages, and since the dry matter yields of forages increase with advancing maturity, the yield of the digestible dry matter will generally increase with progressing maturity. It should be remembered that the decrease in percent digestible dry matter between growth stages was not as drastic as that in percent crude protein.

CHAPTER VII

SUMMARY AND CONCLUSION

The overall objective of this investigation was to determine the yield and quality implications associated with harvesting summer annual forages at the vegetative, boot and soft-dough stages of maturity. The results clearly demonstrate the lower yield and higher quality of early-cut forages compared to those harvested later. However, it appears that the main cause of reluctance on the part of farmers to harvest forages early is the smaller amount of dry matter yields obtained. Nevertheless, the results of this work indicate that both forage yield and quality are important and emphasize the need to advise forage producers that dry matter yield *per se* is a poor index of productiveness. The goal of management should be to achieve the best compromise between yield and quality, for a given livestock operation.

Thus in forage management and utilization, careful attention must be paid to the changes in dry matter and chemical composition associated with advancing maturity. For example, in this work it was observed that as cutting frequencies decreased and the grasses increased in height,

1. crude protein contents dropped sharply,
2. *in vitro* dry matter digestibility percentages decreased gradually,
3. percent acid-detergent fiber increased slowly,

4. dry matter yields and other agronomic characteristics increased rapidly.

Judicious management of forage plants for a given livestock operation requires adequate understanding of such yield and quality changes as plants approach physiological maturity. It is only after then that the desirability of harvesting at recommended stages of growth can be appreciated.

Unfortunately, however, many previous studies designed for determining the "proper" stage of maturity to harvest summer annuals used herbage production as the sole criterion for determining the suitable uses of these grasses. Other investigators stressed quality as the variable of importance, while only a few made management recommendations based on critical evaluations of forage yield and quality. It must be emphasized that only the last category of these research objectives provides a sound basis for forage evaluation, and is the criterion that was adopted in this experiment. Based on a joint consideration of dry matter yield and digestible dry matter yield, the forages were grouped within stages of maturity as follows:

	VEGETATIVE	BOOT	SOFT-DOUGH
1.	Millex	Super Chow Maker	Forage Sorghum
2.	Trudan 6	Sudax	Sudax
3.	Piper	Millex	Super Chow Maker
4.	Super Chow Maker		Millex
5.	Sudax		

Within each category, there was no significant difference among the forages listed ($P < .05$). Forages not listed within a given cutting management were generally significantly inferior.

It has generally been accepted in the past that the sorghumsudan hybrids are poor for pasture production, primarily because of low energy content and fear of complications due to prussic acid poisoning. With respect to energy content, this study disputes previous claims, because these forages contained high percentages of digestible dry matter under the three- and four-cut systems (Tables 5 and 11). Furthermore, the dry matter yields and crude protein contents of Super Chow Maker and Sudax were generally statistically similar to those of the other forage plants frequently recommended for pasture production (Tables 4, 6, 10, 12). However, the sorghumsudan hybrids are very stemmy and therefore could hinder effective animal utilization under grazing management.

Several previous experiments have recommended the use of Piper sudangrass and Trudan hybrid sudangrass for hay production, arguing that these forages are leafy and consequently would produce hay with high dry matter digestibility and crude protein content. The results of this work strongly support this viewpoint. However, since decisions for utilizing forages should be based on a joint consideration of yield and nutritional attributes, in this study the sorghumsudans and pearl millet were superior to the sudangrass cultivars because of their higher yields and higher digestible dry matter yields.

At the soft dough stage, Piper and Trudan were generally inferior to the other forages in dry matter yield and digestible dry matter yield.

Thus harvesting them at this growth stage for silage production may be undesirable.

Finally, it must be emphasized that as the cost and preparation of grains increase in the future, more and more attention will be focused on the utilization of forages for livestock production. As a result, the need to efficiently manage these crops, in light of their yield and quality components, will become more and more recognized. For example, in this work, handling of the six representative cultivars of the *Sorghum* and *Pennisetum* genera failed to show any of the entries to be truly outstanding with respect to all the variables considered, i.e., dry matter yield, crude protein percentage and yield, *in vitro* dry matter digestibility percentage and yield, and percent acid-detergent fiber, at all growth stages. It is probable that if only quality or yield characteristics alone had been used as the basis for evaluation, different conclusions would have been drawn, when ranking the forages within growth stages.

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APPENDIX

Appendix Table 1. Silage Yields (Tons/Acre at 60% H_2O) of Six Summer Annuals When Harvested at Three Growth Stages Hutchinson

Variety	Grazing				Boot			Soft-Dough
	C_1	C_2	C_3	Total	C_1	C_2	Total	
Piper	5.31*[b]	4.21	4.98[ab]	14.50[ab]	13.10[c]	9.09	22.19[c]	15.46[d]
Trudan	5.43[b]	5.06	5.88[a]	16.36[a]	14.43[c]	9.17	23.60[c]	23.07[c]
S. C. Maker	5.83[ab]	4.90	5.93[a]	16.66[a]	16.02[bc]	12.65	28.67[b]	44.73[a]
Sudax	6.86[a]	4.14	5.72[a]	16.72[a]	19.20[b]	16.12	35.32[a]	30.98[b]
Millex	2.18[d]	5.19	5.21[ab]	12.58[b]	15.30[c]	4.71	20.01[c]	23.94[c]
F. Sorghum	3.28[c]	4.63	3.23[b]	11.38[b]	28.40	–	28.40[b]	34.22[b]
$LSD_{.05}$	1.05	ns	2.05	3.68	3.65	2.46	3.68	3.68
$\overline{X}$	4.82	4.69	5.16	14.66[c]	17.74	10.35	26.37[b]	28.26[a]

* Means within a column followed by the same letter or letters are not significantly different at the 0.05 level, according to the Waller-Duncan multiple comparison test.

Appendix Table 2. Extended Height Measurements of Six Summer Annuals When Harvested at Three Growth Stages Hutchinson

Variety	Grazing				Boot			Soft-Dough
	C_1	C_2	C_3	$\overline{X}$	C_1	C_2	$\overline{X}$	
Piper	107.75*[a]	96.75[b]	138.75[bc]	114.42[a]	155.00[cd]	153.75[b]	154.38[c]	186.50[de]
Trudan	107.50[a]	85.25[cd]	145.50[bc]	112.75[a]	148.50[d]	140.00[b]	144.25[c]	192.50[cd]
S. C. Maker	105.75[ab]	109.75[a]	163.00[a]	126.17[a]	175.50[b]	183.00[a]	179.25[b]	237.75[b]
Sudax	102.50[ab]	91.50[bc]	151.50[ab]	115.17[a]	141.25[d]	173.25[a]	157.25[c]	201.25[c]
Millex	97.50[b]	80.25[d]	118.00[d]	85.08[b]	167.00[bc]	91.75[c]	129.38[d]	172.25[e]
F. Sorghum	57.00[c]	116.00[a]	135.25[c]	114.67[a]	259.75[a]	---	259.75[a]	270.00[a]
$LSD_{.05}$	13.06	8.47	13.69	14.30	14.91	16.89	14.30	14.30
$\overline{X}$	96.33	96.58	142.00	111.38[c]	174.50	148.35	170.71[b]	210.04[a]

* Means within a column followed by the same letter or letters are not significantly different at the 0.05 level, according to the Waller-Duncan multiple comparison test.

Appendix Table 3. Silage Yields (Tons/Acre at 60% H_2O) of Six Summer Annuals When Harvested at Three Growth Stages
Manhattan

Variety	Grazing					Boot			Soft-Dough
	C_1	C_2	C_3	C_4	Total	C_1	C_2	Total	
Piper	3.83^{*bc}	4.29^{ab}	4.17^{ab}	2.66^{a}	14.29^{a}	8.95^{a}	9.72	18.67^{ab}	21.66^{d}
Trudan	3.47^{bc}	4.47^{a}	4.21^{ab}	1.88^{ab}	14.02^{a}	10.55^{a}	7.49	18.04^{b}	24.01^{cd}
S. C. Maker	5.12^{b}	3.25^{bc}	5.14^{a}	1.55^{b}	14.67^{a}	12.66^{a}	10.75	23.41^{a}	47.33^{a}
Sudax	4.82^{b}	3.49^{abc}	5.08^{a}	2.14^{ab}	15.54^{a}	12.86^{a}	6.75	19.60^{ab}	26.02^{c}
Millex	7.05^{a}	3.38^{abc}	4.91^{a}	2.13^{ab}	17.46^{a}	11.94^{a}	9.30	21.24^{ab}	38.21^{b}
F. Sorghum	2.70^{c}	2.52^{c}	2.73^{b}	1.48^{b}	8.38^{b}	10.25^{a}	--	10.25^{c}	34.77^{b}
$LSD_{.05}$	1.82	1.12	1.92	1.07	4.80	4.38	ns	4.80	4.80
$\bar{X}$	4.50	3.57	4.37	1.97	14.06^{c}	11.20	8.80	19.20^{b}	32.00^{a}

* Means within a column followed by the same letter or letters are not significantly different at the 0.05 level, according to the Waller-Duncan multiple comparison test.

Appendix Table 4. Extended Height Measurements of Six Summer Annuals When Harvested at Three Growth Stages
Manhattan

Variety	Grazing					Boot			Soft-Dough
	C_1	C_2	C_3	C_4	$\overline{X}$	C_1	C_2	$\overline{X}$	
Piper	77.50*[ab]	98.50[a]	145.50[a]	104.00	106.40	137.75[a]	182.50[a]	160.13[a]	181.00[c]
Trudan	74.75[b]	98.25[a]	138.75[a]	90.25	100.50	139.50[a]	170.75[a]	155.13[a]	186.25[c]
S. C. Maker	89.00[ab]	94.50[a]	153.75[a]	86.67	106.88	133.75[a]	188.75[a]	161.25[a]	226.25[ab]
Sudax	87.75[ab]	92.75[ab]	136.00[a]	87.25	100.93	122.25[b]	153.00[ab]	137.63[bc]	184.25[c]
Millex	95.00[a]	78.00[b]	136.25[a]	93.00	100.56	107.25[b]	141.00[b]	124.13[c]	220.25[ab]
F. Sorghum	84.25[ab]	90.75[ab]	129.67[b]	88.00	95.31	149.00[a]	--	153.13[ab]	242.75[a]
$LSD_{.05}$	19.34	16.27	20.31	ns	ns	25.72	36.48	19.14	19.14
$\overline{X}$	84.71	92.13	139.99	91.53	101.76[c]	131.58	167.20	148.56[b]	206.79[a]

* Means within a column followed by the same letter or letters are not significantly different at the 0.05 level, according to the Waller-Duncan multiple comparison test.

Appendix Tsble 5a. Anslysis of Variance for Hutchinson Data

		% Dry Matter		Dry Matter Yield		Probability > F	
Source	DF	MS	F	MS	F	% DM	DM Yield
Replicates	3	21.321	2.17	7.752	6.06	0.1016	0.0014
Varieties	5	66.521	6.77	37.325	29.17	0.0001	0.0001
Stages	2	1146.797	116.69	167.893	131.19	0.0001	0.0001
Var * Stages	10	27.533	2.80	15.976	12.48	0.0076	0.0001
ERROR	51	0.026	–	–	–		

Appendix Table 5b. Analysis of Variance for Hutchinson Data

		% *In Vitro* Digestible Dry Matter		% Crude Protein		% Acid-Detergent Fiber		Probability > F		
Source	DF	MS	F	MS	F	MS	F	% IVDDM	% CP	% ADF
Replicatea	3	0.012	0.39	0.004	0.28	0.025	0.96	0.7648	0.8403	0.3924
Varieties	5	0.323	11.61	0.045	3.11	0.044	1.71	0.0001	0.0158	0.1590
Stages	2	9.778	351.61	5.944	410.76	1.477	57.49	0.0001	0.0001	0.0001
Var * Stages	10	0.237	8.54	0.078	5.41	0.049	1.92	0.0001	0.0001	0.0769
ERROR	51	-	-	-	-	-	-			

Appendix Table 6a. Analysis of Variance for Manhattan Data

		% Dry Matter		Dry Matter Yield		Probability > F	
Source	DF	MS	F	MS	F	% DM	DM Yield
Replicates	3	3.640	0.40	6.292	2.42	0.7572	0.0759
Vsrieties	5	58.090	6.37	26.741	10.27	0.0001	0.0001
Stages	2	1830.000	200.67	250.924	96.39	0.0001	0.0001
Var * Stages	10	17.802	1.95	15.211	5.84	0.0590	0.0001
ERROR	51	9.120	-	-	-		

Appendix Table 6b. Analysis of Variance for Manhattan Data

		% *In Vitro* Digestible Dry Matter		% Crude Protein		% Acid-Detergent Fiber		Probability > F		
Source	DF	MS	F	MS	F	MS	F	% IVDDM	% CP	% ADF
Replicates	3	0.031	0.98	0.016	2.09	0.003	0.12	0.4105	0.1113	0.8848
Varieties	5	0.082	2.60	0.093	12.10	0.110	4.61	0.0356	0.0001	0.0026
Stages	2	414.723	466.06	6.220	814.01	2.187	118.27	0.0001	0.0001	0.0001
Var * Stages	10	0.044	1.39	0.050	6.47	0.059	2.49	0.2100	0.0001	0.0233
ERROR	51	-	-	-	-	-	-			

PART II. COMPARATIVE FEEDING VALUE OF SUMMER ANNUAL GRASS HAYS AND SILAGES FOR LAMBS

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CHAPTER I

INTRODUCTION

As emphasized in Part I, changes in climatic conditions correspondingly change the growth and distribution patterns of forage plants. The importance of year-round forage management was also emphasized. Where this is practiced, forages may be harvested during the lush season and conserved in several forms, two of which are field-cured hay and wilted silage. These harvested feeds can then be used in ruminant rations during the winter or the latter part of the summer, mainly as a source of energy.

The conservation of forages, either as hay or silage, is therefore a means of providing relatively cheap livestock feeds. On all forage-growing farms, producers are confronted with the decision as to which way forage should be conserved. Such a management decision should be based partly on the cost of labor and partly on the relative merits of hay and silage. McCullough (32) and Wellmann (62) have outlined the advantages and disadvantages of silage, and of silage and hay, respectively.

As indicated by McCullough (32), studies in most research fields (including those on silage and hay) were most productive during the first two or three decades of research in that field. During that time span, the overriding principles and the major parameters within which those principles operate were discovered. Therefore, research findings published subsequent to that time served mainly to clarify the early findings, to refine the understanding of factors involved, and consequently to enable the making of more reliable forage-use recommendations.

In research on forage conservation methods, some forages have been more extensively studied than others. One group of forage plants which have not received appropriate attention, despite their importance, are the summer annual grasses. Very little information has been reported on the comparative feeding value of summer annual hays and silages for animal production. With a view of securing more information on this subject, it was hoped that the present study would meaningfully contribute to this very small pool of published data.

To estimate the overall feeding value of various forms of conserved forage, both chemical attributes and voluntary dry matter intake must be determined. As Crampton (11) acknowledged, proximate data may be very informative in estimating the value of forages as stock feeds, but none of the components consistently correlates with significant animal performance criteria. Wilkins *et al*., reporting at the Fifth Silage Conference (10), amplified this point, stating that any investigation was unlikely to accurately predict voluntary intake from simple measures of feed composition, considering all the many factors involved. Similarly, Crampton *et al*. (12) stressed that the voluntary intake of a forage by ruminants is an important basic indicator of feeding value and is particularly useful when combined with other quality attributes, such as digestibility. Many techniques have been proposed for estimating forage digestibility, e.g., (54,55), but similar information is lacking for voluntary feed consumption determinations. Thus the only current method of estimating forage quality by this indicator is through animal-feeding trials.

To pursue the objective outlined above, larger acreages (than discussed in Part I) of three summer annual forages were harvested at the boot stage and stored as sun-cured hay and wilted silage. The plants used were: Northrup King 'Millex 23' hybrid pearl millet (*Pennisetum typhoides* (Burm) Stapf and C. E. Hubb), Northrup King 'Piper' sudangrass (*Sorghum bicolor* (Stapf) and DeKalb 'Sudax SX-11' hybrid sorghumsudan grass. To properly evaluate the success of these storage forms, their acceptability by lambs was studied, with dry matter content and proximate principles as primary variables.

CHAPTER II

LITERATURE REVIEW

Methods of Hay and Silage Preservation

Ensiling and haymaking are only processes of preserving a forage that is taken from the field. Consequently, neither process improves or increases the feeding value of the standing herbage. Thus, an ideally preserved forage has quality equal to that of the standing crop from which it was cut. However, this equality can never be accomplished because of losses during harvesting and preservation processes.

With respect to ensiling crops, the method of preservation greatly determines the value of the resulting feed. Silages can be divided into three categories depending upon the moisture content of the forage when ensiled, namely: high-moisture (direct-cut), in which forage is ensiled immediately after being harvested; wilted silage, where forage is allowed to wilt in the field before being ensiled; and low-moisture silage (haylage) in which the forage is wilted for an extended period of time to drastically lower its moisture content before being put in the silo. The approximate moisture contents of high-moisture, wilted and low-moisture silages at ensilage are greater than 65%, 65-70%, and 50%, respectively (22,43).

Of these methods of crop preservation, direct-cut silage making is clearly the least desirable. It minimizes field losses of dry matter, but is often associated with extreme losses of dry matter due to seepage and the development of undesirable acids (32). Consequently, wilting crops has become a universally accepted on-the-farm practice. The primary intent of wilting is to increase the dry matter content of the forage to be ensiled and thus to concentrate the desirable fermentable carbohydrates and reduce seepage (32).

Nevertheless, the biochemical changes responsible for the marked improvement in silage quality and preservation attained by wilting are not well understood. In an attempt to explain these, Wieringa (63) reported that the osmotic pressure of the forage liquid phase is increased by wilting or adding salt. The increased osmotic pressure favors the development of a desirable fermentation by suppressing the development of butyric acid-forming bacteria.

However, wilting crops to the moisture levels stated above for low-moisture silage may create problems. The material may become so dry that it does not pack well. Thus, if air-tight silos are not used, the ensiled material could easily become too hot and moldy, and its overall feeding value may decrease sharply.

Many researchers such as (6,21,36,43) have concluded that fermenting low-moisture silage in structures that completely exclude oxygen increases the dry matter content of the resulting silage. Such silage is voluntarily consumed to a greater extent than wilted and high-moisture silages. As a result of this increased dry matter consumption, greater weight gains for low-moisture-silage-fed animals than those fed wilted-silage or high-moisture silage have generally been reported.

The extremely high costs of oxygen-limiting structures generally required for ensiling low-moisture silages prohibit their use on many farms. However, research, as well as farm experience, has shown that low-moisture silage can be successfully stored in conventional silos when proper management practices are followed, primarily fine-chopping the forage and eliminating as much oxygen as possible (6,43).

Depending upon weather conditions, preferences of the farmer or researcher and availability of drying equipment, etc., hay may be completely field-cured (6,43) or barn-dried (22,28). In the latter case, the forage is chopped from the windrow at 35-50% moisture and then artificially dried. If done successfully, these two methods of haymaking are approximately equally efficient. For example, in evaluating the influence of heating on nutritive value of alfalfa-bromegrass hay, Yu et al. (64) heated field-cured hay at 90°C for 0, 8, 16, 32, 48 and 56 hours and found that heating did not produce heat damage nor protection of forage protein from rumen microbial degradation. In addition, they reported that voluntary intake, dry matter digestibility and all proximate principles were unaffected ($P < .05$) by heating. Thus, for the purposes of this thesis, the efficiencies of the two haymaking methods will be assumed equal, and comparisons to be made later between wilted silage and hay will be made without identifying the haymaking process involved.

Comparative-Feeding Value of Hay and Silage

Interchangeability of Cattle and Sheep in Feeding Trials

Silages and hays have been compared in many feeding trials. It was stated earlier that the intake level of a forage is of a greater practical significance in determining forage quality than is either its nutrient or useful energy concentration. In trials on assaying fodder intake, the relative feeding value of different forms of a given forage was determined.

There is evidence suggesting that sheep and cattle may be used interchangeably to determine the voluntary intake of roughages. For example, in an investigation concerning factors affecting the intake of roughages by sheep and cattle (39,50), sheep were used either in preliminary studies to provide data for planning subsequent trials with cattle, or used simultaneously with the latter. In either instance, forage rankings based on intake or performance were similar for both types of animals. This finding justifies the inclusion, in this report, of investigations using cattle.

Inconsistencies in Comparative-Feeding Value Trials

As implied above, investigations on evaluating the comparative feeding value of hay and silage have significantly enhanced the management skills of farmers and provided great challenges for continued research. Ironically, however, the results from such studies are often quite inconsistent. These inconsistencies may be caused by the difficulties encountered in controlling and describing quality variations which occur within each class of forage or from differences in the evaluation methods used (22). Variations have been observed in voluntary dry matter consumption, chemical composition of fodder and animal performance.

Voluntary dry matter intake. Cambrum, Gordon, Hillman, and coworkers (7,22,26) reported lower dry matter intake from wilted silage than from hay. Brown *et al*. (4) and workers at Cornell (47) agreed with these findings. However, Dijkstra (15) reported results that were at variance to those cited above, i.e., higher dry matter intake from silage than from hay, while other workers (6,16,28,62) reported mathematically equal intakes.

The effect of supplementary concentrates on the intake of silage and hay was determined by Murdoch (37). In that study, he found that when no concentrates were included in the ration, the dry matter intake of hay was significantly greater than that of silage ($P < .01$). But, when concentrates were added, the difference in intake between hay and silage was smaller and nonsignificant ($P < .01$). Consequently, he concluded that a significant decrease in the dry matter intake of hay and a slight but non-significant increase in silage intake resulted with concentrate supplementation. Campling (8) reported similar results, with cows. He thought that this effect was probably due to a much smaller depression in the rate of disappearance, from the digestive tract, of silage than of hay digesta. To test this hypothesis, he conducted a digestibility trial and found much smaller changes in the digestibility of crude fiber, retention time of food residues and ruminating behavior of cows when concentrates were added to the diet of silage than to that of hay.

Chemical composition. Methods of storage influence the chemical composition of the forage when fed. However, as with dry matter intake, variability in results is striking. For example, Waldo *et al*. (56) reported lower dry matter digestibility for silage than for hay. But while comparing the feeding value of alfalfa hay, wilted silage and low-moisture silage, Byers (6) reported no significant differences in the digestibility of hay and silage. Similar results were obtained by Ekern and Reid (16). Contrary to these findings, Cornell workers (47) published the results from ten comparisons of wilted silage and hay in which they found the dry matter digestibility of the silage to exceed that of hay.

Many reports have been published showing that inconsistencies in forage digestibility resulted mainly from year to year variations (22,38,43). For example, hay and silage were found to be equally digestible (22,38), or silage greater (42) or hay greater (22,38,43).

Unlike the variabilities in dry matter digestibility, there seems to be common agreement on several important forage-quality components. It has generally been found that forage preserved as hay contains lower crude protein, ether extract and ash and higher nitrogen free extract (NFE) contents than that preserved as wilted silage. The differences in NFE and ether extract were explained by Gordon *et al*. (22) to be a conversion of carbohydrates in hay to ether extractable materials, thus lowering the ether extract content and increasing the NFE. Such a conversion occurs to a lesser extent in silages.

Animal performance. Comparative feeding-value experiments have also produced conflicting data on animal performance. For example, in a series of trials, Thomas _et al_. (50) observed greater animal performance with hay than with silage, but in the vast majority of cases performance was equal. In 1963, Kerr _et al_. (28) also reported no significant differences in the daily liveweight gains for bullocks fed hay and for those fed silage. They found that although the hay-fed cows consumed more dry matter than those given silage, the difference in body weight gain was nonsignificant.

But many published works have indicated greater performance on hay than on silage. As examples, Waldo _et al_. (56) reported consistently greater gains by hay-fed animals than did the silage-fed animals. The same result was obtained in another study where the growth rates of heifers fed an all-silage ration was distinctly less than when hay was fed as the only forage, the average weight at two years being 646 and 911 pounds for the silage-fed and hay-fed groups respectively (45). Gordon _et al_. (22) and Roffler _et al_. (43) reported that liveweight gains and milk production were higher on hay than on wilted silage and that cows fed hay gained more body weight than those fed wilted silage, respectively. Wellmann (62) agreed with these findings. He reported lower utilization of nutrients in cattle fed silage than those fed hay, although the silage groups consumed more nutrients in approximately the same amount of dry matter than the corresponding hay groups. The daily gains were 197g and 677g by the hay-fed and silage-fed cattle respectively.

Contrary to these findings, other researchers have obtained better performance from animals fed silage than from those given hay. In 1963, Brown _et al_. (4) found a higher efficiency of dry matter utilization for milk production when cows were fed silage than when fed hay. Stone and co-workers (49) suggested that the superiority of silage over its corresponding hay might be associated with organic acids contained in the silage. These acids might be absorbed directly from the rumen with little or no change and, thus, represent an improved economy over the fermentation in the rumen of the same forage as hay. In addition to ease of organic acid absorption, they also explained the higher productive value of silage than of comparable hay from the standpoint of the distribution of volatile fatty acids (VFA's) in the rumen. In this light, they indicated that a high ratio of propionic or butyric acid, or both to acetic acid in the rumen might result from the ingestion of silage, and consequently represents a higher energy efficiency for fattening. Other investigators (16) observed equal or greater efficiency of energy utilization for silage-fed cattle than those hay-fed.

Causes of Variation in Fodder Intake

As shown above, the question of whether the consumption of dry matter is greater for hay or silage has not yet been resolved. Several attempts have been made to explain what factor(s) present in silage has a depressing effect on appetite of animals. While investigating some of these factors, Hillman *et al*. (25) soaked hay in water to increase its moisture content equivalent to silage and neutralized the silage with NaOH to adjust its pH equal to that of hay. They found no differences in dry matter intake after these treatments.

Later, Thomas *et al*. (51) found that dry matter intake of heifers was also not appreciably affected by adding water to hay or drying silage to equal the dry matter content of hay. Therefore, they concluded that factors limiting the appetite of animals for silage are not water or pH *per se*.

The reduced feed intake when silage is fed cannot be so much the result of lack of capacity of animals to consume enough silage to meet their requirements. If capacity were the factor limiting adequate intake of silages, a more severe limitation would definitely occur when animals are on pasture or when fed freshly clipped material. Thus, Crampton (11) observed that the differences in roughage consumption probably are related to rate of digestion of a feed which in turn is inhibited by anything that depresses microbial activity. Depression of microbial activity retards rumenal motility, and hence reduces the frequency of appetite recurrence. The more quickly the ingested meal moves out of the gastrointestinal tract, the sooner hunger recurs and therefore, more food is consumed over a given period of time. Thus Crampton (11) concluded that the extent of voluntary consumption of a forage (i.e. its apparent acceptability) is limited primarily by its rate of digestion, rather than by nutrients contained, or the completeness of their utilization.

Waldo *et al*. (56) reasoned that the reduced intake of silage is possibly due to changes in the form of nitrogen or energy occurring during silage fermentation in the rumen. During this process, the nitrogen becomes more readily available for microbial protein synthesis and energy becomes less useful for microbial growth. Such changes obviously retard microbial activity and result in a slower removal from the rumen of the material causing the reduction. Thus Demarquilly and Jarrige (13) conjectured that the slower rate of passage of silage residues than of hay residues is more the consequence rather than the cause of low intake. However, work has been reported showing that alfalfa-silage residues disappear as rapidly from the reticulo-rumen as those of hay (47). This finding indicates that there is no difference in the voluntary intake of dry matter as hay or silage.

Effect of Oven-Drying on the Chemical Composition of Hay and Silage

It has been shown that the digestibility of efficiently conserved forages does not appreciably differ from that of the standing herbage from which they were cut (23,45,61). It has been reported further that heating does not alter the dry matter digestibility and proximate constituents of hays (64). Therefore, part of the variation that occurs in dry matter digestibility of hays and silages obtained from the same crops at the same time is probably due to the losses of silage dry matter that are associated with oven-drying.

The extent to which these losses occur depends upon the proportion of volatile constituents present and the drying temperature (23). In any case, however, there will always be some losses of volatiles; and since these represent dry matter losses, oven-drying silage underestimates the true dry matter content of the silage.

In this study, as in most investigations, quality determinations are expressed on a dry-matter basis. As mentioned above, this practice unfortunately leads to loss of volatile constituents and underestimation of the true dry matter digestibility of silages. Therefore, for accurate comparison of the relative efficiency of hay and silage for animal performance, this bias in dry matter determination must be avoided, as has been proposed by (14,58).

Correlation of Dry Matter Content and Quality Components with Voluntary Intake

Chemical composition, dry matter content and dry matter digestibility are important factors influencing silage and hay dry matter intake. Of these, dry matter content has been found to be most highly correlated with dry matter consumption. As examples, Ward et al. (60) reported a correlation coefficient of 0.95 between average silage dry matter content and silage dry matter intake. Thomas et al. (51) showed that variation in dry matter percent accounted for 62% of the variation in silage intake by heifers, while Owen (42) reported an almost perfect correlation ($r = 0.98$) between dry matter content and consumption. Because of these high correlations between dry matter content and consumption, wilted silage has become much preferred to high-moisture silage (60).

With respect to quality attributes, it has been suggested that dry matter digestibility is an important determinant of the ad libitum intake of hay by sheep (2), but that this relationship may not be applicable to silage (2,23,31,36,41). Nilsson et al. (41) suggested that the failure of this relationship to hold may be a reflection of the complex nature of silage fermentation.

In order to produce desirable silage, lactic acid must be produced rapidly, so that the silage pH drops low enough at 4 days to sterilize the silage and prevent further bacterial degradation of carbohydrates (44).

But Nilsson et al. (41) found that the optimum temperature of 80 - 100°F required for lactic acid-producing bacteria is also optimum for the bacteria which produce volatile acids and break down proteins into simple nitrogenous compounds. They further explained that the disintegrated proteins raise the silage pH and thus protract the fermentation at the expense of lactic acid already produced, unfermented protein and possibly the structural carbohydrates. These undesirable changes occur to a greater extent in high-moisture silage than in wilted or low-moisture silage (58).

The rapid production of volatile organic acids, especially acetic and propionic acids, is detrimental to silage dry matter consumption (31). The reduction in silage intake may be associated with the chemostatic regulation of appetite by these acids. Therefore, the usually positive correlation of intake with digestibility may be reversed if high dry matter digestibility is at the same time associated with factors which limit intake. For example, Harris and Raymond (23) fed two silages of differing digestibilities and reported an r value of -0.68 between silage intake and digestibility. McCullough (31) also found a similar negative correlation between silage dry matter digestibility and intake. These findings indicate that Moore and Thomas (36) were correct in their conjecture that the factor from fermentation that influences silage dry matter intake may be of nitrogenous origin. To determine if this were true, McCullough (31) studied the factors associated with silage fermentation and dry matter intake and observed that crude protein, and not crude fiber, was the factor most positively associated with silage-dry matter intake.

CHAPTER III

MATERIALS AND METHODS

Field Procedures

Forage Production, Harvesting and Processing

The three grasses utilized in this research were grown using similar agronomic practices prior to harvesting and during the same period as were reported in Part I. However, only the Manhattan location was utilized because of its close proximity to forage processing and storage equipment and to the experimental animals. To maintain uniformity of soil conditions, the forages were planted immediately adjacent to the plots described in Part I, and the plants were harvested at the boot stage of maturity. At this growth stage, one half of the acreage allotted to each grass was harvested for hay and the other half for silage.

As mentioned in Part I, the boot stage of growth was suggested to be optimum for hay production and soft-dough for silage. Furthermore, it was concluded that based on considerations of dry matter yield and quality components, sudangrass is a poor hay or silage crop. However, since these feeds were intended for growing animal rations, where forage quality may be of greater importance than yield, it was decided to harvest all three grasses at the boot stage.

The silages were cut with a Hesston swather and wilted in the field for 48 hours to reduce the moisture content to about 65-70%. The wilted material was then forced through a 2-inch recutter screen (5 cm), and the processed forage was packed in a loading wagon and blown into 10 x 50 ft. concrete stave silos, without the aid of preservatives.

The hays were simultaneously harvested, crimped and windrowed. The material was then field-cured for 72 hours before being baled into conventional rectangular bales. The bales were safely stored in the barn and were coarsely chopped (6 cm) before feeding. The weather conditions during the hay making and ensiling periods were mainly fine and sunny, minimizing field dry matter losses.

The first cutting of each grass for hay and silage was done on July 22 and the second on August 26. The earlier-cut silages were ensiled on July 24 and latter on August 26. Thus, the hays and silages not only came from the same plants, but were cut and conserved at the same time.

Immediately before the trial began, each silage was transferred from its silo into barrels containing plastic sacks. The hays were chopped and similarly transferred. The sacks were properly sealed to exclude air and/or adverse weather conditions. Each barrel was appropriately labelled and trucked to the site of the feeding trial.

Animal Feeding Trial

Fifty-four crossbred western-white faced lambs (native to Texas) averaging about twenty-five kilograms were used as the assay animals in this trial. The lambs were housed in a semi-enclosed barn. Since the winter of 1977 was one of the coldest in the history of Kansas, it was found necessary to protect the animals against draft. This was accomplished with the aid of thick plastic sheets which were appropriately cut and placed. Each pen contained a wooden feed bunk and an automatic waterer. The waterers were equipped with well-regulated heaters to prevent freezing or over-heating of drinking water. Thus, the animals had access to clean and thermostatically drinkable water during the entire experiment.

Since their previous diet was not known, it was necessary to adjust the lambs to the hays and silages during a preliminary period, i.e., the time interval allowed for <u>ad libitum</u> consumption for animals to become reasonably stable before commencement of actual measurements. The importance of this period and its influence on voluntary intake is well known (19,25). Familiarity and habit may influence the time required for animals to adapt to a given forage, because livestock are often slow in accepting feeds that are new to them. After some thorough investigations, Heaney and Pigden (25) recommended that when measuring voluntary intake for forage evaluation purposes, a two-week preliminary period to adjust the daily forage offered to the appetite of the animal for that forage would normally be long enough to avoid errors in consumption caused by previous experience.

In this study, the preliminary period was two weeks long. During this time, lambs were fed forage sorghum silage at the standard rate of 1 3/4 of body weight (DM basis). Such a feeding regime would meet maintenance requirements and still allow for some degree of growth.

None of the test forages was used during this period so as not to bias the experimental results.

At the beginning of the experiment the lambs were randomly allotted to the six rations: (1) Pearl Millet hay, (2) Pearl Millet silage, (3) Sudangrass hay, (4) Sudangrass silage, (5) Sorghum-sudangrass hay and (6) Sorghum-sudangrass silage. Randomization of lambs was restricted so that animals could be divided as uniformly as possible into groups by placing trios into a pen on the basis of body weight. All weights were taken early in the morning, after fasting the animals for fifteen hours. The water supply was also cut off during the same period of time to reduce the variability in body weight due to differences in the contents of the digestive tracts (29). This 2 x 3 factorial experiment was replicated three times, totaling eighteen pens of three lambs each.

The feeding trial began on December 14, 1977 and ended on January 18, 1978 (35 days). The rations were formulated to 13% crude protein with rolled milo and soybean meal, and were all equally fortified with minerals and vitamins. Liquid molasses (3%) was added to the hay rations primarily for dust control. In order to eliminate variability between forage forms due to the inclusion of molasses, dry molasses (3%) was added to the supplements and the supplement-molasses mixture, in turn, added to the respective silages.

Each pen of lambs was fed its assigned feed twice daily, early in the morning and late in the evening. Group-daily feed allowances were adjusted to the extent of appetite to minimize the amount of feed refused. Each ration, nevertheless, consisted of 75% forage and 25% supplement. The uneaten meals were weighed back once a week and generally amounted to approximately 7-10% of the forage offered. It was assumed that due to the high feed selectivity which is so characteristic of the dietary habits in sheep (1), all the supplement fed was consumed, leaving only forage material probably of lower quality.

Final weights of the lambs on each of the six rations were taken after fasting, averaged, and recorded (e.g. the average of the weights of nine lambs per ration). The difference between the average final weight and average initial weight was recorded as average total gain. To obtain average daily gain (ADG), the average total gain was divided by thirty-five lamb days. The efficiency of feed utilization was determined from the daily liveweight gain and feed consumption data.

Laboratory Procedures

Grab samples of the forages before feeding and weighbacks were taken once a week and kept under refrigeration. At the end of the trial, the samples were composited for dry matter content and quality determinations. Each thirty-five day composite was divided into four smaller portions and oven-dried at 50°C for about three days, and the resulting moisture contents of the four subsamples were averaged as the "original" moisture content for the particular sample. The dried sample was then ground through a Wiley mill to pass through a screen 1-mm in diameter. The ground sample was then submitted for quality determinations.

In the laboratory, the dry matter content of samples was determined by drying them to constant weight at 100°C in a Unitherm oven. Estimates of *in vitro* dry matter digestibility and proximate principles were determined based on the dry matter content of the sample after the second drying procedure. Proximate analysis was executed according to standard A.O.A.C. procedures (27) and in vitro dry matter digestibility according to the Tilley and Terry technique (54).

It can be recalled that in Part I a strong argument was made concerning the weaknesses of the proximate analysis system to differentiate the digestible from the indigestible fractions of the carbohydrates in feedstuffs. It was stressed that nutritionally the Van Soest acid-detergent fiber procedure (55) is preferred over the crude fiber methodology of the proximate system. However, in the second part of this work, the proximate system was utilized for quality determinations with an awareness of its weaknesses. This decision was precipitated by several important considerations, two of which are as follows.

First, the use of proximate data is a legal requirement for commercial transactions involving foods and feedstuffs in many places. Second, some simple regression equations for predicting the total digestible nutrients (TDN) in feeds use crude fiber data to accomplish this goal. In short, it can be emphasized that much use is still made of the proximate system, and its inclusion in this part of the thesis should not be construed as a contradiction to claims made in Part I.

Statistical Procedures

All forage and animal data from this trial were analyzed by analysis of variance procedures as described by Snedecor and Cochran (48). Significance between the treatment means of the animal performance and feed acceptance data were tested by the Waller-Duncan multiple comparison test (59). A probability of $P < .05$ was accepted as being significant. Since only one bulked dried sample of feed offered and refused from each forage was obtained, no statistical comparisons between the quality data were made.

CHAPTER IV

RESULTS AND DISCUSSION

Qualitative Data

Within cultivars, the chemical composition was consistent with respect to the contents of ether extract, nitrogen free extract (NFE), ash and crude fiber. Here, the percentages of crude fiber and ash were slightly higher, and those of nitrogen-free extract lower, than those in the hays. These results followed the generally accepted trend reported in the literature. However, whereas most previous studies reported consistently lower crude protein content in forages preserved as hay than those made into silage, in this experiment hays were either greater than or equal to silages in this component.

The crude protein data in this study emphasize the influence of morphology on forage quality. When conserved as hay, greater shattering of leaves is associated with legumes than with grasses. Thus, data on the contents of crude protein in silages and hays as reported in the literature have been obtained because the vast majority of silage and hay research has been done with legumes.

In vitro dry matter percentages were higher in the silages than in their corresponding hays, except with pearl millet, in which the reverse trend was true. Other investigators have reported similar inconsistencies.

For example, Waldo *et al*. (56) found hay to be more digestible than silage, while Slack *et al*. (47) reported to the contrary.

The *in vitro* dry matter percentages shown in Table 1 and the other quality variables, are expressed on dry-matter basis. As recorded in Chapter II, oven-drying of silages underestimates the dry matter content and digestibility but does not affect hays. It may therefore be assumed that the true silage-*in vitro* dry matter digestibilities are somewhat higher than reported herein.

Voluntary Dry Matter Consumption

Assessment of the dry matter intakes (Table 2) shows that within forages there was no statistical difference in the acceptability of silage- and hay-dry matter, although some lambs showed preference for hay while others preferred silage. These results indicate that the constituents which have been postulated to be produced during silage fermentation, which cause a decrease in acceptability, were not present in these silages. This was probably due to the fact that wilting the forages before ensiling resulted in materials of high dry matter content, and therefore enhanced the ensiling process.

Many studies have shown that the digesta derived from silage remains longer in the reticulo-rumen than digesta derived from hay. This difference in retention time has been identified as the cause of the low intake of silage-dry matter. Some workers have published the reverse of the above, while others have found no differences. Thus with respect to the rate of passage of digesta, the results of this study are in agreement with those of the last group of workers, i.e.,

Table 1. Nutritive Value of Summer Annual Grass Hays and Silages Included in the Lamb Rations*

Quality Component	Pearl millet		Sudangrass		Sorghum-sudangrass	
	Hay	Silage	Hay	Silage	Hay	Silage
DM when fed, %	86.2	26.8	87.9	25.8	88.1	34.2
Crude protein, %	20.9	19.3	18.8	17.7	14.7	14.8
Crude fiber, %	23.8	26.0	26.3	28.2	26.8	29.0
Ether extract, %	2.7	3.2	2.7	3.5	2.5	3.4
NFE, %	38.9	37.2	41.3	39.4	43.8	42.4
Ash, %	13.7	14.3	10.9	11.1	11.2	11.4
IVDDM, %**	69.0	64.7	65.9	66.5	63.3	65.8

* Determinations based on 100% dry matter basis.

** _In Vitro_ Digestible Dry Matter.

Table 2. Voluntary Dry Matter Intake and Lamb Performance When Fed Summer Annual Grass Hays or Silages

Performance Parameters	Pearl millet		Sudangrass		Sorghum-sudangrass	
	Hay	Silage	Hay	Silage	Hay	Silage
No. of lambs	9	9	9	9	9	9
Initial wt., kg	24.09	25.04	25.14	25.27	25.41	25.45
Final wt., kg	30.04	30.45	29.77	31.00	29.18	31.00
Avg. total gain, kg	5.64	5.45	4.68	5.73	4.09	5.54
Avg. daily gain, kg	$.16^{*ab}$	$.15^{ab}$	$.13^{bc}$	$.18^{a}$	$.12^{c}$	$.16^{ab}$
Avg. daily feed, kg						
Forage^{+}	.88	.96	.84	.80	.82	.84
Supplement^{+}	.29	.32	.28	.27	.27	.28
Total^{+}	1.17^{ab}	1.28^{a}	1.12^{b}	1.07^{b}	1.09^{b}	1.12^{b}
Feed, kg/Gain, kg	7.40^{ab}	8.15^{bc}	8.52^{bc}	6.39^{a}	9.19^{c}	7.13^{ab}

* Means within the same row followed by the same letter(s) do not differ significantly ($P < .05$).

$^{+}$ 100% dry matter basis.

no difference in the rate of passage of hay and silage residues, and hence no difference in voluntary intake.

The effect of concentrate supplementation was not measured in this feeding experiment. However, Table 2 clearly shows that the addition of concentrate supplement to the rations caused no significant differences in the extent to which the different rations were consumed, contrary to some researchers (8,37) who observed that concentrate supplementation reduces the voluntary intake of the drier feed to a greater extent than of one that is moister. The results of this study indicate that much further work is needed to examine the effects of adding concentrates to silage and hay and whether such effects are typical of practical, on-the-farm conditions.

Animal Performance

Table 2 shows inconsistent animal performance. It shows that the silages made from sudangrass and sudan X sorghum hybrid were used with a greater efficiency for gain than their companion hays, in agreement with the trend shown by (4,49). But similar to work done by Thomas *et al*. (56) and by Wellmann (62), pearl millet hay was more efficiently used than the corresponding silage. The first two workers cited above explained the greater efficiency of silage over hay in light of the greater ease with which organic acids from silage are absorbed from the rumen, and the higher ratio of more energetic volatile acids in silage (propionate or butyrate or both) to acetate, than in hay.

The analytical procedures employed in this study made it statistically impossible to determine the association between quality attributes and dry matter consumption with certainty. However, it appeared that there was no relationship between dry matter intake and feed efficiency. As shown in Table 2, there were no significant differences, within forages, in the consumption of feeds. On the contrary, significant differences existed in the efficiency of feed utilization for growth. Within forages, dry matter digestibility and crude protein content appeared to be positively correlated with daily gain and feed efficiency, as was daily gain with feed efficiency.

CHAPTER V

SUMMARY AND CONCLUSION

This feeding experiment was planned to determine the preservation efficiency, chemical quality and relative feeding value of three summer annual grasses: hybrid Pearl millet, 'Piper' sudangrass and 'Sudax SX-11' sorghumsudan hybrid, when harvested at the boot stage as wilted silage and sun-cured hay. The forages were grown in the same field and the hays and silages were fed to fattening lambs.

Very high correlations of dry matter content with voluntary dry matter consumption have generally been found when hay and sometimes silage are fed. Although such correlations were not analyzed in this research, it is emphasized that the ensiling of summer annuals at the greatest practical dry matter content commensurate with animal utilization should be encouraged.

Method of preservation influenced the chemical composition of the roughages. As widely reported, the hays were consistently lower in crude fiber, ether extract and ash contents, but higher in nitrogen free extract, than their companion silages. However, the results of this study were at variance with many of those previously reported, regarding crude protein content, in that the hays were not always lower than the silages. The *in vitro* dry matter digestibilities (IVDMD) were also inconsistent. Pearl millet hay contained the highest IVDMD percent (69.0) and sorghumsudan hay the lowest (63.3).

Within forages, no statistical differences were noted in the consumption of dry matter of corresponding hays and silages, indicating that the mean retention times of residues from these forage forms were similar. The efficiency of utilization and average daily liveweight gains on the rations were inconsistent. The maximum average daily gain, 0.18 kg, was obtained when sudangrass silage was used as roughage, and lowest, 0.12 kg, when sorghumsudan grass hay was fed. Daily gains were higher on the silages than on the hays, except with pearl millet, where the gains were statistically similar. Feed efficiency was generally correlated with average daily gain. Thus, the least amount of feed required for a pound of gain occurred on sudangrass silage (6.39 kg), and the greatest (9.19 kg) on sorghumsudan grass hay.

This study indicates that the three summer annual forages ensiled successfully, and that the resulting silages were equally relished by lambs, as their companion hays. In addition, the overall feeding value of the two forms of conserved forage was similar.

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PART II. COMPARATIVE FEEDING VALUE OF SUMMER ANNUAL GRASS HAYS AND SILAGES FOR LAMBS

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IVDMD decreased gradually, and ADF increased slowly, and dry matter yields increased rapidly.

Based on a joint consideration of dry matter yield and digestible dry matter yield, the forages were grouped within stages of maturity as follows:

	VEGETATIVE	BOOT	SOFT-DOUGH
1.	Millex	Super Chow Maker	Forage Sorghum
2.	Trudan 6	Sudax	Sudax
3.	Piper	Millex	Super Chow Maker
4.	Super Chow Maker		Millex
5.	Sudax		

Within each category, there was no significant difference among the forages listed ($P < .05$). Forages not listed within a given cutting management were generally significantly inferior.

PART II. COMPARATIVE FEEDING VALUE OF SUMMER ANNUAL GRASS HAYS AND SILAGES FOR LAMBS

In a 35-day feeding trial, 54 feeder lambs were used to evaluate silages and hays made from three summer annual grasses: pearl millet (PM); sudangrass (sudan); and 'sudax SX-11' sorghumsudan hybrid (SS). Each forage was harvested at the boot stage of maturity as sun-cured hay and wilted silage. Silages were ensiled in 3.1 x 15.0 m concrete stave silos. A 2 x 3 factorial design (replicated three times) was used. The six rations contained 75% of the appropriate silage or hay and 25% supplement on a dry matter (DM) basis. Three pens of three lambs each were randomly assigned to each of the rations, which were fed twice daily to appetite. Percents DM, crude protein, crude fiber, ash and in vitro DM digestibility, respectively, for the six silages and hays were: PM hay, 86.2, 20.9, 23.8, 13.7 and 69.0; PM silage, 26.8, 19.3, 26.0, 14.3 and 64.7; sudan hay, 87.9, 18.8, 26.3, 12.9 and 65.9; sudan silage, 25.8, 17.8, 28.2, 11.1 and 65.8; SS hay, 88.1, 14.7, 26.8, 11.4 and 63.3; SS silage, 34.2, 14.8, 29.0, 11.2 and 65.8. For sudan and SS gains were higher ($P < .05$) for silages than hays; for PM gains were similar for silage and hay. Daily gains ranged from .12 kg for SS hay to .18 kg for sudan silage. Within species, DM intakes were similar for silage and hay and ranged from 1.07 to 1.28 kg/day for sudan silage and PM silage, respectively. Feed efficiencies were inconsistent within species. Lambs fed SS hay were the least efficient (9.19 kg DM/kg gain); lambs fed sudan silage were the most efficient (6.39 kg DM/kg gain).