DISSERTATION

DETERMINANTS OF THE NUTRITIVE AND FEEDING VALUE OF FORAGE SORGHUM IN FORAGE-FED BEEF PRODUCTION SYSTEM

Submitted by

Muhammad Sani Kallah

Department of Range Science

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY MUHAMMAD SANI KALLAH

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Committee on Graduate Work

C. Travis Cook

Richard M. Hansen

Cheryl V. Nichols

Larry R. Rittenhouse
Adviser

William C. Krueger
Department Head

ABSTRACT OF DISSERTATION

DETERMINANTS OF THE NUTRITIVE AND FEEDING VALUE OF FORAGE SORGHUM IN FORAGE-FED BEEF PRODUCTION SYSTEM

The *Sorghum bicolor* x *S. sudanense* hybrid 'NEB 306F' was used in two trials 27.4 km north of Akron, Colorado to evaluate components associated with pasture primary and secondary productivity. Trial I examined seeding rate (5.6, 9.0, 11.2, and 16.8 kg · ha^{-1}) and row spacing (25, 51 and 76 cm) effects on plant morphology, density, phytomass, forage physical composition (leaf and stem proportions) and nutrient quality of forage types (leaf, stem and whole-plant) at various phenological stages. The nutritive quality parameters evaluated were: P, CP, cell contents (NDS), NDF, ADF, ADL, hemicellulose (H), cellulose (C) and *in vitro* digestibility (IVDMD). Trial II evaluated the performance of long-yearling steers in relation to pasture phenology and row spacing influences.

In Trial I seeding rate x row spacing interaction was not significant with respect to forage yield components examined. Responses of yield components varied with phenological stage. Leaf and stem biomass and DM · $plant^{-1}$ increased; the leaf:stem ratio declined with maturity. Plant height and DM physical composition were not influenced by seeding rate or row spacing.

Plant density, leaf number, and leaf and biomass increased with seeding rates at all harvests. Despite reduced stem diameter and DM · $plant^{-1}$, larger phytomass occurred at higher than lower seeding rates. Although row spacing effects were inconsistent with growth stages, in

the mature forage stem diameter, DM · plant^{-1} and phytomass declined with wider spacing. Simple and multivariate analysis of yield components indicated that variations in phytomass were associated with plant morphology, density, DM · plant^{-1} and leaf and stem biomass. Plant density was strongly associated with leaf number · area^{-1} ($r = .933$) but not with leaf:stem ratio.

Variations in nutritive quality among DM types within and among growth stages were generally significant. Row spacing had no influence ($p > .05$) on nutrient composition. Leaf was consistently higher in P, CP, and fiber components than stem, while stem was higher in IVDMD and NDS than leaf. The IVDMD of the early vegetative leaf, stem and whole-plant were 71.5, 71.9 and 71.9%, respectively. In the frosted forage the IVDMD of the respective DM types were 63.3, 65.0 and 65.1%. Generally, the feeding value parameters of the whole-plant DM were intermediate. Leaf proportion was a poor indicator of the whole-plant nutritive quality. The relationship between leaf percentage and CP, P, IVDMD, NDS, NDF, ADF, ADL, C, H. and H:C ratio of whole-plant were: $r = .518^*, .472^*, .126, -.486^*, .486^*, .464^*, .196, .469^*, .355$ and $-.024$, respectively. Lignification of fiber and cell walls did not satisfactorily explain the comparative digestibilities of leaf and stem.

The results of Trial II concur with data of Trial I, i.e., row spacing did not influence forage physical or nutrient composition. Differences within grazing treatment among periods, and differences in CP and IVDMD between leaf and stem were significant in both pre-grazed and residual pastures. Irrespective phenological stage the pre-grazed pasture was higher in feeding quality than the residual pasture.

Estimates of steer "apparent DM intake" by the pre- and post-grazing clipping method were unrealistic. The observation became more apparent when phytomass was partitioned into leaf and stem proportions. There was no evidence that steers selected leaf or rejected stem forage. Steer performance suggested that DM yield, intake and quality of intake were not limiting. There was no difference ($p > .10$) in weight gain among the steer groups. The initial steer gains on the early vegetation forage were not sustained on the more mature forage. However, daily gain (ADG) within treatments among grazing periods were not different ($p > .01$). For the entire trial period ADG ($kg \cdot steer^{-1}$) and beef production ($kg \cdot ha^{-1}$) in the 25-, 51- and 76-cm row spacing treatments were: 1.14 and 81.3; 1.23 and 88.0; and 1.01 and 65.4 respectively.

Muhammad Sani Kallah
Department of Range Science
Colorado State University
Fort Collins, Colorado 80523
Fall, 1980

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CHAPTER I

INTRODUCTION

In recent years a great deal of new interest has been generated in the area of forage-fed beef. Reasons for such new developments are: food as it is related to the global energy crisis; the consequent exhorbitant cost of cultural energy to finish cattle for slaughter; rising public concern over the capacity of world food supply to keep pace with increasing population demand; increasing public consciousness over environmental pollution; the desire to conserve energy as well as protect the environment; consumer aversion to animal fats; and the desire to curtail consumption of fatty diets. The outcome of these demands and many other developments will result in higher costs for animal production with non-reciprocating net increases in beef cattle prices.

It has been a tradition of the livestock industry to use high levels of grain in diets for intensive cattle production. Upgrading carcass qualities of grass-fed beef with grain is a practice confined only to a few industrialzed nations but currently seems to be attracting more attention in many other countries. In recent years, however, when human demand for food appears to outweigh the supply, questions are raised to challenge the wisdom of the extensive use of grains for livestock production. Critics often ask — in a dwindling world food supply proportionate to its human population — who should have higher priority to grains, people or animals? Critics of grain-fed beef argue that the practice is morally unjustified in a time of world food

shortages because cattle on concentrate feeding yield only 1 pound of protein for every 20 pounds they consume in grain (Lockeretz 1975). Comparing energy input to actual pounds of beef produced, Ward and Knox (1975), and Ward *et al.* (1977) reported range grass feeding of yearling to be 3.5 to 7.6 times as efficient as total confinement feeding on various types of corn rations.

Consequent to these new developments livestock researchers, particularly in the United States, perceived the necessity of re-examining the feed inputs for beef production. Grass-fed feeder cattle that are to be grain-finished are normally put into feedlot at a stage when they have already attained 60 to 65% of their weight gain (Ensminger & Olentine 1978). Pope and Schake (1975) estimated that 86% of the dry matter required to produce beef comes from non-grain sources. Of the 14% from grain, only 1.5% is used in the breeding herd, the remaining 12.5% being used to finish cattle. However, of the total expenditure in producing a slaughter animal from a weaned calf 75% of it is accounted for by the finishing phase when animals are maintained on high grain concentrate rations (Farris & Dietrich 1977). It, therefore, seems that if the livestock industry is to continue providing its services, an equitable retail price would have to be charged to at least cover the cost of production. In other words, as the cost of production increased so would the retail price of beef.

The ultimate goal of the cattle industry is to supply the consumer with reasonably priced beef that has a high degree of eating satisfaction, while at the same time maximizing its profit. If the cattle industry is to achieve this goal and if the current developments in the world energy situation were to persist, then research on alternative ways of beef production seems to be imperative.

Alternative means for reducing cost of beef production are (1) to lower the level of grain in feed mixture during finishing period in the drylot, (2) to feed concentrates on grass or feed harvested roughage before cattle are placed on finishing rations or (3) to develop all the weight and flesh possible by grazing. The continued use of grain in cattle finishing rations will be dictated by availability and prices relative to alternative feed sources. This in turn is, certainly, contingent upon the cost of cultural energy and the intensity of competition between the desire to satisfy human needs for grains and the livestock industry in the future.

Concentrate supplementation to grazing animals as a panacea to human-livestock competitive demand for grain may be restricted by its economic aspect and the increasing public's concern over energy conservation and the desire to optimize natural resource utilization with minimum wastage. Research results indicate that continued energy supplementation during the grazing season would result in decreased feedlot gain and feed conversion efficiency (Denham 1977); whereas, protein supplementation during the latter part of the growing season (Denham 1977) or winter (Rittenhouse *et al*. 1970) plays but only a minor role in enhancing the performance of yearling beef cattle grazing native range. Rittenhouse *et al*. (1970) have demonstrated that whereas total dietary intake and digestibility were increased with successive increments of energy supplementation, supplemental energy above 0.041 Mcal · kg $W^{-0.75}$ significantly depressed forage intake and had no influence on dry matter digestibility of winter forage diets, *per se*. Several other experiments with livestock grazed or fed harvested forages (Corbett & Boyne 1958; Langlands 1969; Kenney *et al*. 1978;

Vadiveloo & Holmes 1979; Weston 1978) have shown that whenever herbage is readily available, supplementary feeding depresses herbage intake and as a result responses in production are less than would be expected from the nutrient content of the supplements given. Alternatively, where energy supplementation has been found to improve animal performance on pasture the practice often proved to be uneconomically feasible (Hoveland *et al.* 1971; Raleigh *et al.* 1967). Therefore, it is apparent from the studies cited that where offering grain supplements to grazing animals is adopted as a production system it is necessary to ensure that animals make maximum use of the pasture so that minimum quantities of expensive grains are required to produce the desired marketable product.

Of the production alternatives available to the livestock industry, the forage-fed beef production system least appears to compete with human needs for grains or space for producing crops which have higher priority for direct human consumption. In the future, it seems, slaughter cattle may of necessity have to be produced with less grain and increased use of pasture and harvested forages. Research efforts in forage-fed beef must focus attention on increasing productivity in terms of unit of output per unit of input. This means a more thorough understanding of the biology and dynamics of pastoral production is a basic requirement.

Total dry matter production and consistency of production over a period of time, while highly desirable, would not be an adequate goal of forage-fed beef programs. The nutrient requirements of beef cattle are met by a combination of the available dry matter, nutrient concentration (digestible organic matter and digestible crude protein) in

the feed and intake of the feed. Physical bulk of less digestible forages and the capacity of the ruminant's gastrointestinal tract are the dominant factors limiting forage intake (Ellis 1978). All forage diets are nearly always energy deficient for finishing cattle (Dinius *et al.* 1975). Experience in drylot trials indicates that any time roughage components exceed 20% there would be a reduction in live-weight gain and feed conversion efficiency (Dinius *et al.* 1975; Hunter 1978). Holt (1977) has quoted the following ranges in forage digestibilities that meet the nutrient requirements of various classes of beef cattle: dry cows 46 to 56%; cow with calf 56 to 60%; primiparous cow or 270 + kg steer 62 to 68%; and 113 kg steer greater than 70%. In tropical, warm-season grasses, forage dry matter digestibility may change rapidly with advancing stage of physiological maturity from 76% in the lush growth to as low as 27% in the dry, lignified forage (Butterworth 1967; Minson 1972). A similar trend occurs in temperate, cool-season grasses, although with a narrower range and slower rate of decline.

Is there a scope, then, for increasing the efficiency of production procedures and utilization of pastures? Is it possible through production and management practices to alter the pattern in forage production and quality to finish cattle for slaughter as yearlings on pasture forages? Although it is possible to finish cattle for slaughter on pasture, the task is a difficult one because of the vulnerability of pasture to decline in digestibility with physiological stage of maturity of the plant species or varietal-type and environmental conditions. These changes are reflected in marked intake responses by the grazing animals, even though selective grazing may

to some extent offset some of the effects. Economic practices may influence dry matter production and to a lesser extent nutritional quality. Obviously, it appears that if forages are to meet the nutrient requirements of growing animals, they must be utilized at relatively young age. The application of this principle to harvested forages is direct and simple. However, frequent harvest (young forage, larger leaf:stem ratio) has a negative effect on dry matter production, thus both cannot be optimized. A still greater challenge is to apply the principle of early utilization under grazing condition, so as to harness optimum leaf:stem ratio and provide forage of acceptable nutritive quality to meet the needs of the grazing animal but at the same time not to restrict the available forage and intake by the procedure.

At the Eastern Colorado Research Centre, Akron, alternative systems of beef cattle finishing are being tested. The experiments described in this report were designed to determine the role that forage sorghum might play in forage-fed beef production system. The objective of the experiments are two fold: first to determine pasture establishment procedure that maximizes yields and quality of forage components, the contribution of plant component to total dry matter production and nutritive quality of the composite forage; and second to determine the physiological stage of maturity at which dry matter and nutrient concentration are optimum as measured by chemical analysis and body weight changes of yearling beef cattle grazing the pasture. Specifically, the effects of plant density, plant morphological characteristics, leaf:stem ratio, age of plant component at grazing on herbage dry matter and quality of forage potentially available to the grazing animal were examined. The yield and quality of residual

herbage following grazing were determined. Animal performance in relation to available herbage, apparent forage and nutrient intake were evaluated.

CHAPTER II

LITERATURE REVIEW

Forage is the cheapest and probably the healthiest form of animal feed-stuff, particularly when grazed *in situ* by the animal itself. One of the major groups of summer forages grown in the United States comprises the sorghums, *Sorghum bicolor* (L.) Moench, and the sorghum-sudangrass, *S. bicolor* X *S. sudanense* (Piper) Stapf, derivatives. These crops are grown throughout the country in regions where the summers are warm and rainfall moderate, and as such they have been extensively studied. In too many instances dry matter yield has been the sole criterion used to evaluate the treatments under study. In other instances nutritive value may be the only criterion evaluated. That is to say, the components of the soil-plant-animal complex are more often studied in isolation of one another. If the desire to use forages to put more of the finish on animals were to continue, feeding high-quality plant material will be necessary. This implies that an integrated approach incorporating both agronomic and animal nutrition data to serve as a quantitative criterion of feeding value will be highly desirable in evaluating forage management experiments.

Sorghum, *Sorghum* spp., has the C_4 pathway for CO_2 fixation (Hatch *et al.* 1967) which is associated with high rates of photosynthesis under high radiation and temperature (Cooper 1970). The genus uses water efficiently (Blum & Naveh 1976; Downes 1970) and has morphological (Cummins & Dobson, Jr. 1972; Downes 1970; Freeman 1970; Hanna *et al.* 1977) as well as physiological (Downes 1971a) advantages under moisture

stress conditions. Diverse races evolved specific photosynthetic mechanisms to adapt to high and low radiation environments in the tropics and subtropics (Downes 1971b; de Wet & Huckabay 1967; de Wet *et al.* 1970). In the subtropics the crop is mostly grown when the mean daily temperature exceeds 20°C, reaching 25 to 27°C during the season. In tropical regions the mean daily temperature may exceed 30°C during the whole of the growing season, the limits of which are fixed by moisture stress (Downes 1972; Pasternak & Wilson 1969).

Sorghums used for forage are not restrictive in their soil requirements. Although tolerant of many soil conditions, the forage sorghums are grown primarily where rainfall is insufficient for maize, *Zea mays* L. Forage sorghums excel on rich loam soil, but can be grown productively on soils ranging from heavy clay to light sands (Owen & Moline 1970). Sudangrass does not tolerate alkali soils but grows well on soils of low pH (Hein 1957).

Sorghums are normally planted in late spring, because they respond poorly in cold, wet soils. Sudangrass, sorghum-sudangrass hybrids and millet seeded June 1 through July 1 produced grazing when perennial forages were dormant (Odland *et al.* 1942; Utley *et al.* 1976). Earlier planting of sorghums was less successful. Sullivan (1961) reported that low temperature reduced the yields of sudangrass. Higher dry matter yields were obtained from sudangrass grown at environmental temperatures 26.7°C and 32.2°C than at 21.1°C. At 15.6°C plant growth was insignificant.

Although sorghums tolerate severe moisture stresses, yield reductions up to 50% have been reported for sudangrass grown under drought conditions (Jung & Reid 1966). In a California study, yield

reductions of 22% were attributed to soil compaction and physical damage to the stubble caused by harvesting equipment (Sumner 1968). With the advent of high-yielding sorghum hybrids the livestock producer acquired another group of forages to plant and feed. Over 100 varieties and hybrids have been released from breeding programs (Owen & Moline 1970) — the choice of which sorghum to use being dependent upon its ultimate use. Forage intended for use as a maintenance ration would emphasize maximum dry matter production, while forage intended for production (growth, fattening or lactation) would emphasize the proper balance between dry matter yield and forage quality including chemical composition, digestibility and net energy value.

Sorghums, sudangrass and the sorghum-sudangrass derivatives make large yields of dry matter and their potential carrying capacity are high (Fribourg *et al.* 1976; Hedges *et al.*1978; Hoveland 1969; Hoveland *et al.* 1971; Sheridan *et al.* 1972; Sotomayor-Rios & Telek 1977; St. Louis *et al.* 1979; Wheeler & Hedges 1972). Digestible dry matter of sorghum-sudangrass is higher than warm-season perennials, such as bermudagrass, *Cynodon dactylon* (L.) Pers. or Pensacola bahiagrass, *Paspalum notatum* Flügge; and compares favorably with cool-season perennial grasses and legumes (Hoveland 1969; Hoveland *et al.* 1967; Hoveland *et al.* 1969; Smith *et al.* 1966; Utley *et al.* 1976). Their protein content can also be high (Sotomayor-Rios & Telek 1977). Sorghums, however, are probably deficient in lysine (Davis & Stallcup 1966) as well as calcium and cobalt (Owen & Moline 1970). Likewise, recent reports from Australia, East Africa and New Zealand have indicated that the sulfur and sodium content of sorghum hybrids is

inadequate to meet the needs of the grazing stock, and that upon ingestion by ruminants the hydrocyanic acid content of sorghum forages may further exacerbate the sulfur requirements and induce sulfur deficiency (Archer & Wheeler 1978; Bouchard & Conrad 1973; Hedges *et al.* 1978; Hunt *et al.* 1979; Morris & Gartner 1971; Said *et al.* 1977; Stobbs & Wheeler 1977; Wheeler *et al.* 1975).

In the United States, sorghums used for forages are grown primarily in the Great Plains where moisture is insufficient for good maize production. States leading in the yields of sorghums for forages are, in descending order: Kansas, Texas, Nebraska, Oklahoma and Colorado; and in production of silage: Kansas, Nebraska, Texas, South Dakota and Oklahoma (Owen & Moline 1970). Both increased demand for forage feeds and improved varieties of sorghum suited for forage production have played a significant role in their acceptance as forage crops. Sudangrass and sorghum-sudangrass crosses are used for pasturage or hay in nearly all states of the United States. Many farmers and ranchers use the sorghum for hay, silage, soilage (greenchop in confine feeding) or rotational summer pastures. Alternatively the crop may be allowed to stockpile for emergency summer feeding, late fall *in situ* utilization or supplemental winter feeding. In addition, sorghums are often used in solid seeding for weed control and soil erosion control and make an excellent residue for reestablishing grasslands (Everson *et al.* 1965; Owen & Moline 1970).

Since sorghums are used so widely, production system and utilization management vary widely. Under appropriate environmental conditions sorghums have potential to produce large quantities of highly

digestible forage because of their fast growth rates, higher water-use efficiency and efficient leaf arrangement in the plant canopy (Downes 1970). It is recognized, however, that this forage production and its distribution during the season, and digestibility of the harvested biomass are intimately related to management of genotypes and concomitant effect on their morphology and physiology (Ademosum *et al*. 1968; Beuerlin *et al*. 1968; Burns & Wedin 1964; Cummins & Sudweeks 1976; Webster & Davies 1956).

With forage crops, in contrast to native forage species, the quantity and quality of herbage available to the ruminant is governed to a much greater extent by the production and utilization system. As forage sorghums are tall, robust growing crops, plant height, stem size, the proportion of leaf:stem, leaf numbers and plant density may be factors, additional to the more conventional ones, in determining the quality of the herbage biomass, as well as the accessibility and the extent to which they are utilized by the ruminant. Changes in production practices such as high plant density and narrow row spacings cause microclimatic changes that affect temperature, evaporation and light intensity at the soil surface (Grimes & Musick 1959; Stickler & Laude 1960; Stickler *et al*. 1961) and modify the subsequent establishment and survival of grass swards (Cook *et al*. 1967; Holt 1965, 1970; Kiesselbach & Anderson 1925; Lavin & Springfield 1955; McGinnies 1970; Mueggler & Blaisdell 1955). There is considerable evidence that plant density, distribution and the consequent effects on competition for plant nutrients influence the productivity of summer annual forage crops (Blum & Naveh 1976; Bunting 1971; Burger & Campbell 1961; Burnside *et al*. 1964; de Peralta 1935; Hart & Burton 1965; Koller & Scholl 1968;

Rutger & Crowder 1967a, 1967b; Sumner 1965). There is also indication that forage nutritive value may be modified by plant population and distribution (Alexander *et al*. 1963; Doss *et al*. 1964; Dungan *et al*. 1958; Hart & Burton 1965; Koller & Clark 1965; Nandpuri 1963; Phipps 1975; Sims & Cook 1967; Thomson & Rogers 1968; Worker, Jr. 1973).

Density and Spatial Distribution Effects

Maximum yields of nutritious herbage, low in fiber and highly digestible is of major importance in forage-fed beef programs. Each step taken to increase production and utilization of such herbage will be highly desirable. It is often said that forage production practices which maximize dry matter production frequently also will maximize nutrient output per unit area. Thus more animals may be carried per unit area and generally more gain per unit area but gain per animal may not follow the same pattern. The latter is highly important in forage-fed beef programs and it is a function of quality as well as quantity of available forage. There is evidence that forage dry matter production and nutritive quality may be modified by plant population and distribution.

Changes in production practices such as high plant populations and narrow spacings introduce microclimatic changes in the environment and affect the morphological as well as physiological responses of the plant to the environment. Such responses may be manifested in terms of morphological, quantitative or qualitative changes within the plants. Variations in plant density and distribution affects temperature, evaporation and light intensity at the soil surface (Grime & Musick 1959; Stickler & Laude 1960; Stickler *et al*. 1961).

Burnside *et al.* (1964) remarked that increased plant population with consequent increase in number of leaves will increase shading on soil surface, promote water conservation, and reduce weed growth but may also be conducive to the development of insects and diseases. Variation in plant density induces morphological changes within the plant itself. In maize, *Zea mays* L., for example, depth of rooting (Worden 1964) and leaf angle (Loomis *et al.* 1968) — which in turn can affect either the amount of environmental resources available at different densities or efficiencies with which they are utilized, were all noted to be influenced by plant density and distribution. Bowers *et al.* (1963) compared 101.6 and 50.8-cm rows and two populations of 0.32 x and 2.59 x 10^5 plants/ha and reported that row spacing significantly influenced net radiation absorbed by sorghum. Increased net water use and reduced net photosynthesis were also observed in sorghum grown at high densities (Blum 1970; Akhanda *et al.* 1978).

The association between plant density and dry matter production has been studied extensively under optimal conditions, where light interception or CO_2 supply are major yield barriers. However, forage crop production is also allocated to dry lands where the major limiting factor is water supply. Under semi-arid conditions the amount of available moisture limits the quantity of dry matter that can be produced (Blum 1970; 1972; Blum & Naveh 1976; Brown & Shrader 1959; Bond *et al.* 1964; Karchi & Rudich 1966). Plant competition under dry land condition is probably the major factor which limits the number of plants that can be supported per unit area without inducing reduction in forage productivity for two main reasons: a) a certain percentage of plants, up to 12% according to Karchi & Rudich (1966),

wither prior to the age of production, and b) the under-developed plants grow on limited environmental resources at the expense of the yield producing plants.

Nevertheless, it is generally assumed that there should be an optimum density, distribution, height and size of plants that will produce the maximum herbage with the limited resources. When seeding forages, plant density and spatial distribution can be determined by adjusting drill-row spacing and seeding rate. The size and height of a plant will be determined by interaction of genotype, plant density and available nutrients.

Although there is considerable data on the effects of plant density and row spacing on grain sorghum production, comparatively relatively few data have been reported on the relationship between plant density and distribution on quantity and nutritive quality components of forage sorghum dry matter. Furthermore, studies under semi-arid conditions on the influence of row spacing and/or seeding rate on the production of panicoids, cool-season grasses as well as grass-legume mixtures, have generally yielded conflicting results (Blum & Nevah 1976; Burger & Campbell 1961; Burnside *et al.* 1964; Canode 1968; Cook *et al.* 1967; Holt 1970; Lachange 1965; McGinnies 1970; Springfield 1965; Stickler & Laude 1960; Worker 1973).

Morphological Components of Forage Yield and Quality

Morphological traits, such as stem diameter, culm height, number of leaves, while genetically determined are affected by the environmental variables to which plants are subjected. A number of experiments have found that stem diameter can be influenced by row spacing

and/or seeding rate (Burger & Campbell 1961; Holt 1965, 1970; Kiesselbach & Anderson 1925; Stickler & Laude 1960). There is also evidence that plant density and distribution may affect plant height (Akhanda *et al.* 1978; Burnside *et al.* 1964). Still other experimental data have indicated that leaf number may come under the control of an array of environmental variables (Arnold 1969; Chase & Nanda 1967; Duncan & Hesketh 1968; Eik & Hanway 1965; Hoshino *et al.* 1978; Hunter *et al.* 1970).

Burger & Campbell (1961) noted that average stem diameter of the original primary culms in broadcast sudangrass was much greater than that of drilled sudangrass, but the drilled sudangrass, produced more herbage. In a study of 'Sudax-12' sorghum x sudangrass hybrids in rows 25, 51, and 102 cm at plant densities ranging from 1.45 x to 13.45 x 10^5 plants/ha Holt (1970) reported that plant size was inversely proportional to plant population with larger plants occurring in wider rows so that forage yield/ha did not differ greatly. Burger *et al.* (1961), experimenting on the influence of seeding rate (13.4, 27.0, 40,3, 53.8 kg/ha) on stem diameter as related to the drying qualities of sudangrass hay, reported that herbage of sudangrass cultivars with thick stems dried more slowly than that of thin stemmed varieties. Small stem diameter were found to be a result of genotypic characteristics, high rates of seeding and heavy tillering. The authors concluded that smaller stem diameter, whether it be a genotypic characteristic or a consequence of rates of seeding or both will speed up the drying of sorghum herbage in hay production.

It is generally assumed that the taller the plant height the better the distribution of light within the plant population and that

tall genotype is more advantageous in the efficiency of dry matter production compared with short genotype. Hoshino *et al.* (1978), comparing isogenic lines of sorghum differing only in dominant or recessive height gene, reported that although tall genotype resulted in higher dry matter yield than short genotype, more lodging not apparent until relatively late in stage was noted with the tall genotype. Porter *et al.* (1960) reported that sorghum height increased with narrow row widths while Burnside *et al.* (1964) reported that narrow rows compared with wider rows decreased sorghum height. In dryland sorghum grown in Nebraska, narrow row spacings (25.4 and 50.8 cm) as compared with wider row spacings (76.2 and 101.6 cm) were found to increase sorghum population and lodging, and decrease sorghum height. Burnside *et al.* (1964) reported that sorghum height in 101.6-, 76.2-, 50.8- and 15.4-cm row spacings was 142.2, 139.7, 137.2 and 132.1 cm, respectively. Lodging increased from 20% in 101.6 cm rows to 60% in the 25.4 cm rows. Similarly, Akhanda *et al.* (1978) working with the sorghum cultivars Pioneer B-815 and Bird-A-B00 II at densities 20, 30 and 40 plants/m^2 reported that with increasing plant population, plant height increased up to the 30 plant/m^2 treatment but then declined sharply at 40 plants/m^2 density.

Investigators have also noted that leaf number, while genetically determined is affected by environmental variables and management practices. Leaf number was reported to decrease as plant population is increased (Eik & Hanway 1965) and to increase to a minor extent with increasing temperature (Arnold 1969; Duncan & Hesketh 1968) and fertility (Eik & Hanway 1965). Length of photoperiod is also thought to modify leaf number (Chase & Nanda 1967). Leaf area index, which is

a function of leaf size and leaf number, and provides an index of the dry weight increment of plant population during the growth cycle, is generally reported to increase with plant density (Akhanda *et al.* 1978; Allen *et al.* 1973; Hoshino *et al.* 1978; Hunter *et al.* 1970; Itnal *et al.* 1978).

Several researchers have examined the interrelation of morphological traits in an attempt to resolve the practical problem associated with the determination of the stage of plant development during which maximum yield of quality forage can be harvested repeatedly over a period of time suitable to the desired system of management. Harvest readiness, as this stage is often called in practice, is determined by forage yield, its nutritive quality and the morphological as well as the physiological status of the plants: the essential compromises being dependent upon the purpose of the planting — whether it is for grazing or for harvesting mechanically. Plant height, number of internodes, stem diameter and number of leaves are the gross morphological traits suggestive of plant stage of maturity. Relationship between these parameters and selected yield components would essentially result in growth rate patterns plotted against a measure of growth other than time. It is reasoned that these morphological traits if reliable might be of value in evaluating harvest readiness of sorghum forages, since a knowledge of these parameters can be easily acquired in the field with only simple instruments. Such indices would also be particularly valuable in research programs in which a unit of measurement more consistent with the physiological development of the plant would be used as a substitute for the more conventional use of time for scheduling harvest treatment.

Dhimmar and Desai (1978) examining 14 morphological characteristics as indices of sorghum forage and grain yield, observed that plant height and stem diameter have higher heritability value (79.8% and 80.0%, respectively) and higher significant positive correlations with forage yield ($r = 0.8731$ and $r = 0.741$, respectively) than number of leaves whose heritability and correlation coefficient are 44.3% and 0.512, respectively. The authors suggested that for forage yield, emphasis should not be placed on number of leaves or leaf area, rather, selection should be based on plant height and stem diameter since they are highly positively correlated with forage yield. Several researchers, however, have found that leaf number is significantly correlated with plant height and time of inflorescence and anthesis; and, in general, early maturity hybrids have fewer leaves while later maturing hybrids have larger numbers of leaves and larger-sized leaves (Allen *et al*. 1973; Arnold 1969; Chase & Nanda 1966, 1967; Duncan & Hesketh 1968; Kuleshov 1932, 1933; Sieglinger 1936; Swanson 1941).

Spain & Santiago (1973) examined the relationship of several morphological traits with yield and qualitative components for determining harvest readiness in Napier grass, *Pennisetum purpureum* Schum. They reported that culm length or number of elongated nodes correlated most closely with yield or nutritive quality components. The number of internodes longer than 2.5 cm were significantly correlated with total fresh weight, total dry weight, total crude protein output, live-leaf dry weight and live-leaf percentage crude protein, showing correlation coefficients of 0.91, 0.92, 0.80, 0.91 and -0.68, respectively. Spain & Santiago (1973) suggested that for Napier grass, harvesting at an intermediate stage when 8 to 10 internodes have begun elongation

appears most satisfactory for obtaining high yield of good quality forage.

Nowhere in the literature has the latter information been found pertaining to the new sorghum hybrids or the sorghum x sudangrass complex. The literature cited indicate that from the practical point of view and regardless of use to be made of sorghum forage, occasional measurement of one or more of the gross morphological traits considered should serve as a useful guide to harvest readiness.

Forage Dry Matter Yield

Pasture forage production is a product of dry matter per plant and plant population. Many experiments have been conducted to determine the optimum plant population and changes in yield components associated with increasing population. It has been demonstrated that, in general, the relationship between dry matter yield per unit area and plant density is asymptotic, described by the linear model $w^{-1} = \alpha + \beta\rho$, where w is weight per plant and ρ, density per unit area while α and β are regression constants (Bunting 1971; Holliday, 1960; Mead 1970; Nelder 1966; Shinozaki & Kira 1956; Willey & Heath 1969; de Wit 1960). Varying row spacing does not affect the pattern of yield response to density (Bunting 1971) but environmental conditions such as moisture regimes may modify the relationship to asymptotic or parabolic. The latter relationship with maximum yield at intermediate densities (Akhanda *et al*. 1978; Brown *et al*. 1970; Bunting 1971; Farazdaghi 1968; Phipps 1975) is obtained when development at high densities is apparently arrested by low soil moisture content. The relationship may also be influenced by genotype as

suggested by data reported by Blum (1970). On studies of three isogenic lines of sorghum, differing only in date of inflorescence following emergence, at population densities ranging from 2.9 to 27.9 plants/m^2 Blum (1970) reported that dry matter yield of a late maturing hybrid was highest under low population densities and that of an early maturing hybrid was highest under the high density. The highest yield recorded was from the earliest maturing hybrid at densest plant population.

Row spacing and seeding rate studies with sorghum hubrids have yielded variable results. Yield components measured,and probably the confounding of environmental variables introduced by the variations in plant population,may have further influenced the results obtained. Porter *et al.* (1960) reported forage yield decreases and grain yield increases as row spacing increased. Brown and Shrader (1959) noted that there was an inverse relationship between sorghum forage production and water use efficiency. Under irrigation sorghum yields were highest for narrow rows (Grimes & Musick 1960; Porter *et al.* 1960). With limited irrigation, however, wide rows yielded more (Brown & Shrader 1959; Grime & Musick 1959). Similar data were also reported for maize, *Zea maye* L., in which yields were significantly higher at higher densities in narrow rows on irrigation, but when irrigation was not supplied higher densities and narrow rows were found to depress yield (Brown *et al.* 1970) with the rate of decline being affected by such factors as genotype and fertility (Hoff & Medereski 1960; Lang *et al.* 1956). The optimum row spacing, then, depends on the available soil moisture so that as water becomes limiting the optimum width increases.

Numerous research reports indicate that optimum population appears to be related to moisture availability. It is also determined by plant

size with smaller plants requiring a higher population for optimum dry matter yield. Rutger and Crowder (1967a) presented evidence of increasing yield of forage dry matter with increasing density up to the highest level studied (8 plants/m^2) and later the same authors (Rutger & Crowder 1967b) reported that in trials in New York State, no falling off in dry matter yield was found at density of 12.5 plants/m^2. Bunting (1971) suggested that, from the point of view of productivity, under moderate rainfall conditions at least 10 plants/m^2 is required for maize for fodder or silage and, under irrigation or in areas where rainfall is less likely to be limiting a density of 15 plants/m^2 may be preferrable. It has been noted, however, that in the drier areas of the United States maximum yield of forage dry matter is usually reached at much lower densities of 2 to 5 plants/m^2 (Termunde *et al.* 1963) and frequently further increases in plant population lead to a reduction in yield (Alessi & Powers 1965; Rossman & Cook 1966).

In early studies Kiesselbach and Anderson (1925) in Nebraska reported only a 14% forage yield increase for sudangrass with seeding rates ranging from 28 to 168 kg/ha in 18-cm drill rows. Holt (1965) obtained differences in yield at first cutting due to seeding rate, but no difference in total yield for the season. In a later study Holt (1970), working with 'Sudax-12' sorghum x sudangrass hybrid at plant densities ranging from 1.45 x to 13.45 x 10^5 plants/ha in rows 25, 51, and 102 cm apart, reported that number of plants established was not porportional to the number of seeds planted; plant size was inversely proportional to plant population with larger plants occurring in wide rows so that yield/ha did not differ greatly; and within a two-fold change in plant number, yield did not differ significantly by seeding

rate. These results contrast with a number of reports that forage dry matter production responds up to optima at intermediate density and/or intermediate row spacing beyond which either no further increase or gradual decline in production was observed (Brown *et al.* 1970; Bunting 1971; Hunter *et al.* 1970; Itnal *et al.* 1978; Phipps 1975; Rao & Reddy 1978; Reddy & Rao 1978). It should, however, be remarked that these latter authors were working with dual-purpose forage crops.

Broyles and Campbell (1961), Burger and Campbell (1961) and Stickler and Laude (1960) reported that forage yield of dryland sorghum cultivars showed no significant difference in trials with row spacing treatments ranging from 10.2 to 101.6 cm. Burger and Campbell (1961) reported that although row spacing and seeding rate influenced morphological traits such as stem diameter and tillering, no significant effect on herbage yields of sudangrass was attributable to row spacings 10.2, 20.3 and 40.6 cm apart or seeding rates 13.4, 20.2 and 27.0 kg/ha. Peters (1964) reported that dry matter production of sudangrass and sudangrass hybrids, varied with frequency of clipping as row spacing decreased from 101.6 cm to 30.5 cm. Stickler *et al.* (1961) emphasized that any yield superiority of sorghum observed in narrow rows (50.8 cm) where high population was used as compared to wider rows (101.6 cm) was due to high plant population and not to narrow row width, *per se*. These reports, however, are at variance with later research results reported by a number of investigators.

In a study where sorghum population was held constant, Blum and Naveh (1976) showed that although competition effects reduced forage dry matter per plant, as well as tillering and leaf area, double rows of 40 cm were superior in total yields than regular rows of 160 cm.

Burnside *et al.* (1964) reported that narrow row spacing reduced 'RS 501' dryland sorghum height in Nebraska but sorghum population and forage yields were higher in narrow rows than wide rows. In that study sorghum population in 25.4, 50.8, 76.2 and 101.6-cm row spacings were 6.67x, 5.68x, 4.94x, and 4.94 x 10^4 plants/ha, respectively; the respective forage yields were 4596, 4607, 4058, and 3924 kg/ha. Similarly, studies of 'NK 120' sorghum hybrid in row spacings varying from 15.2 to 101.6 cm planted at a range of 1.94x to 7.75x 10^5 seeds/ha showed that population had little effect on yield but a linear trend for increased yields was observed as rows narrowed from 101.6 to 25.4 cm (Robinson *et al.* 1964). Incidently, in a study on the influence of row spacing, nitrogen fertilization and irrigation of 'Sart' sorghum, a sweet forage sorghum hybrid, Doss *et al.* (1964) reported that closer row spacing (45.7 cm) in combination with 336 kg N/ha fertilizer treatment increased forage yield by approximately 3.92 metric tons/ha. Reducing row spacing from 91.4 to 45.7 cm was found to be more effective than N-fertilizer rate and almost as effective as the next increment of irrigation.

The controversy over the influence of seeding rate and row spacing on dry matter production of summer annual forage crops is further augmented by the data reported by Cummins and Burns (1966), Koller and Scholl (1968) and Worker (1973). Cummins and Burns (1966) tested the effects of row spacings on 'Sudax-11' sorghum x sudangrass, 'Suhi-1' sudangrass and 'Gahi-1' pearl millet and determined that these summer annuals produced more forage in narrow rows. Hoveland *et al.* (1967) stated that seeding Sudax-11 at 33.6 kg/ha in 15.2-cm rows produced a maximum yield of forage. Koller and Scholl (1968)

planted 'Piper' sudangrass and 'Sudax-11' sorghum x sudangrass in 17.8-, 35.6-, and 71.1- cm rows at seeding rates varying from 8.4 to 53.8 kg/ha. They reported that forage yields in narrow (17.8-cm) and intermediate (35.6-cm) rows were similar and exceeded that of the wider row (71.1-cm); and, forage production increased as seeding rate increased, particularly in narrow rows. Worker (1973) studied 'Piper' sudangrass and the sorghum x sudangrass hybrids, 'Sudax-11' and 'Trudan 1' in California all grown at 28 kg/ha in four row spacings ranging from 35.6 to 88.9 cm. He reported that dry matter production of all cultivars decreased as row spacing was increased from 35.6 to 88.9 cm when cut at two harvest stages — pasture stage and flowering stage. At the pasture stage, Sumner *et al.* (1968), also in California, found that dry matter yield from 45.7- or 50.8-cm was more than that from wider or narrower row spacing treatment.

From the data noted above and a number of reports in the literature, it appears imperative that the maximum density and distribution of plants needed for optimum dry matter yields of summer annual forages requires constant re-examination. This is especially true in semi-arid regions where plant competition and uncertainties of water resources can have profound effects on forage production and thereby threaten the future of the livestock industry.

Forage Nutritive Quality

Forage nutritive value may be affected by plant population and distribution as these determine standability and lodging of forage sorghums but there is also indication that forage nutritional components may be influenced by plant population and spatial

distribution (Alexander *et al.* 1963; Hart & Burton 1965; Koller & Clark 1965; Koller & Scholl 1968; Phipps 1975; Worker 1973).

Alexander *et al.* (1963) found that increasing plant population increased maize, *Zea mays* L., silage yield but decreased percent nutrient content and dry matter digestibility. In the highest plant population and lowest fertilizer rate protein digestibility was significantly lower than in other treatment combinations. Fertilizer increased the digestibility of protein, energy and fat. Nandpuri (1963) reported a reduction in protein content at high densities but maximum protein output (kg/ha) was recorded at the highest plant population studied. Thomson and Rogers (1968) suggested that increasing density from 10.8 to 21.6 palnts/m^2 would have only marginal effects on quality components of maize. However, data reported by Phipps (1975) on nutrient composition of three maize genotypes grown at densities 4.9, 11.0 and 16.7 plants/m^2 in row widths 35 and 70 cm indicated that there was little advantage of higher density in dry matter percentage compared with medium density while row width did not markedly affect this production character. At the highest density (16.7 plants/m^2) crude protein, dry matter digestibility and digestible organic matter were reduced. With the exception of magnesium, the mineral content showed similar declining trends as plant density increased.

Koller and Scholl (1968) reported that row spacing had little effect on the chemical composition of forages of 'Piper' sudangrass hybrid and 'Sudax-11' sorghum x sudangrass hybrid. However, under three-cutting regime, crude protein content decreased and lignin increased at first harvest as seeding rate increased. Seeding rate was found to have no significant effect on chemical composition at

second harvest. In a previous study, Koller and Clark (1965) found that the quality of sudangrass forage at pasture stage decreased but improved at the second harvest as plant density increased. Worker (1973) reported data on the influence of row spacing on chemical composition of irrigated 'Piper' Sudangrass, and 'Sudax-11' and 'Trudan 1' sorghum x sudangrass hybrids when harvested at pasture stage and flowering stage. Crude protein content of all cultivars increased with row spacing at the pasture stage but decreased with row spacing at the flowering stage. Row spacing did not affect fiber, fat or mineral composition. In a study combining row spacing, irrigation and nitrogen fertilization treatments, Doss *et al.* (1964) reported that closer row spacing increased both crude protein content and dry matter yield of Sart sorghum forage and in general, crude protein content varied inversely with soil moisture and directly with rate of nitrogen application. Reducing the row spacing to 45.7 from 91.4 cm was found to be more effective than increasing the nitrogen fertilizer rate, and almost as effective as increasing the next increment of irrigation under the environmental conditions of the study area.

All the studies, cited above, were conducted in sites where environmental resources are adequate for plant development, yet they indicate that plant density and/or row spacing may influence the nutritive value of forages at one stage of physiological development or another. It is not known, however, whether such data apply to forage sorghums grown under semi-arid conditions of north eastern Colorado. Some evidence with cool-season grasses suggests that such response pattern may also hold true for forages cultivated in semi-arid environments (McGinnies 1970; Sims & Cook 1967). In a row-spacing

and seeding rate study in north central Colorado, McGinnies (1970) reported that crude protein content of crested wheatgrass, *Agropyron desertorum* (Fisch. ex Link) Schult., averaged over all seeding rates, declined significantly in one year as row spacing increased but in another year row spacing had no effect on nutrient content. Sims and Cook (1967) investigated the nutritive quality of two populations (thick vs. thin stands) of four introduced wheatgrasses, *Agropyron spp.* in Utah. Although no significant difference in percent dry matter digestibility was observed between the two populations, the authors reported that herbage samples of all species from thick stands had a higher percentage of cellulose digested (27.4%) than samples from thin stands (20.6%).

Relationship of Distribution of Forage Dry Matter and Quality Within Plant Morphological Components to Whole-Plant, Nutrient Composition and Digestibility

On a gross morphological basis, the proportion of leaves within the forage dry matter is generally considered the most important physical determinant of forage nutritive value. A plant that is leafy is usually considered highly nutritious. Several research reports have, directly or indirectly, indicated that the relative feeding value of forage may be determined by the leaf:stem ratio within the forage dry matter (Craigmiles *et al.* 1958; Fribourg *et al.* 1976; Gangstad 1964, 1966; Hanna *et al.* 1974; Luckett *et al.* 1967; MacDonald 1946; Reid *et al.* 1959; Reid *et al.* 1964; Sims & Cook 1967; Stobbs & Wheeler 1977; Ward *et al.* 1979). While a number of researchers have indicated a significant relationship between leafiness and forage preference

(Gangstad 1964, 1966; MacDonald 1946; Stobbs & Wheeler 1977; Ward *et al.* 1979) or digestibility (Luckett *et al.* 1967; Reid *et al.* 1959; Reid *et al.* 1964), there are other reports within the literature indicating otherwise. Gangstad (1964, 1966) reported that palatability in forage sorghum and sudangrass hybrids was positively correlated with percent leaf, percentage crude protein and total sugar concentration. The data reported by Rabas *et al.* (1970) show that in four sorghum x sudangrass and two sudangrass hybrids studied, percent leaf and percentage dry matter were not associated with palatability to cattle or sheep in 7 of 8 trials. Reid *et al.* (1959) and Reid *et al.* (1964) demonstrated that with first-growth forages consisting of several pure and mixed swards leaf content and percentage digestible dry matter were highly correlated ($r = 0.95$). Yet, in studies by Minson *et al.* (1960) and Mowat *et al.* (1965b) digestibility was not closely related to the proportion of leaf in the crop. Although a progressive decline in leaf:stem ratio and leaf and stem *in vitro* dry matter digestibility were observed in all cool-season grasses and the legume studied with advancing maturity, Mowat *et al.* (1965b) noted that leaf content, even within species, was rather a poor indicator of digestibility.

Nevertheless, there is consensus that leaves and stems exhibit differences in growth rates, chemical composition, digestibility, and in their responses to grazing or clipping treatments. It is recognized that the percentages of leaf tissue decrease and leaf:stem ratio fluctuates as the plant matures. Proportion of chemical constituents and digestibility of nutrient components may also vary differently within the plant parts. These variations may be reflected in the feeding value of the whole-plant forage dry matter. Chemical analyses

and *in vitro* digestibility procedures have developed sufficiently to permit estimation of nutrient constituents and digestibility within leaf and stem fractions (Furuya *et al.* 1979; Goering & Van Soest 1970; Masoaka & Tarumoto 1978; Mowat *et al.* 1965b; Pearson 1969; Pitchard *et al.* 1963; Tarumoto & Masoaka 1978; Tilley & Terry 1963). It will be of interest to examine the interrelations of the whole-plant feeding value to the various dry matter proportions of these plant fractions and the operative variables in their chemical constituent and digestibility as the plant progresses to physiological maturity.

Wilkinson *et al.* (1970) reported that *in vitro* dry matter digestibility (IVDMD) in six successive layers in bermudagrass increased from stemmy basal to top layers, and associated with this increase were lower acid-detergent fiber (ADF), acid-detergent lignin (ADL) and small decreases in cell-wall constituents (CWC). Although quality was greater in the upper leafy layers, higher proportion of dry matter was contained in the lower than in the upper layers. In a somewhat classic study on the adverse effects of physiological maturity on the feeding value of plant fractions, Burton *et al.* (1964) reported that young leaf blades from the top heading culms of 'Gahi-1' pearl millet and 'Georgia 337' sudangrass were more palatable; contained more CP and true protein, and less lignin than older lower leaves taken from the same culms. Eighteen successive leaves taken from top to bottom of a late-maturing millet were noted to decrease in digestible DM from 73.9% to 58.2%. Although no significant differences were recorded in cellulose or total available carbohydrates between young and old leaves, Burton *et al.* (1964) reiterated that young leaves were unquestionably more palatable to cattle than old leaves during the trials.

Previous investigations with cool-season grass species revealed that immature stem tissue is as digestible or more digestible than leaf material (Mowat *et al.* 1965a; Mowat *et al.* 1965b; Pritchard *et al.* 1963), but the rate of decline of digestibility with advancing maturity was greater with stems. In these studies crude protein content of leaf and stem portions of the grass species was similar (Mowat *et al.* 1965b); and differences in IVDMD between leaf and stem from plant at preheading to soft-dough stage was not significant, leaf digestibility was lower for those leaves dead or partially dead; but in mature plants dead leaves were higher in IVDMD than stem or head portions (Mowat *et al.* 1965a). Pritchard *et al.* (1963) reported that IVDMD of the six grass species studied decreased at the rate of 0.5% per day throughout the growing season. Sims and Cook (1967) reported that dry matter and cellulose digestibility of leaf and stem fractions of various wheatgrass species decreased steadily as phenological stage of plants progressed. Digestibility of cellulose for leaf and stems was 25.6% and 22.5%, respectively.

Such apparent resemblance in quality of leaf and stem fractions usually observed in cool-season grasses while in the vegetative stage was not encountered in the literature reviewed in the forage sorghums nor other forages such as legumes (Farhoomand & Wedin 1968; Fribourg *et al.* 1976; Luckett *et al.* 1967; Mowat *et al.* 1965b; Stobbs & Wheeler 1977). Both Luckett *et al.* (1967) and Mowat *et al.* (1965b) reported that stem fractions of legume never attained as high crude protein or digestibility as leaves even at the early growth stages. The report of Luckett *et al.* (1967) indicated that from the bud stage to full bloom alfalfa averaged 52.9% leaf. The leaf fractions averaged 79.5%

DMD, 27.5% CP, 20.3% CWC, 14.2% ADF and 3% lignin; while the stem fractions contained 51.8 - 72.2% DMD, 9 - 12% CP, 44.4 - 62.6% CWC, 35.6 - 54.7% ADF and 6.0 - 11.1% Lignin. The authors (Luckett *et al.* 1967) remarked that changes in whole-plant composition and digestibility appeared to be related to the leaf:stem ratio and to changes within the stem fraction.

All the literature reviewed concur that with advancing phenological stage, forage sorghums increased in total yield of dry matter, declined in proportion of leaves and increased in the proportion of less digestible tissues and nutrient components (Ademosum *et al.* 1968; Burger & Hittle 1967; Burns *et al.* 1970; Eilrich *et al.* 1964; Fribourg *et al.* 1976; Jung *et al.* 1964; Martin & Wedin 1974; Webster 1963; Webster & Davies 1956). Webster and Davies (1956) reported that, in Oklahoma, maximum forage yields were ordinarily recorded in late August or early September at about the hard dough stage. Occasionally, when late summer droughts were followed by good rains in September and October maximum yields were secured in October. In Nebraska, data reported by Ward *et al.* (1979) indicated average (2 trials) leaf:stem ratio of 0.99:1 in grain sorghum residue prior to grazing. Martin and Wedin (1974) noted a decline in the ratio of CWC to cell solubles at frost, thus indicating increases in nutritive value. Earlier, Webster (1963) reported that although dry matter yield increased, decreases in protein content were recorded for RS 301F and RS 303F (16.5 to 8.9%), and Atlas and Rox (16.8 to 7.7%) forage sorghums as the crop approached maturity.

Research results on 'Piper' sudangrass and 'RP 30F' sorghum x sudangrass (Farhoomand & Wedin 1968) revealed significant differences

in CP and CF content of plant fractions with advancing maturity, especially when the forage was saved for fall utilization. In both species, the heads were highest in % DM; leaves intermediate; and stems lowest. Leaves of both species were highest in % CP, heads intermediate and stems lowest. Fribourg *et al.* (1976) reported that 'Sudax-11' and 'Trudan' sorghum x sudangrass hybrids, subjected to four cutting managements, produced much larger DM yields at early-bloom than at vegetative stages; and both cultivars produced more DM with 75-cm than with 50-cm growth. Both 50- and 75-cm growths resulted in material that was predominantly leaf of about 80% IVDMD throughout the season. However, in the silage- or hay-stage, Fribourg *et al.* (1976) noted that leaf IVDMD was slightly lower in early-bloom than in vegetative growth phase but the digestibility of stems and heads was even lower.

Few reports were encountered in the literature pertaining to the mineral constituents of sorghum forage plant fractions. Forage sorghum variety trials in the semi-arid northwestern Texas (Owen & Furr 1967) revealed that all the varieties tested were below the postulated optimum beef cattle requirements for P, Ca, S and Zn. Results of studies by Stobbs and Wheeler (1977) showed that leaf DM of 35- to 49-day growths of Sudax (SX-11a) is higher in sulfur than stems material of comparable growth stages. The sulfur content averaged over three sampling periods were: leaf 0.13 to 0.14%, and stems 0.097%. Brawand and Hossner (1976) reported that Ca and P content of leaves of a grain sorghum were highly variable during the interval from plant-booting to half-bloom while K content decreased generally. In the data reported by Stobbs & Wheeler (1977) leaves analyzed 0.42% Ca, 0.27% P, 3.33% K, 0.03% Na and 0.13 to 0.14% S.

It is evident from the literature reviewed that although there is information on the composition of plant fractions the effects of their various proportions with progressive phenological stage on the feeding value of the total herbage material have not been closely examined. It is hypothesized that if these relations could be defined, such information may serve a useful purpose in predicting the nutritive quality of standing forage crop.

Animal Performance on Forage Sorghum Pastures

Adequate nutrients must be available for animals to attain their genetic potential for production. Consequently, in order to fully evaluate pasture productivity, measurements in terms of the animal product must be included.

The composition of diet of a free-grazing animal is determined by interaction of a range of intrinsic and extrinsic factors; and, the composition of the diet that the animal selects may be quite unrelated to the proportion of various plant parts or species available to it. Nevertheless, all observations indicate that herbivores consume leaf in preference to stems (Aii 1976; Arnold 1964; Arnold & Dudzinski 1978; Cook & Harris 1950; Gangstad 1966; Reppert 1960; Stobbs & Wheeler 1977; Ward *et al*. 1979) and green in preference to dry material (Cook *et al*. 1956; Cowlishaw & Adler 1960; Hodgson *et al*. 1977; Reppert 1960; Thomson 1978). Often, animal trials on cultivated pastures are evaluated on the basis of the relation of animal performance to the yield and quality of the total herbage material. Little emphasis has been placed on performance in relation to the yield and quality of the individual plant components that constitute the diet of free-grazing herbivore. The

relationship of animal performance to pasture composition in terms of distribution of dry matter and nutrients within leaf and stem fractions, and their various proportions at different pasture availabilities and stages of physiological maturity, have not been fully explored. These interactions could be especially important in pastures of stout-growing pasture plants such as the forage sorghum hybrids, where maturation effects, *per se*, on digestibility are further complicated by changes in the biomass and quality of components (Ademosum *et al.* 1968; Aii 1976; Thurman *et al.* 1960; Thurman *et al.* 1964) as plants mature.

Within the past decade research has focussed on the performance of various classes of livestock on sorghum forages (Aii 1976; Archer & Wheeler 1978; Cummins & Sudweeks 1976; Dunavin 1970; Hedges *et al.* 1978; Hoveland *et al.* 1971; Hunt *et al.* 1979; Lippke 1974; Said *et al.* 1977; Sheridan *et al.* 1972; Stobbs & Wheeler 1977; Utley *et al.* 1976; Ward *et al.* 1979; Wheeler & Hedges 1972; Wheeler *et al.* 1975). Acceptability, adequate energy intake, nutrient utilization, nutrient imbalances and toxic substances have been cited as major determinants influencing the outcome of animal trials on sorghum forages. Commonly, passing remarks were made to the degree of leafiness as a critical factor of feeding value.

Effects of Plant Physiological Stage of Maturity, Nutrient Composition and Digestibility

Forage sorghums are known to make large quantities of forage biomass and their potential carrying capacity is high (Dunavin 1970; Hoveland 1969; Hoveland *et al.* 1971; Sotomayor-Rios & Telek 1977; St. Louis *et al.* 1979; Wheeler & Hedges 1972). The literature indicated that nutrient content and digestibility were excellent in the vegetative

stages, but as maturity advances, while yield of DM increases, the concentration of digestible nutrients declines (Aii 1976; Beaty *et al.* 1965; Broyles & Fribourg 1959; Burns & Wedin 1964; Jung *et al.* 1964; Jung & Reid 1966; Mays & Washko 1961; Owen & Moline 1970; Reid *et al.* 1964; Rusoff *et al.* 1961; Sotomayor-Rios & Telek 1977; Sphar & Ormiston 1968; Sphar *et al.* 1967; St. Louis *et al.* 1979; Sumner *et al.* 1965; Thurman *et al.* 1964; Vetter & Wedin 1967; Worker & Marble 1968).

Apparently, nitrogen fertilization has no effect on digestible DM or percent leafiness, although CP content or protein digestibility may be enhanced (Hoveland *et al.* 1967; Hoveland *et al.* 1969; Reid *et al.* 1964; Wheeler & Hedges 1972). In the data reported by Wheeler & Hedges (1972) a preplant application of anhydrous ammonia had no effect on DM available for grazing and tended to depress animal performance. Earlier Yates *et al.* (1964) reported that N-fertilization of *Sorghum almum* Parodi, increased yield and crude protein content but the effects on animal production were relatively small.

The effect of physiological maturity on feeding value of sorghums is especially complex because both plant components and their quality change with maturation. This complex relationship may be explained, in part, by some of the studies reported in the literature. Thurman *et al.* (1960) and Thurman *et al.* (1964) noted that deterioration in feeding quality of sorghum forages is accompanied by increases in yield of herbage biomass. However, these increases in biomass are manifested mainly in higher yields of less digestible stem material while percentages of leaf, sheath and head decreased with yield. Similar data were reported by Wolf and Washko (1967). Likewise, in feeding trials with sorghum forages of 30- to 80-day growth post-planting Aii (1976)

noted that as growth advanced contents of NFE and CF increased rapidly, and the CP:fiber ratio and digestibility of DM decreased steadily.

Since yields of nutrients per unit area increase so dramatically during maturation, some researchers argue that the changes in the nutrient content of DM in the sorghums are of relatively less practical importance. However, such contention could only hold true if maintenance rather than production ration is the primary objective of the pasture establishment. Data from several feeding trials demonstrate that trend in deterioration of DM digestibility is paralleled by decline in intake (Ademonsum *et al.* 1968; Aii 1976; Cummins & Sudweeks 1976; Reid *et al.* 1964; Sheridan *et al.* 1972; Stobbs & Wheeler 1977; Van Wyke *et al.* 1951). Likewise, high positive correlation was noted between sorghum forage intake and steer gain (Lippke 1974; 1980).

The high digestible DM production of forage sorghums at vegetative stages would suggest that animals grazing such forage at the pasture stage should perform satisfactorily. In feeding trials, however, most of the literature reviewed indicate low performance while animals were feeding on sorghum herbage as their sole diet (Aii 1976; Archer & Wheeler 1978; Coleman & Horn 1978; Dunavin 1970; Hedges *et al.* 1978; Hoveland *et al.* 1971; Lippke 1974; Sheridan *et al.* 1972; Stobbs 1975; Stobbs & Wheeler 1977; Wheeler & Hedges 1972; Yates *et al.* 1964). In three-year studies in the humid southeastern United States, Dunavin (1970) and Hoveland *et al.* (1971) reported steer gains of less than 500 g/head/day. The respective total seasonal and annual beef gains in these studies were 168.15 to 246.62 kg/ha, and 72.12 to 136.08 kg/ha. Coleman and Horn (1978) reported daily gains of 520, 340 and 450 g/animal on sorghum-sudan hybrid (SX-17) planted at 16.8, 33.6 and 50.4

kg/ha, respectively. Comparatively, superior animal performances were reported by Utley *et al.* (1976) in summer trials with steers grazing 'Gahi-1' pearl millet and sorghum x sudangrass pastures. During the summer grazing season, steers which grazed 'Gahi-1' pearl millet gained 966 g/day and produced total liveweight gains of 523.51 kg/ha compared with 885 g/day and 341.41 kg/ha for the sorghum x sudangrass summer annuals. Lippke (1974) studied intake and gain of steers fed seven sorghum x sudangrass hays originating from three southern states of the Great Plains. Some of the reported ranges in animal response were: DMD, 49 to 59%; DM intake, 60 to 92 g/kg $W^{0.75}$/day; and daily gain, -130 to 570 g. In this and a later report (Lippke 1980), high correlation coefficients were noted between intake and gain; and DMD and gain, with no significant relationship between intake and digestibility. Lippke (1974) remarked that deviations from the digestibility-intake relationship were associated with differences in leafiness. Similarly, no spectacular results were reported for grazing or feeding trials with other classes of livestock according to the literature reviewed. Aii (1976) reported that when forage sorghum of 30- to 80-day growth post-planting was fed as greenchop to dairy cows DM consumption was equivalent to maintenance and a large portion of stem fractions was rejected as orts. Sheridan *et al.* (1972) and Wheeler & Hedges (1972) reported that young sheep grazing forage sorghums showed liveweight changes of 27 to 55 g/day, and -6 to 62 g/day, respectively.

Few reports from Colorado appeared in the literature review on the performance of animals while on forage sorghum roughages. These reports pertain mainly to winter feeding trials with forage sorghum roughages at the Eastern Colorado Research Centre (Denham 1971a;

Denham 1971b; Denham *et al.* 1965). In two winter-grazing trials with 17 varieties of forage sorghum the mean between variety ranges in forage value components noted were: plant heights, 100.4 to 168.9 cm; DM yield, 2481.9 to 4531.1 kg/ha; IVDMD, 57.9 to 72.7%; and CP, 2.7 to 5.4% (Denham 1971b). When steer calves, ranging in weight from 138.3 to 179.2 kg, were wintered on forage sorghum silage or fodder (Dehham 1971a; Denham *et al.* 1965) maximum average daily gain (812 g) was realized when lightweight calves receiving NEB 305 silage were supplemented with 0.91 kg grain, 0.454 kg cotton seed meal and 1.13 kg alfalfa hay per head per day (Denham 1971a).

There are, apparently from the literature reviewed, no reports from Colorado on the performance of cattle grazing forage sorghums during the pasture stage. Because most of the literature cited are results of experiments conducted in the humid regions of southeastern United States and other countries, it appears more than relevant to examine the performance of animals on forage sorghums at the pasture stage in Colorado.

Effects of Nutrient Imbalances and Toxic Substances

Experiments described in this study do not involve analysis of toxic substances or nutrient imbalance in sorghum forages. However, sorghum pasturage is known for certain nutritional problems. Therefore, a literature review on animal trials on sorghum pastures would seem incomplete without a brief mention of the commonly observed nutritional problems associated with sorghum forage *in situ* utilization and the conditions under which livestock susceptibility may be provoked.

The literature reviewed indicated that sorghum forage may be deficient in several essential nutrients for normal animal productive processes. Studies mainly from southeastern United States cited by Owen and Moline (1970) reported positive animal responses when sorghum forages were supplemented with energy, lysine, Ca and Co. In the case of energy supplementation, however, a three-year study with steers in Alabama (Hoveland *et al.* 1971) showed that while animal performance in terms of carcass quality and grade was enhanced, sorghum forage DM intake was significantly reduced and the method proved uneconomical.

There are indications that Zn content of sorghum forages may also be inadequate in meeting the dietary requirements of livestock for production. According to Ensminger and Olentine (1978) and NRC (1976) the dietary requirements for growing and finishing beef cattle is 20 to 30 mg/kg DM of ration. Underwood (1977) stated minimum Zn requirements of 50 mg/kg DM for productive processes. Preliminary data of diets of yearling steers grazing forage sorghum at the Eastern Colorado Research Centre, Akron, revealed Zn contents ranging from 17.8 mg/kg DM in the vegetative forage in August to 9 mg/kg DM in the weathered forage in January of the ensuing year. This apparent insufficiency of Zn concentration in the sorghum forage in relation to requirements is supported by data reported by Owen and Furr (1967) from the semi-arid northeastern Texas and Luthra *et al.* (1978) from India.

Recent investigations in East Africa, Australia, and New Zealand have reported substantial increases in animal performance by sulfur supplementation and sodium to a lesser extent (Archer & Wheeler 1978; Bouchard & Conrad 1973; Hunt *et al.* 1979; Said *et al.* 1977; Stobbs & Wheeler 1977; Wheeler *et al.* 1975). According to these workers,

livestock responses to S supplements may occasionally be related to an induced deficiency exacerbated by HCN concentration of sorghum forages.

Doggett (1970) and Tapper & Reay (1973) stated that most sorghums contain appreciable amounts of the cyanogenic glucoside, dhurrin, from which the respiratory poison HCN is released within the animal. In ruminants, HCN is normally detoxified in the rumen and liver by reactions with sulfide and cystine and the resulting thiocyanate is excreted (Blakley & Coop 1949; Tapper & Reay 1973). Blakley and Coop (1949) stated that the reaction requires approximately 1.2 g S/g HCN. Consequently, HCN can attain toxic levels and/or S deficiency can be invoked by the inherent low S content of the sorghum type and/or high cyanide intake which renders the ingested S unavailable for productive processes in the animal.

Several studies have shown that the levels of HCN potential in sorghum forages vary widely with the forage variety, its physiological stage of maturity, storage conditions and soil N, P and moisture status (Balasundaram *et al.* 1978; Franzke *et al.* 1939; Harms & Tucker 1973; Jung *et al.* 1964; Loyd & Gray 1970; Patel & Wright 1958; Rabas *et al.* 1970). Loyd and Gray (1970) reported that highest concentration of HCN in sorghum cultivars occurred in leaves one week after emergence; and the concentrations of HCN in leaves, tillers, stems and heads decreased as maturity advanced. Jung *et al.* (1964) reported that HCN level in 'Piper' sudangrass increased with increments of N fertilization and almost all samples containing HCN were those cut at the 30.5-cm stage of growth. According to Owen and Moline (1970) when sudangrass has reached the height of 61 cm or more it is safe to pasture. Earlier, Boyd *et al.* (1938) stated that when sorghums are pale or yellow-green,

they are safe, whether short or tall. They designated HCN levels of 25 to 50 mg/100 g DM as safe, and levels of 75 to 100 g or more as dangerous to livestock.

Under certain conditions of growth, cultivation and fertilization, somewhat analogous to those producing cyanogenesis, sorghums are also known to accumulate levels of NO_3 dangerous to livestock. Gilbert *et al.* (1946) found NO_3-nitrogen varying from 1000 to 4900 ppm in immature sudangrass on two different soil types in Wyoming. Harms and Tucker (1973) reported that N fertilization increased NO_3 and HCN concentration of seven sudangrass cultivars. Artificial light in growth chamber reduced NO_3-nitrogen but had little effect on HCN concentration. Research results showed that the mechanisms of NO_3 accumulation is associated with factors influencing NO_3 reductase activitiy. Hageman *et al.* (1963) summed up that under reduced light intensity, light periods of short duration and cool temperatures, there was low NO_3-reductase activity and high accumulation of NO_3 in plants.

In practice, Owen and Moline (1970) have suggested that effective means of minimizing the problems of HCN and NO_3 are: 1) application of fertilizers containing K, P and Ca; 2) allowing plants to reach a height of at least 45.7 to 61.0 cm before harvesting; 3) raising the stubble height for greenchop harvesting; 4) delaying the harvest of a crop which has had its growth retarded by drought, frost or hail; 5) allowing the crop to mature or field-cure; and 6) preserving the crop as silage rather than feeding as pasture or greenchop.

CHAPTER III

MATERIALS AND METHODS

Two experiments were conducted during the summers of 1978 and 1979 with forage sorghum. Experiment I was a small plot trial while Experiment II a large pasture trial. The field (4.5 ha) on which the small plots were established and the large pasture field (17.1 ha) are sandy plains range sites previously planted to annual forage crops for silage or winter fodder. Experiment I was conducted to evaluate systems of forage production that maximize pasture components in a monoculture as well as plant morphological feastures that result in optimum dry matter yield and nutrient concentration. Experiment II was to assess systems of forage production manipulation and utilization that result in optimum available forage for grazing and animal response.

Description of the Study Area

The Eastern Colorado Research Centre is located in the Central Plains — T5N R52W, 6th P.M. It lies approximately 27.3 km from Akron in northeastern Colorado at an elevation of 1180 m with the topography varying from nearly level to slightly rolling dunes. The soils vary from loamy sands in loessial deposited dunes to sandy loams in the low lying areas. A 13-year summary of the climatic data of the area (Sims & Denham 1969) showed prevalence of highly variable, elastic weather conditions. The climate is characterized by hot, often dry summers; mild, usually dry autumns; cold winters; and moist, cool springs. Average annual precipitation ranged from as low as 252.7 mm to a high

of 492.5 mm with a 378.5 mm 13-year average. Most of the precipitation occurs between April and September. May is normally the wettest month followed by June and July. The growing season is 117 days, approximately early May to the second week of September. Mean monthly temperatures are highly variable throughout the year. July and August are the months with the hottest average maximum temperature, 37.8°C.

Experiment I

Pasture Production Systems

The field for each year's seeding was prepared by disking and then smoothing. Land preparation and seedings were made as soon as possible after soil had thawed and dried enough to permit cultivation. Seedings were made immediately to take advantage of late spring storms and any stored soil moisture but late enough that soils had reached minimum temperature for germination. Planting dates were June 14, 15, 1978; and June 19, 1979. In 1979 because of an intense rain storm on June 24 which washed all fields, the plots were replanted on June 28 and 29. 'NEB 306F' forage sorghum, *Sorghum bicolor* (L.) Moench X *Sorghum sudanense* (Piper) Stapf. hybrid was seeded in all plantings to a depth of 7.6 cm with a grain drill.

The 1978 trial comprised a 3 x 4 factorial, randomized block design (one replicate) with three row spacings and four seeding rates. The 1979 trial was a 3 x 4 x 2 fractorial, randomized block design in two replicates. Treatments consisted of all combinations of three row spacings and four seeding rates (Table 1). The row spacings were 25, 51 and 76 cm; and the seeding rates were 5.6, 9.0, 11.2 and 16.8 kg · ha^{-1}. The individual plots were 8.6 x 73.4 m, with rows running the

length of the plots. About 30 days post-planting, with plants at an average height of 40 cm, all plots were sprayed with 2, 4-D (2, 4-dichlorophonoxy acetic acid) or Banvel (3, 6-dichloro-o-anisic acid) to control weeds.

Table 1. Treatment combinations of row spacings (r) and seeding rates (S) for pasture production systems, 1979.

	TREATMENTS		
	Row spacings		
Seeding rates	r_1	r_2	r_3
S_1	S_1r_1	S_1r_2	S_1r_3
S_2	S_2r_1	S_2r_2	S_2r_3
S_3	S_3r_1	S_3r_2	S_3r_3
S_4	S_4r_1	S_4r_2	S_4r_3

Pasture Measurements

Pasture measurements made included plant height, culm diameter, number of leaves per culm, plant density (number of culms per unit area) and forage yield estimates by leaves and stems. The proportion of forage dry matter accounted for by leaves and the ratio of leaf:stem were also determined. Samples were taken on seven and three sampling dates in 1978 and 1979, respectively, spread over the period of early vegetative growth to desinence of growth following frost. The sampling dates and age of plant at sampling are shown in Table 2.

Table 2. Sampling dates and age of plants (days post-planting) at sampling.

YEAR	Sampling date	Plant age
1978	July 11	26
	July 25	40
	August 8	54
	August 24	70
	September 2	79
	September 16	93
	September 30	107
1979	August 20	52
	September 9	72
	October 9	102

Plant growth during any given period was probably controlled by the amount of available soil moisture. Although no direct meteorological measurements were made, it should be mentioned that 1978 was an exceptionally dry year; whereas, 1979 appeared to be above average. Plant height, culm diameter and number of leaves per culm were determined by measuring no more than 50 plants within a quadrat of 0.5 x 1.5 m. Thus, number of measurements for each parameter may range from zero to 50, depending on the occurrence of plants within the quadrat. Plant density was determined by counting the number of all culms within a quadrat. Twenty of such quadrats were randomly located within each plot at sampling. Culm diameter was measured with vernier calipers at approximately 10 cm above ground. Number of leaves were

determined by counting from the base of the culm to the upper most fully expanded leaf. Following discrete and linear measurements all plants within the quadrat were clipped to the ground. Subsequently, samples were separated into leaves and stems, and chopped into about 5 cm fragments to facilitate and hasten drying. Herbage samples were dried to a constant weight in a forced air oven at 50°C. After drying samples were weighed to determine yields of dry matter. Representative samples of leaf, stem and whole plant material were selected, ground in a Wiley mill, Model 4, through a 20 mesh screen and saved for later *in vitro* digestibility determination, as well as chemical and nutrient analysis. The *in vitro* digestibility determinations and the chemical and nutrient analysis were run only on the samples from the 9.0 kg · ha^{-1} seeding rate treatments. Similarly, from the samples of the 1978 trial only plant components of physiological ages 40, 70 and 93 days post-planting were analyzed. All other chemical and nutrient data of 1978 and of 1979 seeding rate treatments other than 9.0 kg · ha^{-1} were only estimates obtained through empirical equations.

Chemical and Nutrient Analysis

Composite plant, leaf and stem materials were analyzed for chemical and nutrient comstituents. The components determined were neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), crude protein (CP) and phosphorus (P).

Neutral detergent fibre, ADF and ADL were analyzed by the forage fibre analysis techniques described by Goering and Van Soest (1970). Cellulose and hemicellulose were determined by difference. Cellulose content was calculated by subtracting the percent lignin from

the percent ADF. Similarly hemicellulose was estimated as the difference between cell walls (NDF) and ADF (Colburn & Evans 1967; Ford *et al.* 1979; Golding *et al.* 1976; Lippke 1980). Crude protein (N x 6.25) was determined using the standard micro-kjeldahl procedure of the Association of Official Analytical Chemists (A.O.A.C. 1975). Phosphorus was determined by the macro method of A.O.A.C. (1975).

In Vitro Digestibility

Herbage samples of whole plant, leaf and stem material were analyzed for dry matter digestibility. *In vitro* dry matter digestibility (IVDMD) was determined by the *in vitro* techniques described by Pearson (1969). For the 1978 samples only plant materials of physiological ages 40, 70, 93 days post-planting were analyzed. In both years only samples from the 9.0 kg · ha^{-1} seeding rate treatment were analyzed.

Statistical Analysis

As there was no replication in the 1978 experimental design the least-square method with unequal subclass was used to analyze the data. Other data was analyzed by analysis of variance. F-test was used to test the significance of difference among treatment means. Treatment means were separated by the Duncan's Multiple Range test (Little & Hills 1978). Simple and multivariate analysis were used to determine the relationship among parameters and develop predictive equations. The true association among parameters measured was tested by both standard partial correlation and covariance analysis (Snedecor & Cochran 1976). These analysis were done on dry matter, *in vitro* digestibility as well as chemical and nutrient components.

Experiment II

Pasture Production System

Seed variety, land preparation and planting procedures were similar to those reported in Experiment I. A 17.1-hectare field divided into 7.1- and 10-hectare sections by a permanent fence was used in establishing the pastures. The two sections were considered as replicates and sown into forage sorghum on June 14, 1979. A rain storm, already mentioned under Experiment I, necessitated the re-planting of all sections on June 27 and 28. The experimental plan was a randomized block design with two replications. Treatments were three row spacings (25, 51 and 76 cm) at 9.0 kg · ha^{-1} randomly allocated within each replicate section. Thirty days post-planting all fields were sprayed with 2, 4-D or Banvel to control weeds.

Grazing Design

Each pasture-type replicate was divided into three pasture-type subunits with electric fence across row spacing treatment. Pasture-type subunits were utilized in rotation within five grazing periods (each period of average eight-day interval). The experimental design was a 3 x 5 x 2 factorial, randomized block. Treatments were three pasture types (25-, 51- and 76-cm-row spaced plantings) and five grazing periods in two pasture replications (Table 3). Total length of the trial period was 39 days.

Table 3. Pasture type (P_i), replicate pasture-grazing subunit (R_{ij}), and grazing periods during the 39-day trial, 1979.

GRAZING			PASTURE TYPES					
			P_1 = 25 cm-rows		P_2 = 51 cm-rows		P_3 = 76 cm-rows	
Dates	Period	Plant age*	Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2
			Number of animals					
			7	5	7	5	7	5
August 14 - 23	1	48	P_1R_{11}	P_1R_{22}	P_2R_{11}	P_2R_{22}	P_3R_{11}	P_3R_{22}
August 23 - 30	2	56	P_1R_{12}	P_1R_{23}	P_2R_{12}	P_2R_{23}	P_3R_{12}	P_3R_{23}
August 31 - September 9	3	63	P_1R_{13}	P_1R_{21}	P_2R_{13}	P_2R_{21}	P_3R_{13}	P_3R_{21}
September 9 - 16	4**	73	P_1R_{11}	P_1R_{22}	P_2R_{11}	P_2R_{22}	P_3R_{11}	P_3R_{22}
September 26 - 22	5**	80	P_1R_{12}	P_1R_{23}	P_2R_{12}	P_2R_{23}	P_3R_{12}	P_3R_{23}

*Days post-planting.
**Pasture secondary regrowth following the first grazing rotation.

Animals and Body Weight Measurements

Thirty-two steers and four heifers were used in the grazing trial. The heifers were added in order to maintain a constant stocking density between the pasture treatments and within replicate. They were not included, however, in the animal response analysis. At the start of the trial, the stock were approximately 15 months of age and averaged 420 kg body weight. The animals were blocked and divided into six groups according to frame size and body weight. Groups were then randomly alloted to pasture types and replicates (Table 3). The same

group of animals remained in their respective pasture treatment allotment throughout the trial period.

Five periods of rotation grazing were used to utilize the pastures. The first three consecutive periods coincided with the physiological stage of maturity of the plant components while the subsequent two periods encompassed the pasture regrowth following grazing. Water and complexed-mineral salt were offered *ad libitum*. Animals were weighed fortnightly following approximately 16-hour shrinkage over night.

Pasture Measurements

Measurements of botanical and nutrient components of both available and residual pasture following grazing were done to evaluate any factors that may affect performance of stock grazing the pasture. Botanical components measured were total herbage biomass (kg dry matter · hectare^{-1}), forage allowance (kg dry matter · head^{-1} · day^{-1}) and apparent herbage intake (kg dry matter · head^{-1} · day^{-1}). The proportion of stems and leaves in each of these components were also determined. Nutrient components measured were CP and IVDMD.

Forage yield estimates were obtained by clipping to ground level twenty 0.5 x 1.4m - quadrats within each pasture subunit before and after grazing. The samples thus collected were subsequently separated into leaves and stems. Dry matter yield was determined following drying in an oven at 50^{o}C. The difference in herbage biomass between pre- and post-grazing phytomass provided estimates of "dry matter disappearance" which is equated with "apparent dry matter intake." No correction was made for any plant growth that may have occurred during the pre- and post-grazing sampling interval.

Crude protein and IVDMD were determined by the techniques noted under Experiment I.

Statistical Analysis

Statistical analysis and procedures used to analyze the animal and pasture data were similar to those given under Experiment I. Analysis of variance, F-test, mean separation test and regression analysis were used to analyze the data and evaluate the significance of relationships among parameters measured and/or estimated.

CHAPTER IV

RESULTS AND DISCUSSION

Experiment I

Pasture Establishment Trials

Effects of Forage Density and Spatial Distribution on Pasture Yield Components

Results of 1978 and 1979 pasture trials averaged over all row spacing and seeding rate treatments at various stages of plant physiological maturity are shown in Table 4. Pasture materials examined included samples of early vegetative (26 to 52 days post planting) to early bloom, and frosted samples (93 to 107 days post-planting). Pasture yield components including plant height, plant density, number of leaves per unit area, leaf and stem biomass as well as individual plant weight increased with pasture age. The ratio of leaf to stem and percentage of leaf within forage dry matter (DM), on the other hand, declined with advancing stage of physiological maturity. Stem diameter increased initially but then stabilized or declined in the mature forage, presumably as plants dehydrated and/or as higher DM constituted a greater proportion of the plant fresh weight. The declines in stem diameter at an advanced plant growth stage concur with data reported by Burger *et al.* (1961), Holt (1965, 1970) and Stickler & Laude (1960) in trials with several sudangrass varieties. While the magnitude of values for forage yield components differed between the two years, the plant physiological stage effects showed the same pattern for each year (Table 4).

Table 4. Forage yield components of NEB 306F forage sorghum at various stages of plant development under the semi-arid conditions of Northeastern Colorado (average overall row-spacing and seeding rate treatments).

FORAGE YIELD COMPONENT	1979 TRIAL[1]			1978 TRIAL[2]						
	HARVEST I	HARVEST II	HARVEST III	HARVEST I	HARVEST II	HARVEST III	HARVEST IV	HARVEST V	HARVEST VI	HARVEST VII
Plant height, cm	57.45	84.27	86.54	16.83	49.90	54.03	62.30	47.75	65.73	71.71
Stem diameter, mm	12.66	15.09	14.69	-	11.68	12.93	12.55	13.57	14.01	14.80
Plant density, x 10^4 culms·ha^{-1}	28.14	29.21	32.27	11.09	11.86	11.87	15.15	11.29	17.86	20.77
No. of leaves x 10^5·ha^{-1}	18.28	23.31	30.25	7.10	8.71	7.55	10.90	7.15	13.86	18.37
Total forage yield, kg · ha^{-1}	844.92	1909.13	2997.14	-	1046.22	1869.53	3137.45	2369.52	4642.16	5006.58
Leaf DM yield, kg · ha^{-1}	508.62	1089.58	1597.94	-	663.81	1109.67	1690.42	1245.02	2215.26	2359.39
Stem DM yield, kg · ha^{-1}	336.30	819.55	1399.19	-	382.42	761.86	1447.04	1124.50	2426.90	2647.19
DM yield per plant, g	3.30	7.40	10.10	-	10.30	17.30	21.60	24.20	27.80	24.60
Leaf:stem ratio, weight basis	1.59	1.38	1.20	-	1.84	1.44	1.22	1.11	0.95	0.90
Percent leaf, weight basis	61.02	57.74	54.04	-	64.35	59.01	54.50	52.30	47.98	47.33

[1]1979 Trial - Harvests I, II and III were cut at 52, 72 and 102 days post planting, respectively.
[2]1978 Trial - Harvests I, II, III, IV, V, VI and VII were cut at 26, 40, 54, 70, 79, 93 and 107 days post planting, respectively.

As a consequence of the 1978 experimental design, only data from the 1979 trial were analyzed. Means of several pasture yield components across seeding rates and row spacings are given in Table 6. Results of analysis of variance (ANOVA) at three harvests with seeding rates and row spacings as main effects are shown in Table 5. The ANOVA results indicate that main effects, except with respect to plant height and stem diameter at harvests I and II; and leaf:stem ratio and percentage of leaf within forage DM at harvest III, were significant. The data, in agreement with results of trials with crested wheatgrass (McGinnies 1970) and several maize hybrids (Hunter *et al.* 1970), revealed no significant seeding rate x row spacing interraction in all the cases examined (Table 5). Consequently, the effects of seeding rates and row spacing will be discussed separately.

In contrast to the forage sorghum trials of Akhanda *et al.* (1978) and Burnside *et al.* (1964) there is no evidence from the data in the present study to indicate that plant population or seeding rate had significant influence on plant height. Similarly, the leaf:stem ratio and the percentage of leaf within forage DM were not significantly ($p > .1$) affected by seeding rate (Table 5). However, stem diameter, plant density, number of leaves per unit area, leaf and stem biomass as well as forage DM yield per plant were significantly influenced by seeding rates (Table 5). Forage yield components such as plant density, number of leaves per unit area, and leaf and stem biomass increased with seeding rates at all harvests (Table 6). It was noted, however, that stem diameter and forage DM yield per plant were inversely proportional to seeding rate and plant density. Similar data were reported by Burger *et al.* (1961) and Holt (1970) with

Table 5. Summary data of ANOVA on yield components of NEB 306F forage sorghum planted in three row spacing and four seeding rate treatments (1979 trial).

PASTURE CRITERIA AND SOURCES OF VARIATION	HARVEST I (52)* MS	F	Significance	HARVEST II (72) MS	F	Significance	HARVEST III (102) MS	F	Significance
PLANT HEIGHT, cm:									
Main Effects	22.46	0.64	ns**	29.99	1.20	ns	215.32	5.11	.01
Row spacings	42.05	1.20	ns	34.20	1.45	ns	455.33	10.81	.002
Seeding rates	9.40	0.27	ns	27.18	1.16	ns	55.31	1.31	ns
Rows x rates interaction	-	-	-	-	-	-	28.72	0.68	ns
Residual	34.98			23.52			42.29		
STEM DIAMETER, mm:									
Main Effects	3.67	2.96	.109ns	6.12	2.67	.13ns	7.17	5.62	.007
Row spacings	2.59	2.09	ns	1.39	0.61	ns	3.92	3.08	.083
Seeding rates	4.39	3.55	.087	9.27	4.05	.07	9.33	7.32	.005
Rows x rates interaction	-	-	-	-	-	-	1.67	1.31	ns
Residual	1.24			2.29			1.27		
PLANT DENSITY, per ha:									
Main Effects	5.12×10^{10}	19.66	.001	4.95×10^{10}	11.92	.005	5.74×10^{10}	22.88	.001
Row spacings	2.94×10^{10}	11.28	.009	2.43×10^{10}	5.87	.039	0.56×10^{10}	2.22	.151ns
Seeding rates	6.58×10^{10}	25.24	.001	6.62×10^{10}	15.95	.003	9.20×10^{10}	36.66	.001
Rows x rates interaction	-	-	-	-	-	-	2.35×10^{10}	0.94	ns
Residual	0.26×10^{10}			0.415×10^{10}			0.251×20^{10}		
NUMBER OF LEAVES, per ha:									
Main Effects	2.05×10^{12}	8.08	.012	3.04×10^{12}	18.45	.001	4.04×10^{12}	14.20	.001
Row spacings	1.69×10^{12}	6.68	.030	2.27×10^{12}	13.78	.006	0.212×10^{12}	0.75	ns
Seeding rates	2.28×10^{12}	9.02	.012	3.55×10^{12}	21.57	.001	6.58×10^{12}	23.17	.001
Rows x rates interaction	-	-	-				0.217×10^{12}	0.77	ns
Residual	0.253×10^{12}			0.164×10^{12}					
TOTAL FORAGE YIELD, $kg \cdot ha^{-1}$:									
Main Effects	3.347×10^{5}	11.12	.005	5.798×10^{5}	7.70	.014	12.700×10^{5}	3.41	.038
Row spacings	4.739×10^{5}	15.75	.004	3.740×10^{5}	4.97	.053	11.600×10^{5}	3.13	ns
Seeding rates	2.242×10^{5}	8.04	.016	7.171×10^{5}	9.53	.011	13.400×10^{5}	3.61	.046
Rows x rates interaction	-	-	-	-	-	-	3.836×10^{5}	1.03	ns
Residual	0.301×10^{5}			0.753×10^{5}			3.732×10^{5}		
LEAF DM YIELD, $kg \cdot ha^{-1}$:									
Main Effects	1.101×10^{5}	11.50	.005	1.505×10^{5}	9.76	.008	2.564×10^{5}	4.07	.022
Row spacings	1.460×10^{5}	15.25	.004	0.788×10^{5}	5.11	.051	0.831×10^{5}	1.32	ns
Seeding rates	0.861×10^{5}	8.99	.012	1.982×10^{5}	12.86	.005	3.719×10^{5}	5.90	.01
Rows x rates interaction	-	-	-	-			0.635×10^{5}	1.01	ns
Residual	0.096×10^{5}			0.154×10^{5}			0.630×10^{5}		
STEM DM YIELD, $kg \cdot ha^{-1}$:									
Main Effects	0.650×10^{5}	10.19	.007	5.798×10^{5}	7.70	.014	4.382×10^{5}	3.03	.054
Row spacings	1.032×10^{5}	16.18	.004	3.740×10^{5}	4.97	.053	6.346×10^{5}	4.39	.037
Seeding rates	0.395×10^{5}	6.20	.029	7.171×10^{5}	9.53	.011	3.073×10^{5}	2.13	.150ns
Rows x rates interaction	-	-	-	-	-	-	1.413×10^{5}	0.98	ns
Residual	0.064×10^{5}			0.753×10^{5}			1.446×10^{5}		
DM YIELD PER PLANT, g:									
Main Effects	0.000***	.71	ns	0.000	3.86	.065	0.000	7.14	.003
Row spacings	0.000	.04	ns	0.000	0.88	ns	0.000	8.89	.004
Seeding rates	0.000	1.16	ns	0.000	5.85	.033	0.000	5.97	.01
Rows x rates interaction	-	-		-	-	-	0.000	0.36	ns
Residual	0.000			0.000			0.000		
LEAF:STEM RATIO, weight basis:									
Main Effects	0.108	7.12	.017	0.057	4.59	.045	0.095	1.78	.192ns
Row spacings	0.261	17.24	.003	0.089	7.15	.026	0.215	4.04	.046
Seeding rates	0.006	0.37	ns	0.036	2.89	.125ns	0.015	0.27	ns
Rows x rates interaction	-	-	-	-	-	-	0.011	0.20	ns
Residual	0.015			0.012			0.053		
PERCENT LEAF, weight basis:									
Main Effects	0.003	8.65	.01	0.002	4.62	.045	0.004	2.04	.145ns
Row spacings	0.007	20.84	.002	0.002	6.96	.027	0.009	4.74	.03
Seeding rates	0.000	0.52	ns	0.001	3.06	.113ns	0.000	0.23	ns
Rows x rates interaction	-	-	-	-	-	-	0.000	0.25	ns
Residual	0.000			0.000			0.002		

*Pasture age in days post planting.
**ns = not statistically significant.
***Numbers rounded to three decimal places.

Table 6. Effects of row spacing, seeding rates and physiological stage of maturity on forage yield components of NEB 306F forage sorghum grown under semi-arid conditions of Northeastern Colorado (1979 trial).

FORAGE YIELD COMPONENT	TREATMENT	HARVEST I (52)[1]				HARVEST II (72)				HARVEST III (102)			
		Seeding Rates, kg · ha^{-1}											
		5.6	9.0	11.2	16.8	5.6	9.0	11.2	16.8	5.6	9.0	11.2	16.8
Plant height, cm	All row spacings	56.80^{d}	58.57^{a}	59.17^{a}	55.27^{a}	81.47^{a}	85.56^{a}	87.90^{a}	82.15^{a}	85.01^{a}	90.61^{a}	83.60^{a}	86.94^{a}
Stem diameter, mm	All row spacings	14.14^{cd}	12.62^{ab}	12.70^{bc}	11.18^{a}	16.76^{b}	15.41^{b}	15.58^{b}	12.41^{a}	16.00^{c}	14.86^{b}	14.99^{b}	13.00^{a}
Plant density, x 10^{4} culms · ha^{-1}	All row spacings	16.40^{a}	23.68^{b}	22.67^{b}	49.83^{c}	14.40^{a}	26.31^{b}	26.26^{b}	49.85^{c}	19.35^{a}	29.73^{b}	30.86^{b}	49.16^{c}
No. of leaves, x 10^{5} · ha^{-1}	All row spacings	11.63^{a}	15.96^{a}	14.70^{a}	31.13^{b}	12.22^{a}	21.35^{b}	21.36^{b}	38.30^{c}	18.90^{a}	28.39^{b}	29.46^{b}	44.25^{c}
Total forage yield, kg · ha^{-1}	All row spacings	576.55^{a}	728.68^{ab}	834.26^{b}	1240.18^{c}	1305.41^{a}	1745.49^{ab}	2167.53^{bc}	2418.07^{c}	2485.16^{a}	3035.18^{bc}	2911.67^{ab}	3596.54^{c}
Leaf DY yield, kg · ha^{-1}	All row spacings	351.40^{a}	442.65^{a}	493.49^{a}	746.93^{b}	768.88^{a}	1023.98^{b}	1192.75^{b}	1373.10^{c}	1293.16^{a}	1613.45^{b}	1582.74^{b}	1902.32^{c}
Stem DY yield, kg · ha^{-1}	All row spacings	225.15^{a}	286.02^{ab}	340.76^{bc}	493.24^{d}	536.53^{a}	721.91^{a}	974.79^{b}	1044.97^{b}	1151.90^{a}	1421.73^{bc}	1328.93^{ab}	1694.22^{c}
DY yield per plant, g	All row spacings	4.00^{a}	3.00^{a}	3.80^{a}	2.50^{a}	9.50^{d}	6.60^{b}	8.30^{c}	5.20^{a}	12.80^{d}	10.50^{c}	9.80^{b}	7.40^{a}
Leaf:Stem ratio, weight basis	All row spacings	1.59^{a}	1.63^{a}	1.53^{a}	1.60^{a}	1.48^{a}	1.46^{a}	1.25^{a}	1.32^{a}	1.16^{b}	1.17^{b}	1.26^{a}	1.16^{b}
Percent leaf, weight basis	All row spacings	61.18^{a}	61.75^{a}	59.99^{a}	61.16^{a}	59.47^{a}	59.15^{a}	55.46^{a}	56.86^{a}	53.37^{a}	52.76^{a}	55.32^{a}	53.70^{a}
		Row Spacings, cm											
		25	51	76		25	51	76		25	51	76	
Plant height, cm	All seeding rates	57.98^{a}	53.98^{a}	60.40^{a}		81.09^{a}	84.87^{a}	86.84^{a}		94.13^{c}	79.04^{a}	86.24^{b}	
Stem diameter, mm	All seeding rates	13.53^{a}	11.94^{a}	12.51^{a}		15.49^{a}	15.37^{a}	14.41^{a}		15.46^{b}	14.10^{a}	14.51^{a}	
Plant density, x 10^{4} culms · ha^{-1}	All seeding rates	36.39^{c}	19.75^{a}	27.79^{b}		22.43^{a}	37.75^{b}	27.45^{a}		29.22^{a}	33.85^{b}	33.75^{b}	
No. of leaves, x 10^{5} · ha^{-1}	All seeding rates	25.05^{b}	12.06^{a}	17.72^{ab}		16.82^{a}	31.57^{b}	21.53^{a}		28.42^{a}	30.79^{a}	31.55^{a}	
Total forage yield, kg · ha^{-1}	All seeding rates	1119.24^{b}	458.69^{a}	844.81^{b}		1590.35^{a}	2199.98^{b}	1937.05^{ab}		3436.82^{b}	2746.06^{a}	2808.53^{a}	
Leaf DY yield, kg · ha^{-1}	All seeding rates	628.09^{b}	288.24^{a}	609.53^{b}		950.75^{a}	1231.40^{b}	1086.59^{ab}		1712.54^{a}	1517.37^{a}	1563.92^{a}	
Stem DY yield, kg · ha^{-1}	All seeding rates	491.16^{c}	170.45^{a}	347.28^{b}		639.60^{a}	968.58^{b}	850.46^{ab}		1724.28^{b}	1228.69^{a}	1244.61^{a}	
DY yield per plant, g	All seeding rates	3.20^{a}	3.20^{a}	3.40^{a}		8.10^{a}	6.80^{a}	7.40^{a}		12.80^{b}	8.80^{a}	8.80^{a}	
Leaf:Stem ratio, weight basis	All seeding rates	1.29^{a}	1.70^{b}	1.77^{b}		1.55^{b}	1.29^{a}	1.29^{a}		1.01^{a}	1.28^{b}	1.30^{b}	
Percent leaf, weight basis	All seeding rates	56.37^{a}	62.84^{b}	63.85^{c}		60.62^{b}	56.27^{a}	56.32^{a}		50.11^{a}	55.01^{b}	56.19^{b}	

[1] Days post post planting.

[a,b,c,d] Means in rows within a subset with similar letters are not significantly different ($p > .05$) by Duncan's multiple range test.

sudangrass; and by Itnal *et al.* (1978), Rao & Reddy (1978) and Reddy & Rao (1978) with dual-purpose forage sorghum. However, in contrast to the sudangrass (Holt 1970) the forage sorghum in the present trial, despite the reduced stem diameter and forage DM yield per plant, yielded significantly larger amounts of forage DM at the higher than at the lower seeding rates (Figure 1). The results confirm the observation by Stickler *et al.* (1961) that yield advantages of higher seeding rates are as a consequence of higher plant density rather than seeding rate effects, *per se*. In addition, however, the data in the present study suggest that, at least in the mature forage (Table 6), the yield advantages were more specifically attributable to higher yields of leaf rather than stem forage DM material.

The responses of pasture yield parameters to seeding rate effects varied with pasture growth stage. Thus, differences in stem diameter and forage DM yield per plant were most significant with increasing pasture growth while the significance of the differences in leaf, stem and total forage biomass lessened with pasture growth. For example, at harvest I (early vegetative) no significant effects of seeding rates on forage DM yield per plant were observed. However, at later harvests (late vegetative and early reproductive stages) significant differences in forage DM yield per plant due to alterations in seeding rates were noted (Table 5). In contrast to the response of the latter pasture yield component, stem forage DM yields per unit area were initially highly influenced by seeding rates; but as plants matured (harvest III), the differences in stem DM yields were less significant ($p > .10$). Nevertheless, leaf forage DM yields were, even at the latter harvest, significantly influenced by seeding rates ($p < .01$).

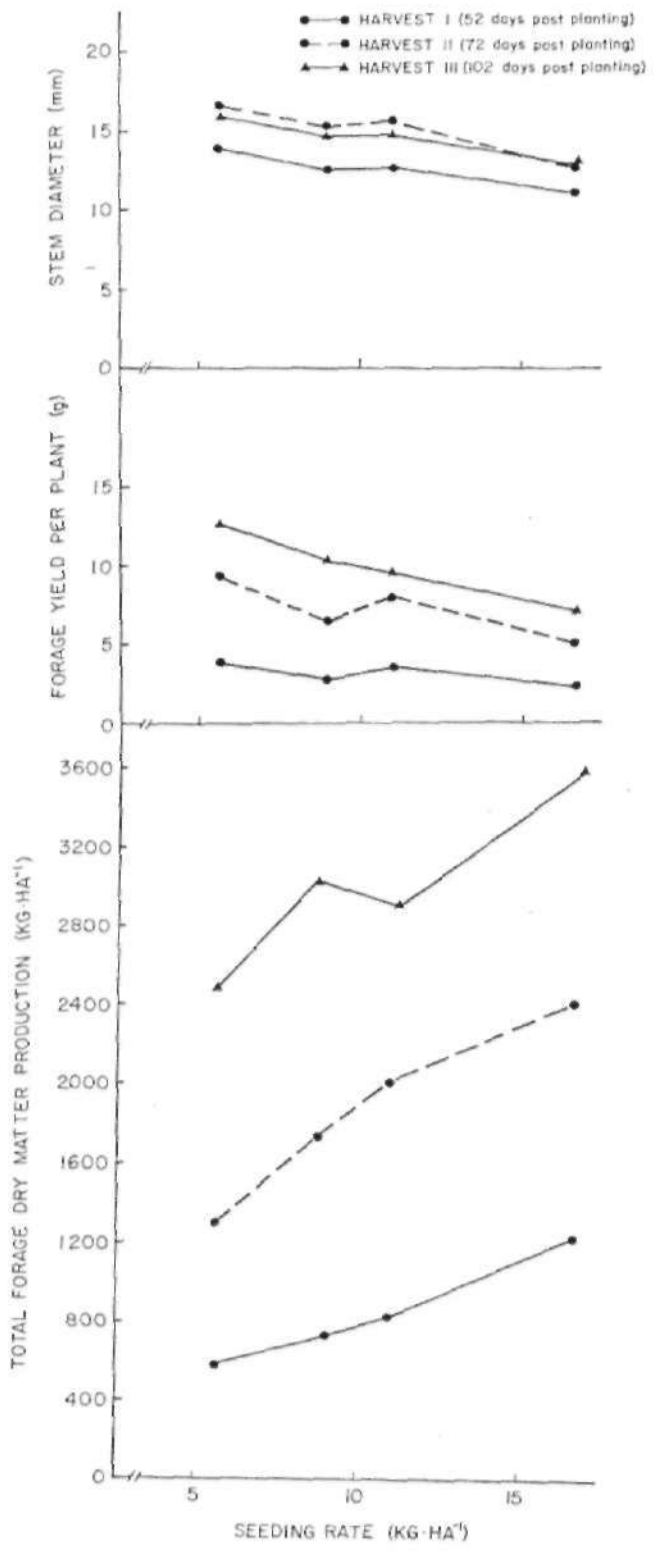


Figure 1. The influence of seeding rate on forage dry matter production, stem diameter and forage yield per plant of NEB 306F forage sorghum under the semi-arid conditions of northeastern Colorado.

Similarly, despite the statistical non-significance, more stem biomass were recorded at the higher than at the lower seeding rates (Table 6). Stem forage DM yields at the early bloom harvest for the 5.6-, 9.0-, 11.2- and 16.8-kg · ha^{-1} seeding rates were 1152, 1422, 1329 and 1695 kg · ha^{-1} respectively. In the same harvest, the leaf forage DM yields for the four respective seeding rates were 1293, 1614, 1583 and 1902 kg · ha^{-1}.

Row spacing had a significant effect at one physiological stage or another on all pasture production characteristics measured (Table 5). Forage DM yield per plant, stem diameter and plant height were affected by row spacing at the early bloom harvest. Harvest prior to that revealed no significant effect of row spacing on these components of pasture primary productivity (Table 5). At the early bloom harvest plant density increased but stem diameter and forage DM yield per plant, as well as total forage DM yield per unit area, declined with wider row spacing suggesting that at constant seeding rate higher plant population and greater intra-row plant competition occur in wide row than in narrow row spacing. In this trial stem diameter, forage DM yield per plant and total forage DM yield per unit area were greater in the 25-cm than in either the 51- or 76-cm row spacing. Conversely, plant density and number of leaves per unit area, except in the early vegetative harvest, were greater in the 51- or 76-cm than in the 25-cm row spacing. In both comparisons, the differences in forage density, number of leaves per unit area, stem diameter, forage DM yield per plant or total forage DM yield per unit area between the 51- and 76-cm row spacings were generally not statistically significant (Table 6). Evidently, stem diameter and forage DM yield per

plant which must to some extent determine the total forage DM per unit area, are production characteristics quite sensitive to competition effects at high intra-row plant densities in row spacing trials or densities accruing from alterations in seeding rates.

Plant height, which was not significantly influenced by seeding rates, as noted previously, showed statistical significance ($p < .01$) at harvest III as a result of row spacing treatments (Table 5). However, this statistical significance must be regarded suspect as shown by the means of plant height within rows in Table 6. The data indicate that the mean plant height within the 25-, 51- and 76-cm row spacings were 94.13, 79.04 and 86.44 cm, respectively. Comparatively, plant heights at harvest II within the respective row spacings were 81.09, 84.87 and 86.84 cm. That the mean plant height within the 51-cm row spacing had declined between the late vegetative and early reproductive stage (84.87 vs. 79.04 cm) is not biologically conceivable in terms of the known relation of cumulative growth with time. Thus, the statistical significance of row spacing effect on plant height observed in harvest III might have resulted from sampling error. Presumably in the present trial both row spacing and seeding rate had no effect on plant height.

Among row spacings, there was no consistent trend in plant density, number of leaves per unit area, total forage or leaf forage DM yield per unit area as plants advanced to physiological maturity. Nevertheless, in general, lower plant density and number of leaves per unit area; and higher yield of total forage in terms of both leaf and stem biomass were noted for the 25-cm than for the 51- or 76-cm row spacing while the differences between the 51- and 76-cm row spacings

were not significant. The results disagree with data reported by Burger and Campbell (1961) in which higher densities of sudangrass were observed in the narrow rows.

The leaf:stem ratio and percentage of leaf within forage DM material were influenced by row spacing treatments as indicated by the ANOVA results (Table 5). However, data in Table 6 indicate no consistency of trend in the leaf:stem ratio between row spacings with increasing pasture growth. Within row spacing the percentage of leaf generally declined but among row spacings the trend was inconsistent.

Row spacing effects on stem forage component were, apparently, more explicit with plant growth as indicated by the magnitude of the differences (Table 6) and the α-levels of significance (Table 5) of the observed differences. Stem diameter within row spacings increased up to an optimum with pasture growth. Between row spacings, though not statistically significantly different, plants in 25-cm row spacing had greater stem diameter than those planted in either the 51- or 76-cm row spacings. Similarly, stem forage DM yield were higher in the 25-cm than in 51- or 76-cm row spacing. At the early bloom harvest total forage DM yield was greater (3437 kg $\cdot$ ha^{-1}) in the 25-cm than in the 51- or 76-cm row spacing (2746 and 2809 kg $\cdot$ ha^{-1}, respectively). The results concur with earlier reports (Burnside *et al.* 1964; Cummins & Burns 1966; Karchi & Rudich 1966) which indicated higher yields of sorghum under dryland conditions in narrow rows than in wider rows. However, the high forage DM yields of narrow rows, observed in the present study, resulted from high yields of stem biomass and yield per plant, while the differences in yields of leaf forage DM between the row spacings were generally not statistically significant. At the early bloom harvest

forage DM yield per plant was 12.80, 8.80 and 8.80 g in the 25-, 51- and 76-cm row spacing, respectively. The stem forage DM yield were then 1724, 1229 and 1245 kg · ha^{-1} in the 25-, 51- and 76-cm row spacing respectively. The leaf forage DM yield within the respective row spacings were 1713, 1517 and 1563 kg · ha^{-1}. Thus, row spacing effect in contrast to seeding rate effect, which influenced the quantity of leaf forage DM produced, differed in the amount of stem forage DM produced. In the literature thus far reviewed the author has not been aware of such differential effects on the typified DM component constituting the forage yield in a pasture. It is, therefore, appropriate to note that the observed differential responses of leaf and stem biomass to row spacing and seeding rate treatments deserve further studies.

Interrelations Among Forage Dry Matter Yield Components

A problem that poses challenges to pasture technicians is determining fairly accurately the quantity of forage DM in a standing crop of pasture from simple field measurements. Several regression estimates expressing the quantitative relations of DM yield to pasture characteristics had been reported in the literature (e.g., reviews by Bunting 1971; Willey & Heath 1969). While the many regression estimates are mathematically sound, quite often, they fail to consider the individual plant morphological constitution or the practical aspect of the problem. The quantity of forage DM within a pasture at a given time will be determined by weight per plant and plant density per unit area. The weight per plant is, in turn, a function of its contents of moisture,leaf and stem materials as well

as stem diameter and plant height all interracting with plant density effects. It would be desirable to estimate the quantity of forage DM of the standing crop of a pasture based on the simple pasture measurements of plant height, stem diameter, number of leaves per culm, plant density or leaf number per unit area. In view of this, a number of interrelations among forage yield components had been examined in the present study.

The simple linear correlation coefficients of the various forage yield components within the pasture are given in Table 7. The data indicate that variations in forage biomass were proportionately associated with the variations in plant height, stem diameter, plant density, number of leaves per unit area, DM yield per plant as well as leaf and stem biomass. While the high positive correlation coefficients between pasture forage DM yield and leaf or stem biomass (Table 7) indicate direct linear relationships, the low and intermediate but highly significant ($p < .01$) linear coefficients between pasture forage DM yield and plant height, stem diameter, plant density or leaf number per unit area suggest that relations other than simple linear bivariate relations must be involved. The linear correlation coefficients between total forage DM yield and stem biomass, leaf biomass, plant height, leaf number per unit area, forage DM yield per plant, plant density or stem diameter were: .99, .99, .77, .65, .63, .42 and .25, respectively. Dhimmar and Desai (1978) reported higher correlation coefficients among dual-purpose forage sorghum forage DM yield, plant height and stem diameter, but lower coefficient between forage DM yield and number of leaves than those obtained in the present study.

Table 7. Matrix of simple linear correlation coefficients among forage yield components of NEB 306F forage sorghum calculated from means in a 3 x 4 x 2 row spacing-seeding rate-replication trial sampled thrice during the pasture development to maturity.[1]

	Plant height	Stem diam-eter	Number of leaves per unit area	Plant density per unit area	Leaf DM yield	Stem DM yield	Total forage yield	Percent leaf	Percent stem	Leaf: stem ratio	DM yield per plant
Stem diameter, mm	.5723										
Number of leaves per unit area	.3534	-.2816									
Plant density per unit area	.0796*	-.5036	.9329								
Leaf DM yield, kg · ha^{-1}	.7641	.2261	.7034	.4711							
Stem DM yield, kg · ha^{-1}	.7575	.2737	.5919	.3614	.9526						
Total forage yield, kg · ha^{-1}	.7699	.2538	.6536	.4194	.9873	.9889					
Percent leaf	-.6710	-.3944	-.3210	-.1333*	-.7074	-.8510	-.7911				
Percent stem	.6710	.3944	.3210	.1333*	.7074	.8510	.7911	-1.0000			
Leaf:Stem ratio	-.6720	-.4075	-.3343	-.1481*	.7070	-.8309	-.7804	.9930	-.9930		
DM yield per plant, g	.7395	.7209	-.0801*	-.3408	.5764	.6605	.6273	-.7088	.7088	-.6895	
Reciprocal of DM yield per plant	-.7618	-.6936	-.0231	.2589	-.6103	-.5998	-.6122	.5880	-.5880	.6088	-.8006

[1] N= 48 cases.

*ns Not significant ($p > .10$).

The leaf:stem ratio and percentage of leaf within the total forage DM were inversely proportional to all components associated with pasture forage production (Table 7). However, the relationship of leaf number per unit area with other indicators of pasture primary productivity such as plant height, stem diameter, plant density, total forage DM yield per unit area, and percentage of stem within forage DM were positive and significant ($p < .05$). The relation between leaf number per unit area and DM yield per plant was negative and not significant ($p > .10$).

It was noted in the previous section that seeding rate, row spacing and the associated changes in plant population accompanying these treatments had significant influences on the pasture forage biomass produced. In the examination of the linear relation among pasture components it was found that extraction of seeding rate or row spacing effects had but only slightly affected the relations. For example, the data in Table 8 (excluding the relations of forage DM yield to yield per plant) indicate slight changes in the magnitude of the coefficients but the direction of the relationships were not affected by controlling the effects of either row spacing or seeding rate. It should however, be remarked that when seeding rates, ignoring row spacings, were considered the correlation coefficients between forage DM yield per unit area and forage DM yield per plant were improved significantly over a coefficient calculated from overall data (all seeding rates — all row spacings). Thus, when treatment main effects were ignored, the correlation coefficient between forage DM yield per unit area and forage DM yield per plant was $r = .6273$ ($p < .001$). However, when the relationship was partitioned by seeding rates the

Table 8. The correlation coefficients of NEB 306F forage sorghum total forage dry matter yield per unit area with several components of pasture primary productivity as influenced by seeding rates and row spacings.

PASTURE CHARACTERISTICS	Seeding rates, kg · ha^{-1}				Row Spacing, cm			All rates and all rows	Log_{10}-Log_{10} all rates and all rows
	5.6	9.0	11.2	16.8	25	51	76		
Plant height, cm	.7074	.8508	.8351	.8574	.7416	.8664	.7160	.7699	.8182
Stem diameter, mm	.5474	.6278	.6358	.6758	.0325*	.3136	.3883	.2538	.3231
Number leaves per unit area	.7646	.8207	.7293	.4984	.6252	.6667	.7722	.6536	.7455
Plant density per unit area	.5221	.5075	.4613	-.0112*	.3497	.4777	.5469	.4194	.5368
Leaf DM yield, kg · ha^{-1}	.9932	.9854	.9874	.9830	.9928	.9906	.9898	.9873	.9950
Stem DM yield, kg · ha^{-1}	.9939	.9876	.9887	.9878	.9950	.9891	.9892	.9889	.9948
Percent leaf	-.8562	-.8812	-.7327	-.8382	-.8067	-.8293	-.7784	-.7911	-.7368
Percent stem	.8562	.8812	.7327	.8382	.8067	.8293	.7784	.7911	.7499
Leaf:Stem ratio	-.8468	-.8934	-.7110	-.8234	-.7767	-.8386	-.7778	-.7804	-.7453
DM yield per plant, g	.8134	.9446	.8907	.9351	.5560	.6792	.6925	.6273	.6863

*Not significant ($p > .1$).

correlation coefficient for the same pasture parameters (Table 8) was modified to r = .8134, .9446, .8907 and .9351 in the 5.6-, 9.0-, 11.2- and 16.8-kg·ha^{-1} seeding rates, respectively. Partitioning the relation by row spacing (Table 8) did not so markedly affect the correlation coefficient. Again, this is yet another demonstration of the differential response of pasture parameter to row spacing and seeding rate effects noted earlier.

Another observation arising from the data in Table 8 is that both the magnitude and significance levels (not tabulated) of the linear coefficient between forage DM yield and plant density, analogous to the DM yield per plant-seeding rate relation (Table 6), declined with increasing seeding rates. Correlation coefficients between plant density and forage biomass for the 5.6-, 9.0-, 11.2-, and 16.8-kg · ha^{-1} seeding rates were r = .5221 ($p < .05$), .5075 ($p < .05$), .4613 ($p < .1$) and -.0112 ($p > .1$), respectively. The negative correlation coefficient (-.0112) noted above suggests that probably at the 16.8-kg · ha^{-1} seeding rate plant density was above the optimum plant population required for maximum forage DM production under the environmental conditions of this study. When all data were considered without regard to seeding rate or row spacing, the coefficient was highly significant ($p < .01$) but the coefficient of determination ($r^2 = .1759$) was too low to account for a substantial proportion of the variation in forage DM yield associated with plant density.

Plant height was significantly correlated with all the forage yield components considered (Table 7) with the exception of plant density (r = .0796). However, the coefficients (the r's < .8000) were too low to describe a simple linear bivariate relationship between

plant height and any of the other pasture parameters examined. The coefficients were lowest for plant height relations with stem diameter and with number of leaves per unit area ($r = .5723$ and $r = .3534$, respectively). Similarly, stem diameter was significantly correlated with all components associated with pasture yield but their coefficients of determination indicate that the simple linear relations were inadequate to account for a major proportion of the variations involved. The stem diameter was negatively associated with plant density, leaf number per unit area, percentage of leaf and leaf:stem ratio within the forage DM material. Likewise, the linear relations between percentage leaf and leaf number per unit area; and between leaf:stem ratio and leaf number per unit area were negative and low ($r = -.3210$ and $r = -.3343$, respectively) but significant ($p < .05$) in both cases.

Plant density was strongly associated with leaf number per unit area ($r = .9329$). There was, however, no significant linear relation between plant density and leaf: stem ratio, percentages of leaf or stem forage within the forage DM material (Table 7). Plant density was negatively associated with forage yield per plant and positively correlated with forage yield per unit area, leaf and stem biomass. Though the correlation coefficients were highly significant ($p < .01$) in all the latter cases, none of their coefficients of determination were large enough to account for more than 22% of the variation between plant density and the components of forage DM yield noted above.

The literature reviewed pointed out that the quantitative relationship between plant population and crop yield is generally asymptotic described by the linear model $w^{-1} = \alpha + \beta\rho$, where w is weight per plant and ρ, density per unit area while α and β are

regression statistics (Bunting 1971; Holliday 1960; Willey & Heath 1969). The data in the present study indicate that forage DM yield per plant was inversely related with plant density ($r = -.3408$) per unit area; stated otherwise, the reciprocal of forage DM yield per plant was positively correlated with plant density. However, the calculated correlation coefficient ($r = .2589$) of the plant density-inverse weight per plant relation suggests that the data in the present study does not lend itself to the linear model cited above. Furthermore, it was noted that the relation was not significantly improved by neither transformations ($\log_{10}$ and/or $\log_e$) nor by the removal of the effects of seeding rates or row spacing (not reported).

However, as noted previously, the plant density-leaf number per unit area relation had a high correlation coefficient. Similarly, the relationships among forage DM yield per unit area, leaf and stem biomass had significant correlation coefficients of large magnitude (Table 7). The log transformation of these pasture yield components further improved their inter-correlation. Regression analysis yielded the general linear model $\log_{10}Y = a + b \log_{10}X$, where Y and X are the dependent and independent variables under consideration while a and b are regression statistics. Stated otherwise, the available data in the present study suggest that the relations between one pasture DM and another pasture DM component, and between the discrete pasture measurements (plant density vs. leaf number per unit area) were adequately described by the general geometric function $Y = aX^b$. The regression lines, correlation coefficients, linear equations and geometric functions of the significant relations are reported in Figures 2 to 5. The preference for the log transformation (i.e.,

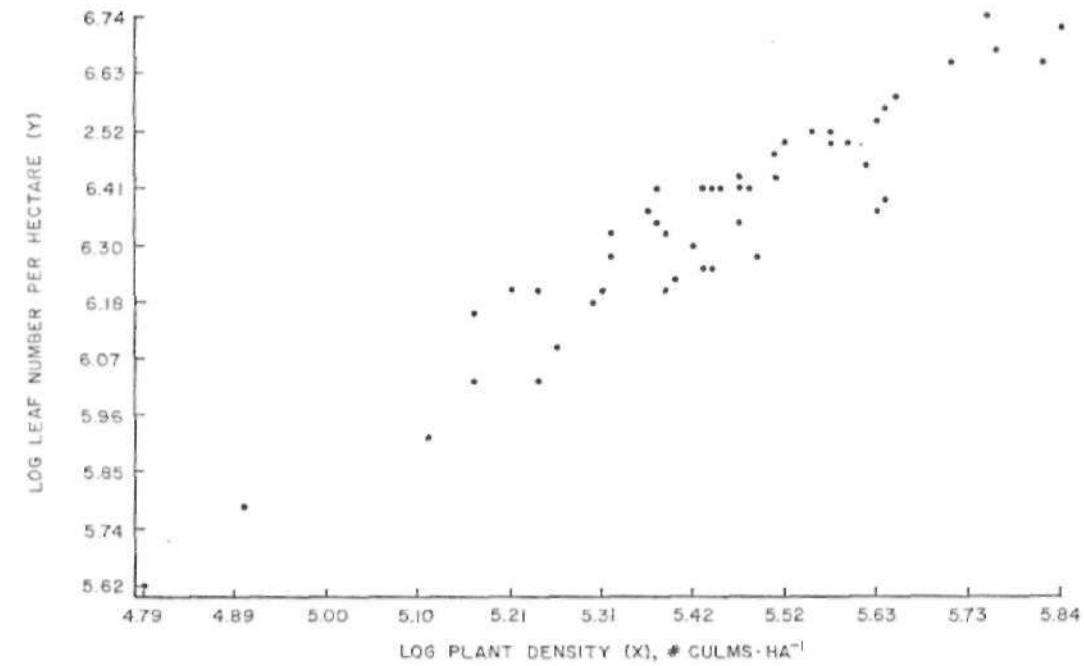


Figure 2. The relationship of leaf number and plant density in a standing crop of NEB 306F forage sorghum pasture in semi-arid northeastern Colorado: $\log_{10}Y = 0.8587 + 1.0109 \log X$ ($r = 0.9468$, $SD = 0.0739$), $Y = 7.223\ X^{1.0109}$.

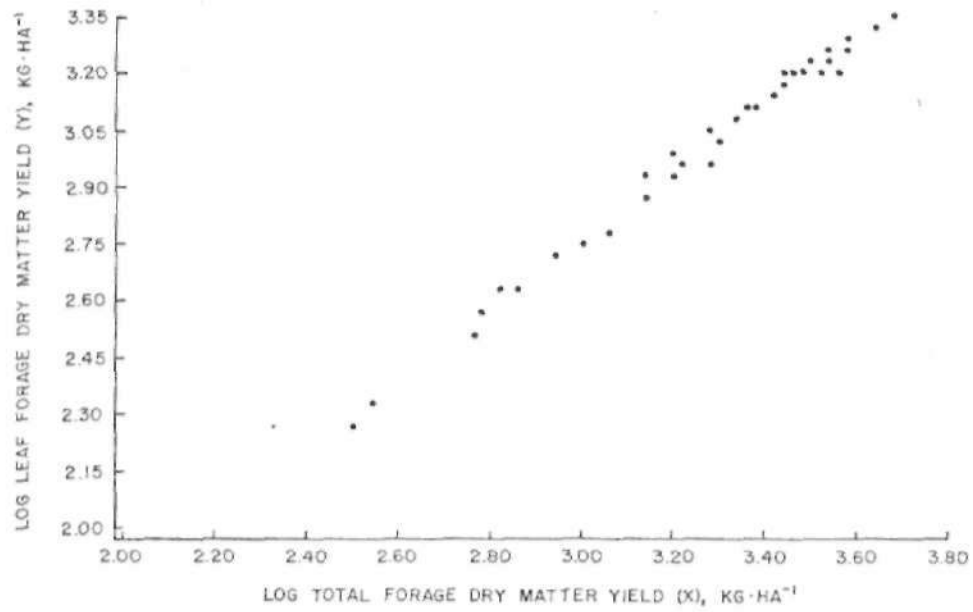


Figure 3. The relationship of leaf forage biomass to total forage biomass in NEB 306F forage sorghum grown in semi-arid northeastern Colorado: $\log_{10}Y = 0.0742 + 0.9014 \log_{10}X$ ($r = 0.9950$, $SD = 0.0259$) and $Y = 1.1863\ X^{0.9014}$.

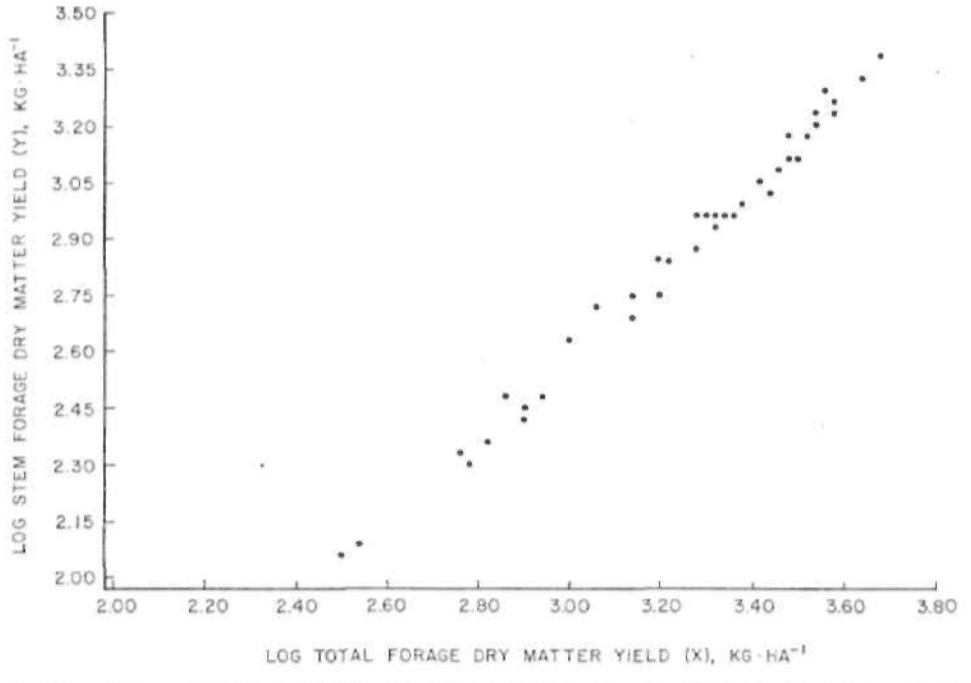


Figure 4. The relationship of stem biomass to total forage biomass in NEB 306F forage sorghum grown in semi-arid northeastern Colorado: $\log_{10} Y = 1.1313 \log X - 9.7952$ ($r = .9948$, SD = .0332) and $Y = 0.1603\ X^{1.1313}$.

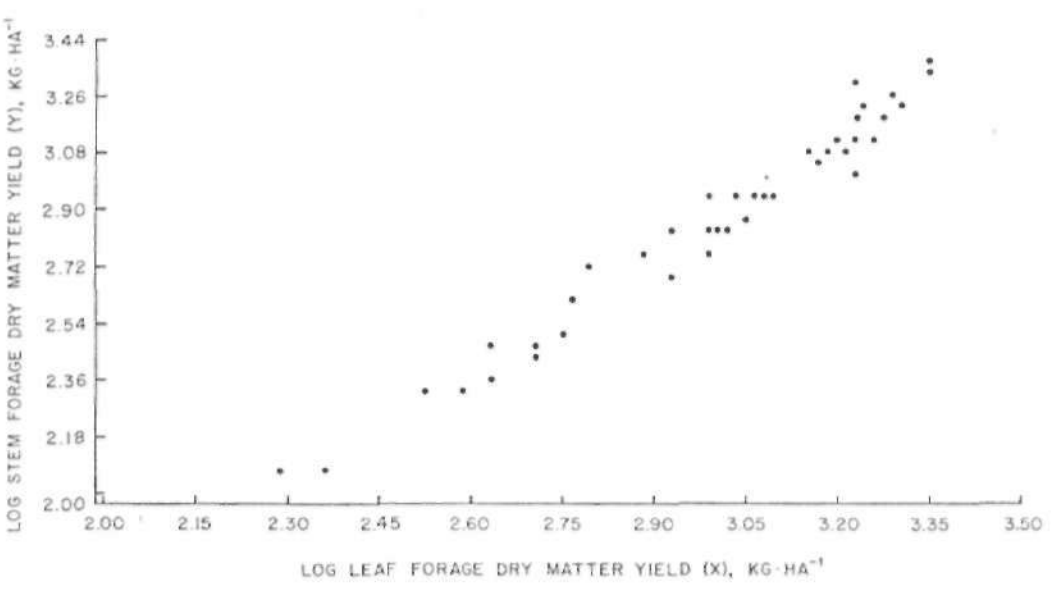


Figure 5. The stem-leaf yield relation in the forage dry matter yield of NEB 306F forage sorghum grown in semi-arid northeastern Colorado: $\log_{10} Y = 1.2299 \log X - 0.8124$ ($r = .9798$, SD = 0.0652) and $Y = 0.154\ X^{1.2299}$.

geometric function) over the simple linear regressions of Y on the X was based on the biological meaning of the Y-intercept in the derived equation. Implicit in the geometric curve is that values of Y or X tend to zero as either of them approaches zero (which is actually the case in practice). The simple regression of the un-transformed Y and X values of the data in the present study yielded Y-intercepts which have no biological meaning. The author is not aware of such models in the literature or NEB 306F forage sorghum or other forage crops in which forage DM was separated into its constituent leaf and stem fractions. Therefore, comparisons of the coefficients in the reported equations cannot be provided here.

While the bivariate analysis of the simple pasture measurements such as plant density, leaf number per unit area, plant height or stem diameter, singly as an independent variable, failed to reveal adequate linear relation with pasture forage DM productivity (yield per plant, total forage, leaf or stem biomass) multivariate analysis of the data revealed relations adequate enough to account for a major proportion of the variations in forage DM yield. The regression and correlation coefficients as well as standard error and coefficient of variation about the regression estimates for some of the significant relationships calculated from treatment means are given in Table 9. Again, for reasons noted earlier, only regressions of the log-transformed variable(s) are reported here. In addition, it was noted that regression analysis of the transformed variable(s) not only resulted in improved coefficient of multiple determination (R^2), but more important, also resulted in a lower standard error and coefficient of variation about the regression line.

Table 9. Regression and correlation coefficients of significant relationships of forage yield components of NEB 306F forage sorghum calculated from treatment means (all seeding rates, all row spacings, all harvests; n = 48).

Independent variable(s) x_1	x_2	x_3	Dependent Variable y	Regression Coefficients Associated With: Intercept	x_1	x_2	x_3	Statistics About Regression: R^2	SD	CV, %
Log_{10} plant height, cm	Log_{10} number leaves · ha^{-1}	Log_{10} kg DM yield per plant	Log_{10} forage DM yield, kg · ha^{-1}	-.5866	.1452	.9174	.7919	.7437	.0329	1.0
Log_{10} plant height, cm	Log_{10} number leaves · ha^{-1}	Log_{10} plant density, # culms · ha^{-1}	Log_{10} forage DM yield, kg · ha^{-1}	-4.1509	1.4610	1.4422	-.8269	.9420	.0503	3.0
Log_e stem diameter, mm	Log_e number leaves · ha^{-1}	Log_e plant density, # culms · ha^{-1}	Log_{10} forage DM yield, kg · ha^{-1}	-4.3747	.4315	1.0158	-.6641	.9200	.1147	3.5
Log_e est. stem volume (cm^3)*	Log_{10} number leaves · ha^{-1}	Log_{10} plant density, # culm · ha^{-1}	Log_{10} forage DM yield, kg · ha^{-1}	-3.8741	.2531	.7186	-.8442	.9339	.1047	3.2
Log_e number leaves · ha^{-1}	Log_e plant density, culms · ha^{-1}		Log_{10} forage DM yield, kg · ha^{-1}	-3.0783	1.2413	-.9442		.9113	.1188	3.6
Log_e number leaves · ha^{-1}			Log_{10} forage DM yield, kg · ha^{-1}	-2.6484	.4042			.7455+	.1909	5.8
Log_e plant height, cm	Log_e # leaves per culm	Log_e # leaves per culm	Log_{10} DM yield per plant, g	-2.5892	.3999	.5195	.5967	.9004	.1158	13.4
Log_e stem diameter, mm	Log_e # leaves per culm		Log_{10} DM yield per plant, g	-2.7453	.6437	.8837		.8634	.1181	14.2
Log_e # leaves per culm			Log_{10} DM yield per plant, g	-1.7690	1.2206			.8301+	.1367	16.4
# leaves per culm	Stem diameter, mm		Log_{10} DM yield per plant, g	-.4559	.1530			.8354+	.1370	16.5
# leaves per culm	Est. stem volume (cm^3)		Log_e DM yield per plant, g	-1.7782	.2566	.1073		.8527	.2727	14.3
			Log_e DM yield per plant, g	-.4972	.2025	.0054		.8342	.2618	13.9
Plant height, cm	Stem diameter, mm	# leaves per culm	Log_e reciprocal DM yield per plant, kg	8.6914	-.0118	-.0987	-.1617	.8968	.2572	5.1
Plant height, cm			Log_e reciprocal DM yield per plant, kg	7.5051	-.0318			.8030+	.3410	6.8
Log_{10} plant height, cm	Log_e plant density, # culm · ha^{-1}	Log_e # leaves · ha^{-1}	Log_{10} reciprocal DM yield per plant, kg	4.1509	-.6345	.7943	-.6253	.9226	.0583	4.5
Log_{10} plant height, cm	Log_e plant density, # culm · ha^{-1}		Log_{10} reciprocal DM yield per plant, kg	4.5589	-1.0401	.1881		.8930	.1134	5.2
Log_e plant height, cm			Log_{10} reciprocal DM yield per plant, kg	6.6100	-1.0210			.8131+	.1451	6.7

*Estimated on the assumption that the stem is perfect cylinder with the volume, $V = .25 \times D^2h$, where D and h are stem diameter and plant height, respectively.
+Simple correlation coefficient.

In the multivariate analysis of the forage DM components it was found that the partial regression coefficients for plant density and leaf number per unit area were negative and positive, respectively; indicating that density and leaf number were, respectively, inversely and directly related to forage DM yield (e.g., the regression coefficients in Table 9). This, again, further emphasizes the contention of the present report that forage DM yield advantages at higher plant densities observed in earlier studies (Bunting 1971; Hunter *et al.* 1970); Kiesselbach & Anderson 1925; Rao & Reddy 1978; Stickler *et al.* 1961) were more specifically attributable to higher yields of leaf rather than stem or total forage DM material.

The multiple regression of forage DM yield (Y) on plant height or stem diameter as X_1 in combination with leaf number (X_2) and/or plant density (X_3) gave a good fit to the linear models in Table 9, described by the general equation:

$$\log Y = a + b_1 \log X_1 + b_2 \log X_2 + b_3 \log X_3$$

with a, b_1, b_2, and b_3 as regression statistics. Similar relations were obtained when Y was predicted from linear combination of the latter two independent variables (X_2 and X_3) with the estimated stem volume.* The best fitting equation was obtained by examining the relationship of kg forage DM yield per hectare (Y) as a linear combination of plant height (X_1), leaf number per hectare (X_2) and kg DM yield per plant (X_3). The resulting regression equation was:

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*See footnote under Table 9.

$$\log_{10}Y = 0.1452 \log_{10}X_1 + 0.9164 \log_{10}X_2 + 0.7919 \log_{10}X_3 - 0.5666$$

(R = .9937, SD = .0329 and CV = 1.0%).

The regression of the log-transformed forage DM yield per unit area on the log-transformed plant density and leaf number per unit area resulted in still high correlation coefficient (R = .9119) but the standard error (SD = .1188) and coefficient of variation (CV = 3.6%) were comparatively larger than those of the model noted above. Nevertheless, in accordance with the objective set out in the introductory portion of this section of the report, plant density in combination with leaf number per unit area appears to have accounted for a major proportion of the variability of forage DM yield in the standing crop of a pasture.

Consequently, assuming that the pasture component relations, as reported in the present study hold true, judicious combination of data in Figures 2 to 5 and Table 9 will not only permit estimation of the forage DM yield within a standing crop of NEB 306F forage sorghum pasture, but also determination of the various proportions of leaf and stem material within the forage DM based on the simple pasture measurement of plant density, leaf number, plant height and stem diameter. Obviously, it is realized that the validity and utility of these suggested pasture parameters in forage evaluation techniques will depend on further extensive research efforts.

Nutrient Composition and Digestibility of Forage Dry Matter Components

Results of chemical composition and *in vitro* dry matter digestibility (IVDMD) analysis of forage dry matter components as

Table 10. Summary data of ANOVA on several nutritive characteristics of NEB 306F forage sorghum planted at 9 kg · ha^{-1} in three row spacing treatments.

ITEM[1]	Years:All Rows		Rows:All Years		Av. Rates:All Years		Tissue Types:Overall	
	F	n.s.ignificance	F	n.s.ignificance	F	n.s.ignificance	F	n.s.ignificance
Crude Protein:								
Leaf	4.23	< .05	0.05	NS[2]	1.67	NS	0.41	NS
Stem	5.65	< .05	0.08	NS	4.07	< .05		
Whole plant	0.45	NS	1.89	NS	9.88	< .01		
Phosphorus:								
Leaf	2.28	NS	1.41	NS	7.03	< .01	0.73	NS
Stem	0.02	NS	0.84	NS	0.01	NS		
Whole plant	0.37	NS	0.00	NS	8.21	< .01		
Cell Wall Constituents:								
Leaf	21.76	< .001	0.13	NS	0.74	NS	8.22	< .05
Stem	28.95	< .0001	0.11	NS	1.75	NS		
Whole plant	26.60	< .0001	0.12	NS	1.31	NS		
Cell Solubles:								
Leaf	21.76	< .001	0.60	NS	1.13	NS	7.39	< .05
Stem	21.71	< .002	0.09	NS	2.29	NS		
Whole plant	26.59	< .0001	0.24	NS	1.31	NS		
Acid Detergent Fiber								
Leaf	17.63	< .001	0.16	NS	0.28	NS	8.54	< .05
Stem	38.52	< .0001	0.62	NS	1.26	NS		
Whole plant	15.97	< .001	0.00	NS	0.59	NS		
Hemicellulose:								
Leaf	2.31	NS	0.73	NS	0.69	NS	2.06	NS
Stem	1.20	NS	0.08	NS	0.90	NS		
Whole plant	11.55	< .01	0.28	NS	1.35	NS		
Acid Detergent Lignin:								
Leaf	8.18	< .01	0.02	NS	0.87	NS	1.63	NS
Stem	15.87	< .001	0.21	NS	0.08	NS		
Whole plant	6.59	< .05	0.20	NS	2.02	NS		
Cellulose:								
Leaf	14.55	< .01	0.24	NS	0.83	NS	0.07	< .05
Stem	28.60	< .0002	0.01	NS	1.97	NS		
Whole plant	11.56	< .01	0.20	NS	0.73	NS		
In vitro DM Digestibility								
Leaf	4.97	< .05	0.14	NS	1.31	NS	3.53	< .1
Stem	4.35	< .5	0.52	NS	0.33	NS		
Whole plant	8.08	< .05	0.00	NS	2.17	NS		
H:C Ratio[3]								
Leaf	1.30	NS	0.09	NS	0.16	NS	1.39	NS
Stem	11.08	< .01	0.42	NS	0.56	NS		
Whole plant	0.19	NS	0.12	NS	0.55	NS		
L:S Ratio[4]	0.62	NS	.39	NS	13.71	< .001		
L:W Ratio[5]	0.94	NS	.53	NS	11.23	< .001		

[1] Content in tissue dry matter.

[2] NS = nonsignificant (p > .1).

[3] H:C ratio = hemicellulose to cellulose ratio.

[4] L:S ratio = leaf to stem ratio.

[5] L:W ratio = leaf proportion within total herbage dry matter

affected by tissue and plant spatial distribution within pasture trials are given in the Appendix Tables I and II. Summaries of the data are shown in Tables 11 and 12. Analysis of variance (ANOVA) comparing differences among treatments, years and harvest periods or stages of growth with respect to chemical constituents as well as IVDMD are shown in Table 10. The interrelations (simple linear coefficients) among several physical and nutrient constituents within and between forage tissue types (i.e., leaf, stem or whole plant) are presented in the Appendix Table III.

The ANOVA results indicate that considerable variations in chemical composition of the plant morphological fractions occurred between the two years of the experiment. Levels of significance for the between-year variations range from the nonsignificant ($p > .05$) to significant ($p < .0001$) probability depending on the nutrient or chemical constituent considered. Thus, the between-year variation (Tables 10 and 12) while significant ($p \leq .05$) for crude protein (CP) of leaf and stem fractions, was not significantly different for that of the intact whole plant dry matter. Hemicellulose content, on the other hand, showed the converse case. The hemicellulose to cellulose (H:C) ratio was significantly different ($p < .01$) within the stem fraction, but not significantly different in either the leaf or intact whole plant dry matter.

Mean two-year averages across dates reveal that row spacing had no statistically significant effect on any of the feeding quality parameters evaluated (Table 10). However, since between-year differences were significant, interractions in combining dates across years may have resulted in a larger error mean square to mask row spacing effects. Nevertheless, the results in the present trial agree in part or whole

Table 11. Effects of phenological stage of development on chemical and nutritive composition of plant parts and intact whole plant herbage dry matter of NEB 306F forage sorghum planted at 9 kg · ha^{-1}.

PHENOLOGICAL STAGE & AGE OF TISSUE		CHEMICAL AND NUTRITIVE CONSTITUENTS														
		Crude Protein			Phosphorus			Cell Wall Constituents			Cell Solubles			Acid Detergent Fiber		
		Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant
		Percent dry matter														
Vegetative	40**	18.54^{b}	15.09^{a}	14.46^{a}	.411^{a}	.367^{a}	.487^{b}	58.56^{a}	56.60^{a}	57.30^{a}	41.44^{a}	43.40^{a}	42.70^{a}	31.85^{a}	29.67^{a}	31.24^{a}
Vegetative	52	13.52^{b}	11.00^{a}	12.19^{ab}	.453^{a}	.469^{a}	.438^{a}	67.60^{b}	63.39^{a}	63.28^{a}	32.40^{a}	36.61^{b}	36.72^{b}	38.98^{a}	37.27^{a}	34.51^{a}
Vegetative	70	11.22^{a}	9.98^{a}	10.72^{a}	.425^{a}	.382^{a}	.393^{a}	65.09^{c}	53.57^{a}	61.85^{b}	34.91^{a}	46.43^{c}	38.16^{b}	36.04^{c}	29.28^{a}	33.24^{b}
Late Boot	93	10.38^{a}	9.06^{a}	9.25^{a}	.300^{a}	.315^{a}	.359^{a}	58.28^{b}	46.84^{a}	49.08^{a}	41.72^{a}	53.17^{b}	50.92^{b}	31.41^{c}	23.68^{a}	28.57^{b}
Frosted	102	9.05^{a}	8.37^{a}	8.69^{a}	.363^{b}	.290^{a}	.342^{ab}	63.60^{a}	59.26^{a}	60.84^{a}	36.40^{a}	42.41^{b}	39.17^{ab}	36.97^{b}	32.51^{a}	32.58^{a}
	Mean	12.54^{a}	10.70^{a}	11.13^{a}	.390^{a}	.364^{a}	.404^{a}	62.63^{b}	56.33^{a}	58.47^{a}	37.38^{a}	45.10^{b}	41.53^{ab}	35.08^{b}	30.48^{a}	32.03^{a}

*H:C ratio = Hemicellulose to cellulose ratio.

**Age of herbage tissue in days post-planting.

a,b,cMeans in rows within a nutrient constituent subset bearing different letters are significantly different ($p < .05$) according to Duncan's multiple range test.

Table 11. Effects of phenological stage of development on chemical and nutritive composition of plant parts and intact whole plant herbage dry matter of NEB 306F forage sorghum planted at 9 kg · ha^{-1} (continued).

PHENOLOGICAL STAGE & AGE OF TISSUE		CHEMICAL AND NUTRITIVE CONSTITUENTS														
		Hemicellulose			Acid Detergent Lignin			Cellulose			*In vitro* Digestibility			H:C Ratio*		
		Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant
		Percent dry matter														
Vegetative	40**	25.71^{a}	26.92^{a}	26.06^{a}	2.29^{a}	2.44^{a}	2.41^{a}	29.56^{a}	27.23^{a}	28.82^{a}	71.45^{a}	71.90^{a}	71.93^{a}	0.908^{a}	0.992^{a}	0.909^{a}
Vegetative	52	28.62^{a}	26.12^{a}	28.77^{a}	3.84^{b}	3.72^{b}	2.90^{a}	35.14^{b}	33.55^{b}	31.61^{a}	64.36^{a}	72.11^{b}	71.28^{b}	0.816^{a}	0.786^{a}	0.924^{a}
Vegetative	70	29.05^{b}	24.30^{a}	28.61^{b}	2.78^{a}	2.57^{a}	2.96^{a}	30.16^{c}	21.15^{a}	25.51^{b}	65.57^{a}	76.91^{c}	70.40^{b}	0.901^{a}	1.137^{c}	1.065^{b}
Late Boot	93	26.88^{b}	23.16^{ab}	20.51^{a}	2.98^{b}	2.08^{a}	2.35^{ab}	28.43^{b}	21.60^{a}	26.22^{b}	66.22^{a}	76.72^{b}	71.81^{a}	0.955^{b}	1.077^{c}	0.783^{a}
Frosted	102	27.63^{a}	26.75^{a}	28.26^{a}	3.96^{b}	3.77^{b}	3.43^{a}	32.02^{b}	28.74^{a}	28.82^{a}	63.26^{a}	64.95^{a}	65.10^{a}	0.875^{a}	0.936^{a}	0.978^{a}
Mean		27.78^{a}	25.45^{a}	26.44^{a}	3.17^{a}	2.92^{a}	2.81^{a}	31.06^{b}	26.45^{a}	28.20^{a}	66.17^{a}	72.51^{b}	70.10^{ab}	0.891^{a}	0.986^{a}	0.932^{a}

*H:C ratio = Hemicellulose to cellulose ratio.

**Age of herbage tissue in days post-planting.

^{a,b,c}Means in rows within a nutrient constituent subset bearing different letters are significantly different ($p < .05$) according to Duncan's multiple range test.

Table 12. Mean nutritive and physical characteristics of NEB 306F forage sorghum planted at 9 kg · ha^{-1} as affected by row spacing treatment.

YEAR TREATMENT	CHEMICAL, NUTRITIVE AND PHYSICAL COMPONENTS OF DRY MATTER														
	Crude Protein			Phosphorus			Cell Wall Constituents			Cell Solubles			Acid Detergent Fiber		
	Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant
	Percent of dry matter														
1978 All Dates:															
25-cm row spacing	12.75	12.17	12.48	0.367	0.349	0.349	59.22	50.92	53.66	40.78	49.08	46.34	31.91	26.34	28.77
51-cm row spacing	15.29	12.65	8.81	0.340	0.337	0.449	59.34	50.87	55.31	40.66	49.13	44.69	31.04	24.71	30.50
76-cm row spacing	11.73	11.48	13.27	0.384	0.378	0.416	58.39	49.32	53.04	41.61	50.68	46.96	32.24	26.01	29.00
1979 All Dates:															
25-cm row spacing	10.16	9.28	12.16	0.429	0.385	0.426	68.03	58.19	62.94	31.98	41.81	37.07	38.65	34.21	34.13
51-cm row spacing	9.31	7.97	9.78	0.371	0.318	0.354	66.95	60.63	63.97	33.05	39.38	36.04	38.43	35.24	34.25
76-cm row spacing	11.69	10.18	11.06	0.430	0.369	0.376	63.68	62.21	62.86	36.32	40.29	37.14	35.47	33.40	34.88
All Years:															
25-cm row spacing	11.27	10.52	12.29	0.406	0.396	0.393	64.25	55.08	58.96	35.75	44.92	41.04	35.76	30.84	31.83
51-cm row spacing	11.88	9.97	9.37	0.358	0.326	0.395	63.69	56.44	60.26	36.31	43.56	39.74	35.26	30.73	32.64
76-cm row spacing	11.43	10.33	11.36	0.410	0.373	0.393	61.41	56.69	58.65	38.59	44.74	41.35	34.51	30.23	32.36
Mean:[4] All dates, All rows 1978:	13.26^{b}	12.10^{b}	11.46	0.380	0.355	0.405	58.98^{a}	50.37^{a}	54.00^{a}	41.02^{b}	49.63^{b}	46.00^{b}	32.06^{a}	25.69^{a}	29.43^{a}
Mean:[4] All dates, All rows 1979:	10.22^{a}	8.91^{a}	10.62	0.410	0.357	0.385	66.22^{b}	60.34^{b}	63.25^{b}	33.78^{a}	40.49^{a}	36.75^{a}	37.51^{b}	34.28^{b}	34.42^{b}

[1]H:C ratio = hemicellulose to cellulose ratio; [2]L:S ratio = leaf to stem ratio; [3]L:W ratio = leaf to whole plant ratio.

[4]Means within columns bearing different letters are significantly different ($p \leq .05$) by the LSD mean separation procedure.

Table 12. Mean nutritive and physical characteristics of NEB 306F forage sorghum planted at 9 kg · ha^{-1} as affected by row spacing treatment (continued).

YEAR TREATMENT	CHEMICAL, NUTRITIVE AND PHYSICAL COMPONENTS OF DRY MATTER																
	Hemicellulose			Acid Detergent Lignin			Cellulose			*In vitro* Digestibility			H:C Ratio[1]				
	Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant	L:S Ratio[2]	L:W Ratio[3]
	Percent of dry matter																
1978 All Dates:																	
25-cm row spacing	27.31	24.58	24.89	2.38	2.53	2.37	29.54	23.81	26.40	67.10	71.57	72.18	0.93	1.05	0.95	1.25	0.54
51-cm row spacing	28.29	26.16	24.81	2.85	2.14	1.98	28.19	22.57	28.53	69.20	74.16	71.00	1.01	1.16	0.87	1.15	0.52
76-cm row spacing	25.16	23.31	24.04	2.81	2.43	3.37	30.42	23.59	25.63	67.95	75.44	70.76	0.83	0.99	0.94	1.36	0.56
1979 All Dates:																	
25-cm row spacing	29.38	23.99	28.81	4.02	3.90	3.58	34.62	30.31	30.55	63.00	66.51	66.22	0.86	0.79	0.96	1.24	0.54
51-cm row spacing	22.52	25.39	29.72	3.53	3.64	3.82	34.90	30.99	30.43	61.88	65.30	67.13	0.82	0.84	0.98	1.42	0.58
76-cm row spacing	29.21	28.81	27.99	3.73	3.41	3.33	31.75	30.00	30.55	64.51	70.51	67.16	0.90	0.97	0.90	1.29	0.56
All Years:																	
25-cm row spacing	28.49	24.24	27.13	3.32	3.31	3.06	32.44	27.52	28.77	64.76	68.67	68.77	0.89	0.90	0.95	1.24	0.54
51-cm row spacing	28.42	25.72	27.61	3.24	3.35	3.03	32.02	27.38	29.61	64.59	69.10	68.79	0.90	0.98	0.93	1.30	0.56
76-cm row spacing	26.90	26.45	26.29	3.33	2.98	3.35	31.18	27.25	29.01	65.98	72.49	68.79	0.87	0.98	0.92	1.40	0.58
Mean:[4] All dates, All rows 1978:	26.92	24.68	24.58[a]	2.68[a]	2.46[a]	2.57[a]	29.38[a]	23.33[a]	26.85[a]	67.74[b]	73.72[b]	71.38[b]	0.92[b]	1.06[b]	0.92[a]	1.25	0.54
Mean:[4] All dates, All rows 1979:	28.70	26.06	28.84[b]	3.76[b]	3.85[b]	3.58[b]	33.76[b]	30.43[b]	30.84[b]	63.13[a]	67.36[a]	66.84[a]	0.86[a]	0.86[a]	0.94[a]	1.36	0.57

[1]H:C ratio = hemicellulose to cellulose ratio; [2]L:S ratio = leaf to stem ratio; [3]L:W ratio = leaf to whole plant ratio.

[4]Means within columns bearing different letters are significantly different ($p \leq .05$) by the LSD mean separation procedure.

with several earlier reports (Coleman & Horn 1978; Koller & Scholl 1968; McGinnies 1970; Sims & Cook 1967; Thomson & Rogers 1968). In the report by Coleman and Horn (1978) no significant differences were found in contents of neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, cellulose and IVDMD of the sorghum x sudangrass hybrid (SX-17) forage due to changes in plant densities. This contrasts with results reported by Alexander *et al.* (1963), Doss *et al.* (1964), Nandpuri (1963), Phipps (1975) and Worker (1973) in which plant density or row spacing was found to appreciably affect nutrient composition and/or digestibility of forage dry matter.

Dates of harvest, averaged across two years, exerted significant influence on the contents of phosphorus (P) and CP within forage types as well as on the leaf to stem ratio and leaf contents as percent of the whole plant forage dry matter. Within each forage type (leaf, stem or intact whole plant) no significant differences in cell contents or cell wall structural components were observed due to dates of harvest, averaged across two years (Table 10). The overall mean two-year data showed significant between-forage-type differences in neutral detergent solubles (NDS), NDF, ADF, cellulose and IVDMD (Tables 10 and 11). However, the between-forage-type comparisons in contents of CP, P, hemicellulose, acid detergent lignin (ADL) or H:C ratio revealed no statistically significant differences between intact whole plant and leaf or stem fractions with respect to these parameters.

Within harvest dates (Table 11) differences within and between forage types were noted in most of the components analyzed as the plants advanced to maturity. The data in Table 11 and Figures 7 to 13 indicate that early in the vegetative stage (40 days post planting) no

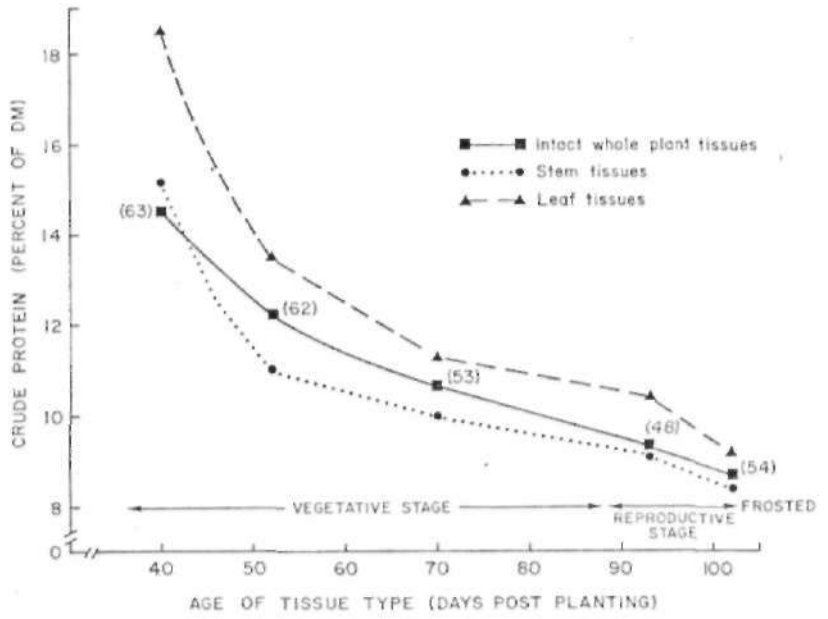


Figure 6. Percent CP in intact whole plant, leaf and stem forages of NEB 306F forage sorghum with advancing stage of maturity averaged over all row spacing treatments. Figures in parenthesis are the percentages of leaf by weight in the whole plant forage dry matter.

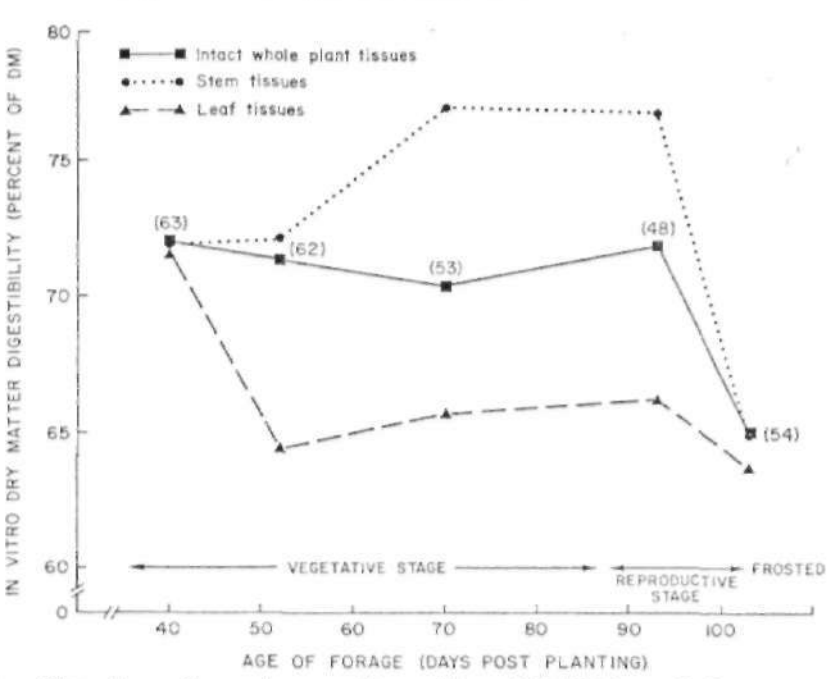


Figure 7. The *in vitro* dry matter digestibility of intact whole plant, leaf and stem tissues of NEB 306F forage sorghum sampled during the vegetative and reproductive cycles of development. Figures in parenthesis are the percentages of leaf by weight in the whole forage dry matter.

significant differences in all but two nutrient components (CP and P) were found between forage types. That is, at this stage of maturity the nutritive value of leaf, stem and intact whole plant forages in terms of cell contents, cell wall constituents and IVDMD were comparable. However, from the second sampling period (52 days post planting) onwards the uniqueness of each fraction of forage dry matter became manifest. In general, although the CP and P contents within each forage type declined progressively with advancing stage of physiological maturity (Figure 6), no significant differences between forage-type within a date were found. Thus, up to the killing frost (102 days post planting) and with the exception of the first sample (40 days post planting) the CP or P content of leaf, stem and intact whole plant forage dry matter were comparatively similar. Early in the vegetative stage CP in leaf, stem and intact whole plant forage were 18.5, 15.1 and 14.5%, respectively. The 18.5% CP content was significantly different from the others (Table 11). At frost the CP content within the respective forage dry matter had declined to 9.0, 8.4 and 8.7%, but the differences between these percentages were not significant. Similarly no significant differences were found among their respective concentrations of NDF, hemicellulose or IVDMD at frost or at the early vegetative stage. Early in the vegetative stage the IVDMD of leaf, stem and intact whole plant forage were comparable — 71.5, 71.9 and 71.9%, respectively. Similarly, at frost the IVDMD of the forage types were found comparable. The IVDMD values of leaf, stem and intact whole plant forage were then 63.3, 65.0 and 65.1% respectively. However, within the course of the plant's development to maturity variations within and between forage-types were found in cell solubles and structural constituents, as well as IVDMD (Figures 7 to 13).

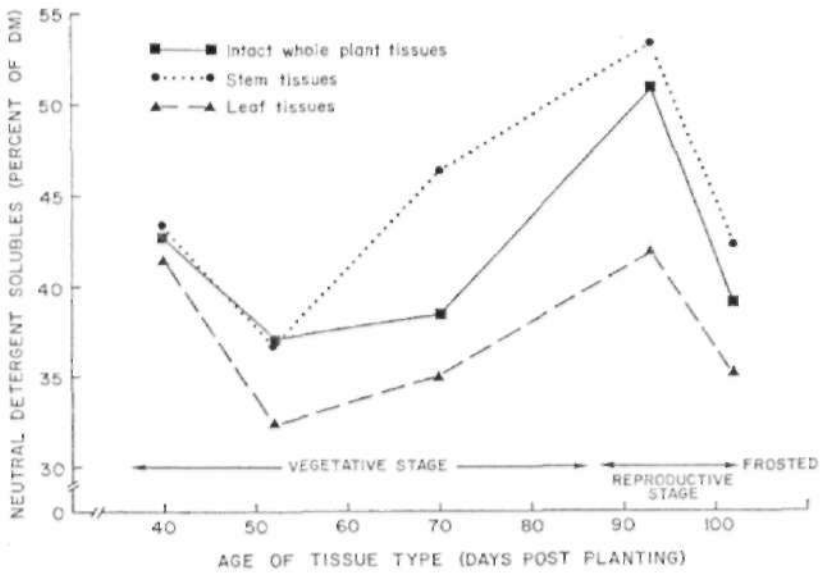


Figure 8. Neutral detergent solubles composition of intact whole plant, leaf and stem forages of NEB 306F forage sorghum with advancing stages of maturity averaged over all row spacing treatments.

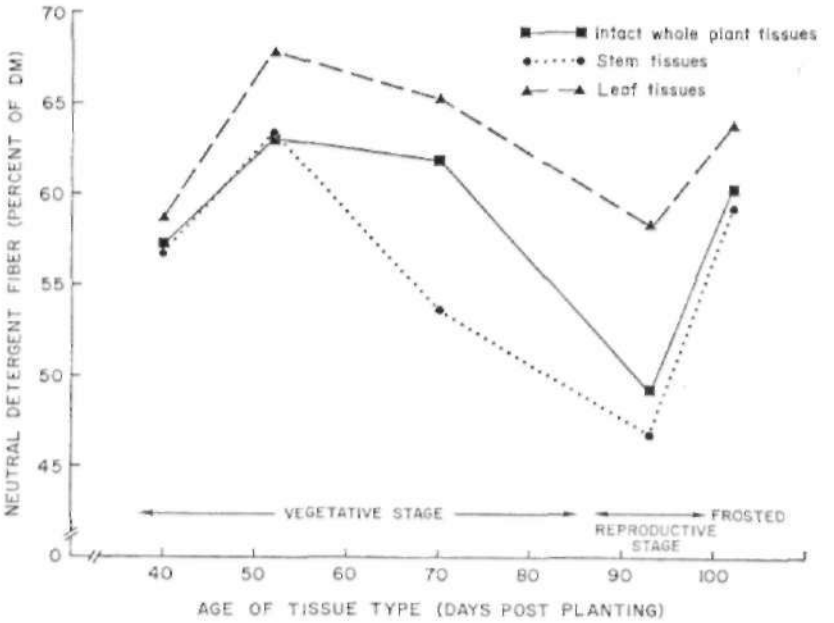


Figure 9. Neutral detergent fiber composition of intact whole plant, leaf and stem forage of NEB 306F forage sorghum with advancing stages of maturity averaged over all row spacing treatments.

Figures 6 to 14 indicate that the various measures of forage nutritive value within each plant morphological fraction showed considerable variation during the active vegetative stages as plants progressed to increasing physiological maturity. While decline in CP within forage-type was consistent (Figure 6) the changes in IVDMD, NDS and components associated with cell structure were not (Figures 7 to 14). Phosphorus and CP (Table 11) in all forages declined with maturity. *In vitro* DMD of the intact whole plant forage was relatively stable during the active vegetative stage until its abrupt decline during the reproductive phase and at the onset of frost. *In vitro* DMD of leaf fractions declined initially and then followed a trend similar to that of the whole plant forage. Paradoxically, IVDMD of the stem fractions increased initially to stabilize at much higher levels than that of the leaf or intact whole plant forage during the active vegetative stage and then declined sharply during the reproductive phase and at frost (Figure 7). Neutral detergent solubles, assumed to be 98% digestible by the ruminant (Goering & Van Soest 1970), declined in all the three forage types but then increased during the active vegetative stage to again decline during the reproductive phase and at frost in a fashion somewhat analogous to that of IVDMD trend. The reciprocal components of digestible energy, associated with cell wall structure oscillated during the same periods. There was an initial increase in each of the structural components — NDF, ADF, ADL, hemicellulose and cellulose — followed by a steady decline during the active vegetative phase and a shape increase during the reprodcutive phase and at frost (Figures 9 to 13).

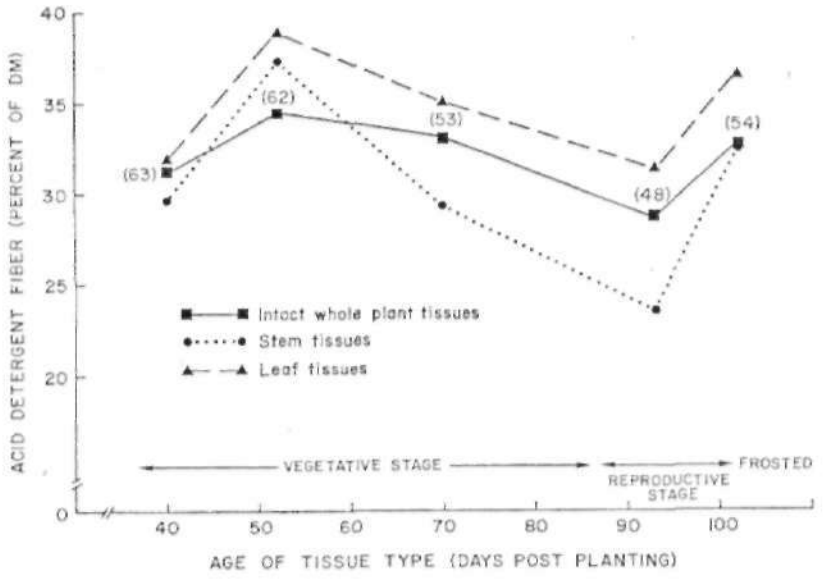


Figure 10. Acid detergent fiber composition of intact whole plant, leaf and stem forage of NEB 306F forage sorghum with advancing stages of maturity averaged over all row spacing treatments. Figures in parentheses are the percentages of leaf by weight in the whole plant forage dry matter.

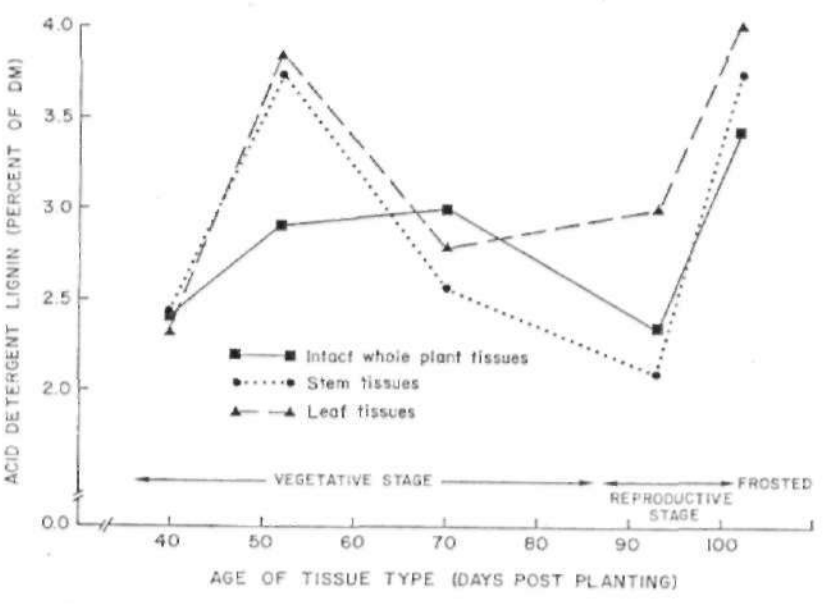


Figure 11. Patterns of the acid detergent lignin content of NEB 306F forage sorghum leaf, stem and intact whole plant forages during the cycle of vegetative and reproductive phases.

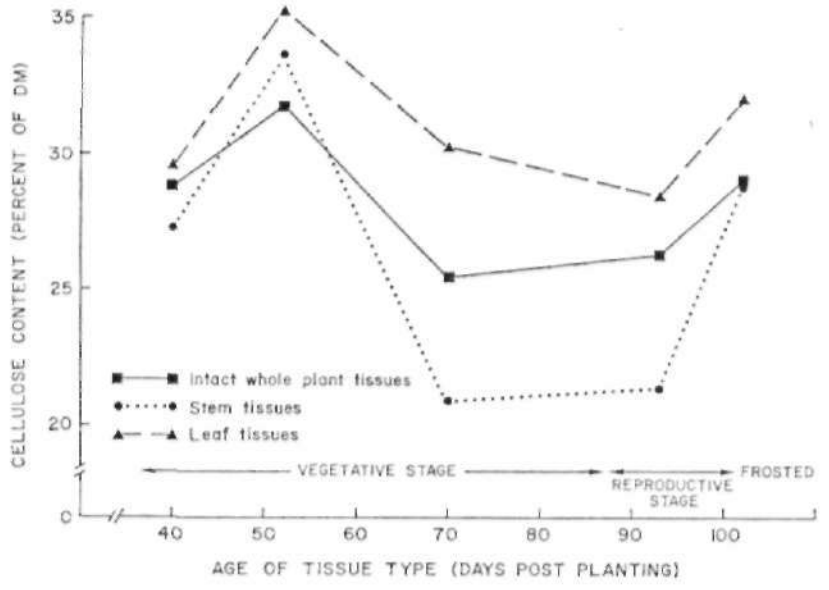


Figure 12. Patterns of cellulose content of NEB 306F forage sorghum leaf, stem and intact whole plant forages during the cycle of vegetative and reproductive phases.

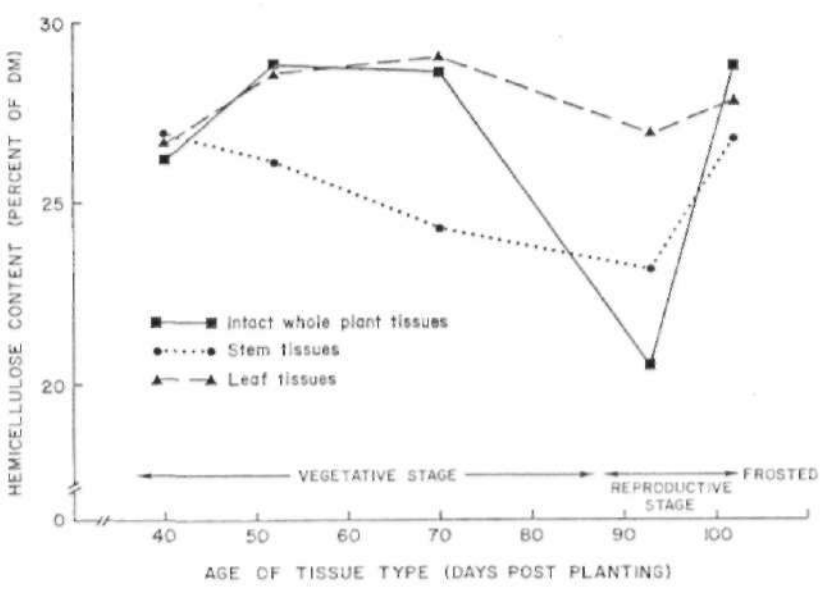


Figure 13. Patterns of hemicellulose content of NEB 306F forage sorghum leaf, stem and intact whole plant forages during the cycle of vegetative and reproductive phases.

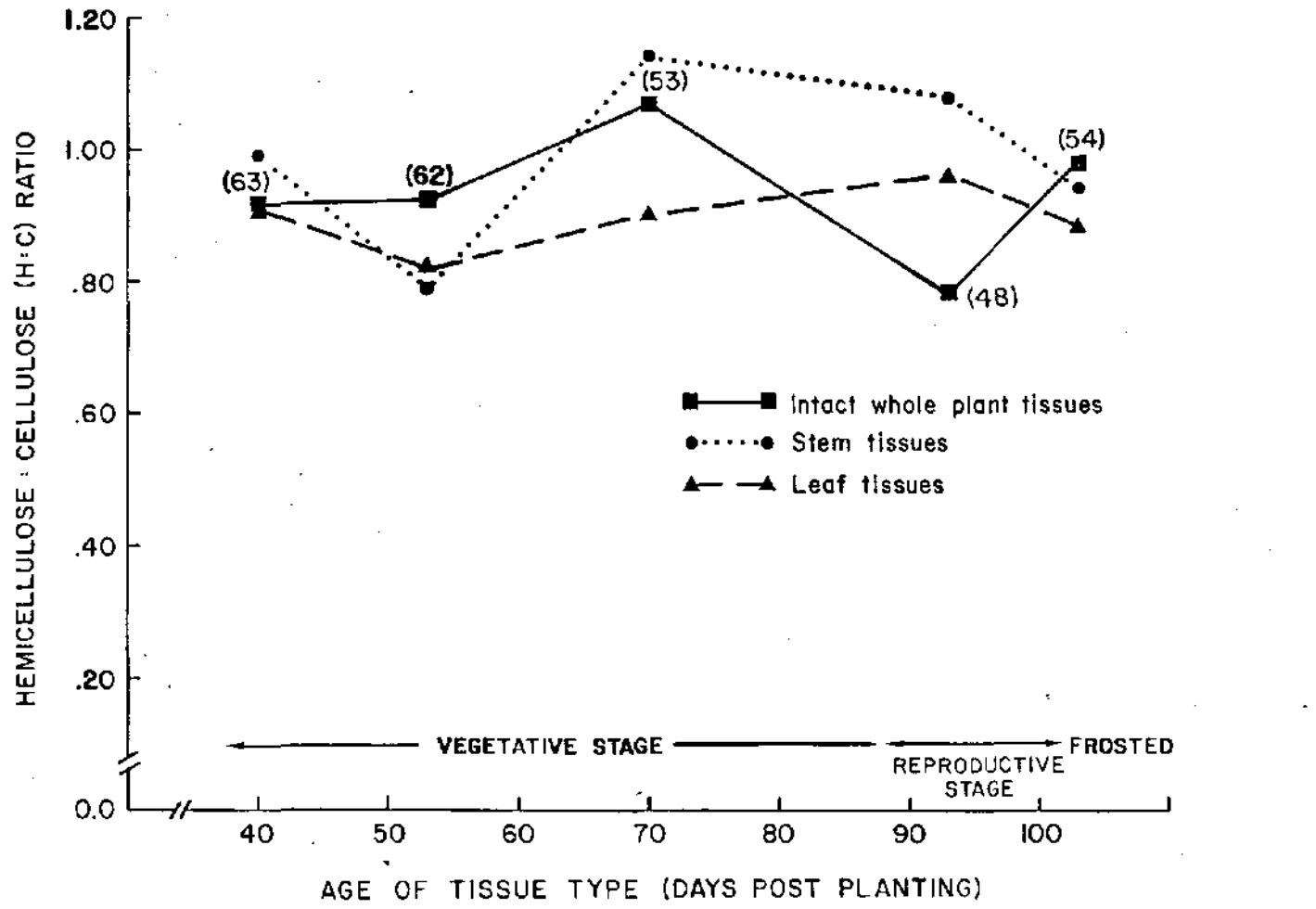


Figure 14. Patterns of fiber utilization, expressed as H:C ratio, within intact whole plant, leaf and stem forages of NEB 306F forage sorghum with advancing stage of maturity. Figures in parentheses are the percentages of leaf by weight of the whole plant forage dry matter.

Nutrient trends with advancing stage of physiological maturity — generally associated with decline in forage nutritive value — are well established in the literature. Therefore, in the present study such trends would not be further emphasized; rather significant differences, distribution of nutritive constituents within plant morphological fractions and their interactions in characterizing the nutritive constitution of the intact whole plant forage (the DM constituent commonly analyzed in routine forage analysis) will be examined.

Patterns in nutrient content and digestibility shown in Figures 6 and 7 and in particular the non-linear relation of digestibility with time and the consistently higher digestibility of stem than leaf fractions differ from, and are apparently contrary to the generally accepted concepts of forage nutritive value (that the leaves are more digestible than stems and that forage fractions high in protein would be more digestible than those of lower protein content). The data in the present study appears to indicate that these concepts might be incorrect with the NEB 306F forage sorghum and perhaps with a number of other grasses. It has already been pointed out that leaf forage was neither as digestible as stem or intact whole plant forage in all the samples analyzed. Paradoxically, though at times not statistically significant, leaf CP content was always higher than that of stem or intact whole plant. Similarly in the second to fourth samples (Table 11, Figures 6 and 7) CP declined in the three forage types but IVDMD increased or stabilized at certain higher values. The changes in IVDMD values were even higher in stems which had the lowest CP content of the three forage types analyzed. Following the reproductive phase and

frost, a period when IVDMD declined sharply, the digestible energy content of stem forage was still greater than that of leaf forage.

Similarly data on chemical components including NDS, NDF, ADF, hemicellulose and cellulose as well as components associated with fiber utilization (H:C, ADL:NDF and ADL:ADF ratios) showed that contrary to the generally held notion of the superiority of leaf forage feeding quality, leaf forage of the vegetative sorghum contained the least content of digestible dry matter while the intact whole plant forage had intermediate values of available energy between leaf and stem forage. These conclusions have also been observed in a number of studies scattered in the literature with temperate cool-season grasses (Dent & Aldrich 1968; Hacker 1971; Jarrige & Minson 1964; Johnson & Waite 1965; Lambourne & Reardon 1962; McDonald 1968; Minson *et al*. 1960; Mowat *et al*. 1965a, 1965b; Pritchard *et al*. 1963; and Terry & Tilley 1964). There are, of course, a number of reports in the literature at variance with the data reported in the present trial (e.g., Farhoomand & Wedin 1968; Fribourg *et al*.1976; Taylor *et al*. 1976). The *in vivo* trials of Fribourg *et al*. (1976) indicated that leaf DDM of 'Trudan' and 'SX-11' sorghum x sudangrass hybrids declined only slightly with physiological stage and was higher than that of head or stem tissues. Similarly in intensive *in vitro* analysis of several C_4 and C_3 grasses grown in Northland, New Zealand, Taylor *et al*. (1976) reported that stem tissues were generally lower in digestibility than leaf tissues. It should be remarked, however, that tissues analyzed in the latter study represent forage materials sampled at 5-weekly intervals — a much longer period than that used in the present study.

In vitro trials (Hacker 1971; Mowat *et al.* 1965a, 1965b; Pritchard *et al.* 1963; Terry & Tilley 1964) reported that in immature grasses stems tend to be more digestible than leaves but the decline with advancing maturity is more than in leaves. *In vivo* results of Minson *et al.* (1960) suggested that young, rapidly growing stems were at least as digestible as the leaf lamina of grasses. Similarly, intake factors of the vegetative grass forage were found to be significantly higher for stems than leaves (Lambourne & Reardon 1962). This apparently seeming paradox is not commonly observed in the non-graminous forages. In previous studies Kallah (1977) noted that stem fractions of heath aster, *Aster ericoides* L. had significantly lower IVDMD and CP, and higher non-structural carbohydrate concentrations than leaves at all the stages of growth examined. Likewise, studies with alfalfa (Kilcher & Heinrichs 1974; Luckett *et al.* 1967 and Mowat *et al.* 1965b) showed that stem fractions never attained as high nutritive constituents as leaf fractions even at the early stage of growth. However, studies reported by Fletcher (1976) indicated that stem digestibility of lucerne was relatively high in spring, exceeding that of the leaf at very immature stages but declined rapidly (0.56% per day) during a 45-day period and remained low in summer. Fletcher (1976) remarked that observations indicated that the rapid decline in stem digestibility was apparently associated with flowering, and that stem digestibility tended to rise again when flowering ceased.

Figures 7 to 13 and Table 11 indicate that at any physiological stage of development when stem forage was superior or similar to leaf forage IVDMD, the latter morphological fraction contained significantly ($p < .05$) higher concentrations of NDF, ADF, ADL,

hemicellulose and cellulose, and lower concentration of cell solubles than stem forage. The CP and P contents of the forage types were generally comparable at most of the stages of maturity studied. However, rate of decline in feeding value with maturity was more rapid in stem forage than in the intact whole plant or leaf forage. Between the late boot stage (*ca* 93 days post planting) and the first killing frost (*ca* 102 days post planting) the IVDMD values of the intact whole plant and stem forages declined from 71.8 to 65.1% and 76.7 to 65.0%, respectively. Comparatively, the change in leaf forage IVDMD during the same period was from 66.2 to 63.3%. Thus during the 9-day period the approximate daily changes in IVDMD were -0.32, -0.76 and -1.30 percentage units in leaf, intact whole plant and stem forage, respectively. These patterns of rates of decline appear to corraborate data reported by Fletcher (1976), Mowat *et al*. (1965b) and Terry & Tilley (1964). In detailed *in vitro* determinations on forages separated into leaf, leaf sheath, stem, inflorescence and dead material Terry & Tilley (1964) showed that in all the grass species digestibility of leaf fractions fell only slowly with advancing maturity (0.13% per day) whereas that of the sheath (0.4%) and stem fractions (0.7%) fell much more rapidly. The authors noted that the immature stem forage was more digestible than the other components but fell slowly up to the time of head emergence, followed by a more rapid fall.

Thus, in earlier studies, as in the present one, the intrinsic differences between leaf and stem forage had been clearly demonstrated. However, what had not been elucidated in the earlier reports is what characteristics of grass stems give rise to the apparently seeming paradox observed in the energy digestiblity of stem compared to leaf

forage. In previous studies energy digestibility was the primary nutritive parameter evaluated. However, the use of chemical fiber analysis, as employed in the present study to partition chemical constituents and digestibility of whole plant into its major morphological fractions might have yet added another dimension toward logical understanding of the probable causes of the differential energy values of leaf and stem forages.

There is no reason to question the validity of the assumption that digestibility of feed-stuff is governed primarily by its chemical composition and, to a lesser extent, its physical structure. The underlying assumption of both the *in vitro* technique (Tilley & Terry 1963) and the chemical fiber analysis (Goering & Van Soest 1970) now commonly used in routine feed analysis, is that forage digestibility is the summation of its contents of digestible cell contents (NDS) and digestible cell wall fractions. The cell contents, comprised mainly of soluble carbohydrates, starches, lipids and proteins, had been shown to be almost completely digested (98%) by the ruminant (Van Soest 1967). The cell wall fraction is digested in accordance with its degree of lignification. Based on this classical approach the digestibility of a forage is determined by its digestible cell content and cell wall fraction that is free from lignification. Therefore, in attempting to establish the probable reasons for the disparity in the IVDMD of leaf, stem and intact whole plant forages, the observed differences in their digestible energy values must as of consequence derive from the contents and/or digestibilities of their cell content and cell wall fractions. The present data, shown in Table 12, confirm the chemical concentration as an important factor determining

the digestible energy content of a forage. Table 11 indicates the significant and non-significant cases of the differences in IVDMD of the morphological fractions in all growth stages correspond with those of their contents of NDS and NDF. It is, however, realized that in a non-simplistic approach differences in the digestible matter of the plant fractions must be examined not only in terms of their contents, but also in the digestibilities of their NDS and NDF. The data in the present study do not provide enough scope for fully examining the latter proposition. Nevertheless, inferential statements can still be made based on the available data and the literature reviewed.

Since the NDS fraction of a forage is 98% digestible in the ruminants (Van Soest 1967), at constant NDS,reasons for the disparative digestibilities of the leaf and stem forages must reside in the content and extent of digestion of their cell wall fractions. The differences in their contents of NDF had been noted earlier.

Many studies have firmly established that fiber digestibility and lignin in forages are strongly negatively associated (Ademosum *et al.* 1968; Ford *et al.* 1979; Goering & Van Soest 1970; Osburn *et al.* 1974; Van Soest & Moore 1965; Wilkins 1972). In the second and third harvests (Table 11 and Figure 11) lignin content though consistently higher in leaf than in stem forage, the differences were shown to be non-significant. Yet, differences in digestibilities of these morphological fractions within the same samples were found to be highly significant. In the third harvest the intact whole plant forage contained an even higher lignin content; yet, the digestibility of the whole plant forage was higher than or comparable to that of leaf or stem, respectively. Conversely, the lignin content of the whole plant and leaf forages in

the fourth harvest samples were significantly different but their digestibilities were not. Therefore, the association of lignin content *per se*, and digestibility seems not to fully account for the differential digestibilities of leaf and stem forages noted in the present studies. Neither does the lignification of fiber (ADF) and cell walls expressed as ADL:ADF and ADL:NDF, respectively; (Ademosum *et al.* 1968; Keys *et al.* 1969; Van Soest 1965, 1967) nor, does fiber utilization expressed as H:C ratio (Lippke 1980; Sullivan 1966) seem to offer a better explanation. The H:C ratios shown in Table 13 indicate that differences were not significant except in the two samples (70 and 93 days post planting), yet differences in IVDMD between forage types were significant all along. The ratios of ADL:ADF and ADL:NDF are also shown in Table 13. Again except in two samples (40-day post planting ADL:ADF and 93-day post planting ADL:NDF ratios) both expressions of lignification of structural components were even higher in the more digestible stem than in either the intact whole plant or leaf forage. Thus, while the H:C ratio appears to be constant throughout plant tissues within a particular stage of growth, and while the ADL:ADF and ADL:NDF seem to follow maturity more closely than did the simple concentrations of ADF and NDF, utilization and lignification of structural constituents as expressed by these ratios cannot account for the disparity in the IVDMD of the forage types analyzed. Similarly, Moir (1971) found no significant relationship within grasses and within legumes between digestible cell wall and lignin, expressed either as concentration in cell walls or acid detergent fiber.

The inadequacy of the common indices of forage digestibility to account for the differences in IVDMD observed in the present study has

Table 13. Influence of growth stage on fiber utilization, cell wall and fiber lignification expressed as H:C,[1] ADL:NDF[2] and ADL:ADF,[3] respectively, of NEB 306F forage sorghum leaf, stem and intact whole plant forages.

PHENOLOGICAL STAGE AND AGE OF TISSUE	FIBER UTILIZATION			LIGNIFICATION					
				CELL WALLS			FIBER		
	Leaf	Stem	Whole plant	Leaf	Stem	Whole plant	Leaf	Stem	Whole Plant
Vegetative 40 days[4]	0.908[a]	0.992[a]	0.909[a]	0.039	0.043	0.058	0.072	0.082	0.077
Vegetative 52 days	0.816[a]	0.786[a]	0.924[a]	0.057	0.059	0.046	0.095	0.100	0.084
Vegetative 70 days	0.901[a]	1.137[c]	1.065[b]	0.043	0.048	0.048	0.077	0.088	0.089
Late boot 93 days	0.955[b]	1.077[c]	0.783[a]	0.051	0.044	0.048	0.095	0.088	0.082
Frosted 102 days	0.875[a]	0.936[a]	0.978[a]	0.062	0.064	0.056	0.107	0.116	0.105

[1,2,3]Hemicellulose to cellulose, acid detergent lignin to neutral detergent fiber and acid detergent lignin to acid detergent fiber ratios, respectively.

[4]Age of forage tissues in days post planting.

[a,b,c]Means in the same row with different letters are statistically significant ($p < .05$) by Duncan's multiple range test.

yet posed another paradox. However, this may not be unconnected to the fact that these indices of forage digestibility were generally derived from analysis of the intact whole plant material (an average of the morphological fractions comprising the plant forage) which may not describe the physical distribution and organization of the different chemical and nutritive constituents within the forage and which must to some extent determine how far plant fibers are digested by the micro-organisms. Furthermore, routine feed analysis tend to treat a forage as a homogenous material, the relationship of lignin to some nutritive parameter, for example, being visualized as similar throughout the plant tissues. However, as results in the present trials clearly indicate leaf and stem forages have intrinsically different chemical and digestibility patterns and the whole plant forage is more realistically considered as made up of morphologically distinct fractions, each of which can be changing in chemical composition and digestibility not necessarily related to other fractions.

Based on the available data higher digestibility of stem forage in the present study relative to leaf or intact whole forage during the vegetative stage coincides with its high NDS and low fiber components (NDF, ADF, ADL, hemicellulose and cellulose). Similarly, the H:C ratio, suggested as an index of NDF (Lippke 1980), cellulose and hemicellulose (Sullivan 1966) digestibility, though not statistically significant (Table 16) was generally higher in stem than in the other forage types. Within the stem forage, in particular, the H:C ratio followed a trend similar to that of IVDMD with plant growth (Figures 7 and 14). Thus, differential feeding value of forage types as observed in this study may have resulted from the quantitative differences in NDS

and all structural components, and possibly from qualitative differences in potential digestibilities of cell wall polysaccharides within forage types. The differential rate of decline in forage quality during the reproductive phase and with the onset of frost appears to be associated with the larger increases in especially cellulose and lignin, and to a lesser extent hemicellulose (Figures 11 to 13). In the frosted forage samples, for example, when the stem IVDMD declined sharply to levels comparable to those of leaf and intact whole plant proportionate decrease in NDS and increase in NDF, ADF, ADL hemicellulose and cellulose also occurred. Thus in the frosted forages there were no statistically significant differences ($p > .05$) in IVDMD, NDF and hemicellulose content between leaf, stem or intact whole plant forages. Similarly there were no statistically significant differences between ADL of stem and that of leaf forage. Nevertheless even at that stage lower values of IVDMD, NDS and H:C ratio; and higher values of NDF, ADF, ADL, hemicellulose and cellulose were noted in leaf than in stem forage. But, CP and P were higher in leaf than in stem fractions or whole plant (Table 11).

While conventional indices of forage digestibility had appeared somewhat inadequate to account for the paradoxical disparity of the energy value of forage types analyzed in the present study, there are scattered reports in the literature that provide indirect evidences and tempt one to suggest possible explanation. In the *in vivo* trials of Lambourne and Reardon (1962) differences in intake factors of young grass stem and leaf forage was explained in terms of chloroplast content. Lambourne and Reardon (1962) concluded that the digestible material of leaf was associated with more chloroplast and proteins,

and that of stem with relatively greater amounts of soluble and digestible carbohydrates with less chloroplast material. While there is no evidence in the literature that chloroplast interferes with forage disgestibility, in the present trial CP content was shown to be in contradistinction to the generally accepted relationship of protein with forage digestibility.

Studies of Stafford (1962) indicated that in many grasses only certain cell walls are characteristically lignified and the lignin content of lignified cells is variable. Stafford (1962) like Pidgen (1953) suggested that the distribution of and extent of lignification may be more important than lignin present in determining the nutritive value of a forage. This implies that the effect of a given quantity of lignin on digestibility of other cell wall components is, therefore, likely to vary according to the distribution rather than content of lignin in relation to other cell wall components. Later studies of Wilkins (1972) demonstrated that in all the grass species examined, even at head emergence, lignified tissues were more extensive in leaf with growth while the distinction of lignified and non-lignified tissues in stem forage was not clearly distinct. The studies (Wilkins 1972) further indicated that in plant morphological fractions both lignin and lignified tissues increased with plant growth but potential cellulose digestibility was more closely related to lignified tissues ($r = -0.905$) than lignin content ($r = -0.862$), *per se*. Moir (1972) reported that total cell wall had some effect on the amount of cell wall digested, but the lignin concentration in the cell wall had no effect.

Many studies have suggested that the source of cell wall polysaccharides (hemicellulose and cellulose) has significant influence on the extent to which they are digested by ruminants (Ford 1973; Gaillard 1962; Keys *et al*. 1969; Sullivan 1966; Wilkins 1972). Keys *et al*. (1969) and Sullivan (1966) reported that grass hemicellulose and cellulose were more digestible in ruminants than those from alfalfa. Ford (1973) reported that although *Lolium perenne* L. and *Setaria splendida* were found to be chemically similar, apparent digestibility of *S. splendida* was much lower than that of *L. perenne*. The author noted that while in each species hemicellulose and cellulose were digested to similar extent, between species the cell wall polysaccharides of *L. perenne* were digested to a much greater extent than those of *S. splendida* (*ca* 79 and 49%, respectively). Ford *et al*. (1979) further reported that active growth consequent to increasing growth temperature resulted in lower NDF values in *Panicum maximum* (tropical species) due to reduced cellulose content but resulted in higher NDF values in *L. perenne* (temperate species) due to increased lignin, hemicellulose and cellulose with increasing growth temperature. Results in the present trial showed a much lower content of these nutritive value parameters in the stem forage especially during the active vegetative growth stage.

Therefore, if differences in the extent of tissue lignification (Stafford 1962; Wilkins 1972) and intake factors between young grass leaf and stem forage (Lambourne & Reardon 1962); and if differences in the extent of hemicellulose and cellulose digestion between grass (*Gramineae*) and alfalfa (*Leguminoceae*) forages (Key *et al*. 1969; Sullivan 1966) as well as between grass species (Ford 1973)

were shown to be significant, then presumably such component differences between morphological fractions within a plant might also occur. The latter hypothesis appears to be corraborated by the report that relationship between lignin and potential cellulose digestibility (Wilkins 1972); and between lignin content and IVDMD (Johnson & Waite 1965) were different for stem forage than for other morphological fractions. An alternative hypothesis, in accordance with the data reported by Ford *et al.* (1979) seems to suggest that the leaves of the warm-season forage sorghum during the active vegetative growth might analogously be behaving like the temperate species, *L. perenne* while the stem forage might be behaving like the tropical species, *P. maximum*. In the present trial lignin, hemicellulose and cellulose content of leaf forage were especially high during the active vegetative growth resulting from the warmer summer temperatures.

Irrespective of the case, the differences in the digestible energy values of the intact whole plant, leaf and stem forage, as observed in the present study, might not be explained in terms of their contents of NDS and structural constituents alone, but presumably also resulted from the extent of tissue lignification and differential digestibility of both hemicellulose and cellulose of each morphological forage type.

Experiment II

Animal Performance Trials

Yield and Composition of Available and Residual Pasture Dry Matter

Forage yield, leaf: stem ratio, percentages of leaf, digestible DM and CP content of the available (pre-grazed) and residual

Table 14. Pre-grazing and post-grazing dry matter yield, physical and nutritive constituents in the primary growth and secondary regrowth of NEB 306F forage sorghum pastures planted at 9.0 kg · ha^{-1} in three row-spacing treatments under the semi-arid conditions of north-eastern Colorado.

	PASTURE GROWTH STAGE CHARACTERISTICS														
	Pasture Primary Growth									Pasture Secondary Regrowth					
	Grazing period #1			Grazing period #2			Grazing period #3			Grazing period #4			Grazing period #5		
	Row Spacing Treatments														
PRE-GRAZING STANDING CROP	25-cm	51-cm	76-cm	25-cm	51-cm	76-cm	25-cm	51-cm	76-cm	25-cm	51-cm	76-cm	25-cm	51-cm	76-cm
Forage Yield:															
kg DM per hectare	387.4[a]*	1161.3[b]	697.3[a]	773.1	1212.6	885.7	1104.4	2002.4	1606.7	885.9[a]	1909.7[b]	1468.9[b]	803.4[a]	2198.7[b]	1549.8[ab]
Leaf:stem ratio	1.63	1.24	1.58	1.61	1.45	1.59	1.51	1.26	1.35	1.18	0.94	0.53	0.51	0.60	0.73
Leaf percentage	61.91	55.10	61.05	61.62	59.64	61.19	60.13	55.77	56.67	54.18	48.31	34.35	33.89	37.52	42.16
Crude Protein (% DM):															
Leaf forage DM	10.33	10.45	11.80	10.62	9.17	9.62	9.56	10.34	10.49	8.64	10.99	11.38	8.12	8.17	9.42
Stem forage DM	7.87	7.67	8.24	6.32	6.18	6.08	6.10	6.18	6.17	5.10	5.90	5.62	4.14	3.91	6.12
In vitro Digestibility (% DM):															
Leaf forage DM	63.01	64.66	64.31	63.99	57.66	59.84	55.52	51.53	54.20	55.24	59.43	60.52	57.03	46.87	51.99
Stem forage DM	71.36	68.40	72.95	68.52	65.88	65.18	62.12	61.12	60.42	50.57	54.91	58.87	50.73	46.89	60.55
POST-GRAZING STANDING CROP															
Forage Yield:															
kg DM per hectare	384.0[a]	886.6[b]	334.1[a]	461.6	1042.2	547.3	382.2[a]	1711.3[b]	603.4[a]	677.9	932.1	679.1	454.2[a]	1642.9[b]	1060.5[b]
Leaf:stem ratio	1.10	1.18	0.85	0.70	0.81	0.77	0.40	0.44	0.55	0.58	0.66	0.76	0.61	0.49	0.55
Leaf percentage	52.17	52.63	45.87	41.06	44.63	43.28	28.38	30.68	34.30	36.57	39.53	42.90	37.91	33.04	35.64
Crude Protein (% DM)															
Leaf forage DM	7.70	8.43	9.10	9.58	8.92	8.75	6.66	5.54	6.14	8.78	7.99	8.76	6.94	6.53	6.26
Stem forage DM	7.75	6.97	6.70	6.33	4.58	5.64	2.90	2.76	3.66	5.28	4.57	4.96	3.03	3.23	3.79
In vitro Digestibility (% DM):															
Leaf forage DM	62.19	63.60	61.89	59.55	59.39	57.99	56.36[b]	42.96[a]	48.26[a]	50.01	53.11	52.25	52.66	50.10	54.10
Stem forage DM	65.02	67.26	65.71	66.00	63.29	60.22	46.10	41.67	41.08	41.01	44.07	48.68	42.64	46.64	48.23

*Means between treatment within a grazing period with different letters are significantly ($p < .05$) different according to Duncans Multiple Range test.

(post-grazed) standing crop for pasture treatments in each grazing period are given in Table 14. The pattern of pre-grazed and residual pasture total forage DM yield including the proportions of leaf and stem forage are illustrated in Figure 15. Admittedly, site effects had markedly influenced the patterns of forage yields in this trial. The highest yield was consistently obtained from the pastures in the 51-cm row spacing treatment. The pastures in the 25-cm row spacing yielded lower amounts of forage DM than pastures in the other treatments. The consistently low yields of the 25-cm row spacing pastures reflects the poor soil conditions in one of the replicates of this treatment in which forage yield was rather low. Spots of such poor soils have also occurred in the other treatments but to a much lesser extent than in the latter treatment. At any rate, forage yield in the three treatments during the first two grazing periods of the trial was below the yield at which maximum DM intake was recorded in the study reported by Allden *et al.* (1970).

In all treatments yield of forage DM increased while leaf:stem ratio and leaf percentage in the pasture primary growth declined as grazing was delayed. A two-week rest period following grazing resulted in pasture secondary growth with DM yield, physical and nutrient composition comparable to those obtained in the preceding late-grazed pasture primary growth (Figure 15 and Table 14).

Within a grazing period, among treatments there is no evidence that row spacing had influenced the physical composition of the pre-grazed or residual standing crop. Hence mean forage physical composition, as leaf: stem ratio and leaf percent, are given in Figure 16 to illustrate their patterns of change with respect to pasture growth

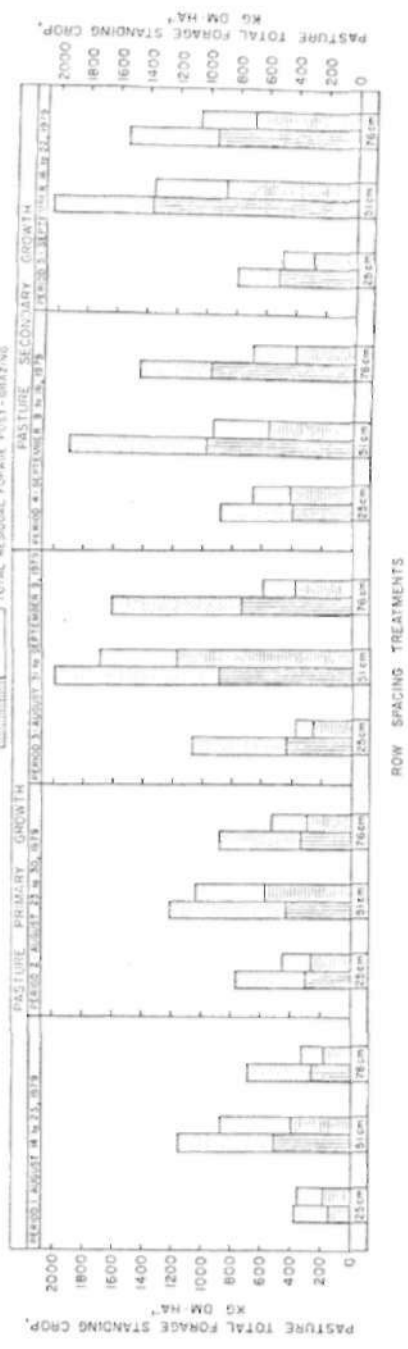


Figure 15. Total forage dry matter yield by plant morphological fractions in the available (pre-grazing) and residual (post-grazing) NEB 306F forage sorghum standing crop planted at 9.0 kg • ha-1 in three row-spacing treatments in the semi-arid northeast of Colorado.

stage and grazing effects. The similarity of the pre-grazed leaf:stem ratio or leaf percentage within a grazing period, despite the marked differences in total forage yield among treatments, indicates that either index is an intrinsic plant property. The similarity of the physical composition of residual standing crop, on the other hand, reflects more the animal effects on the pastures. At a given grazing period the leaf:stem ratio and leaf percentage of the residual standing crop in 25-, 51- and 76-cm row spacing treatments which were similar, which suggests that the pastures were grazed to the same extent and, perhaps, also DM intake as well as quality of intake (CP and digestible DM) of the steer groups were similar.

Irrespective of grazing period or pasture growth stage (i.e., primary growth or secondary regrowth) the pre-grazed pasture was found to differ in DM yield and physical composition from the residual pasture. The data indicate the residual pastures had lower leaf:stem ratios and leaf percentages than the pre-grazed pastures (Figure 16, Table 14). Similarly,stem percentages (not reported) were generally lower in the residual than in the pre-grazed pastures. Analogous to these results, Coleman and Horn (1978) in grazing trials with SX-17 forage sorghum reported that seeding rate had no influence on the forage physical composition; and leaf:stem ratio was lower at the end of the trial than at the beginning while stem percentage was lower at the beginning of the trial than at the end. However, in the data reported by Coleman and Horn (1978) stem percentages within pre-grazed forage DM were lower; and leaf:stem ratios within both the pre-grazed and residual forage DM were higher in the SX-17 than in the NEB 306F forage sorghum of the present trial. The data in Table 14 indicate that for the

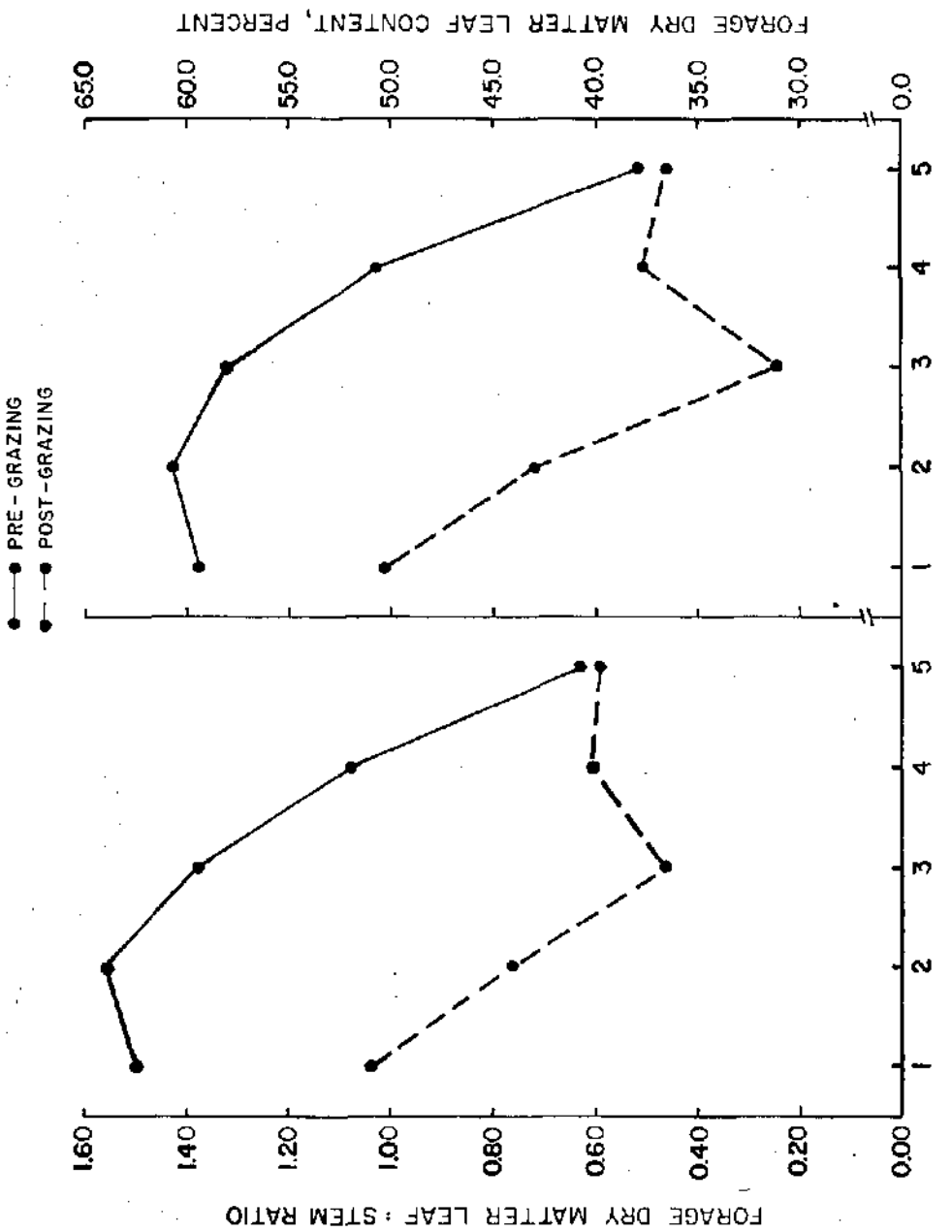


Figure 16. Changes, at various grazing periods, in the physical composition of forage dry matter within the primary growth (grazing periods 1, 2, and 3) and secondary regrowth (grazing periods 4 and 5) of NEB 306F forage sorghum pastures planted at 9.0 kg · ha^{-1} in the semi-arid northeastern Colorado as depicted by pre-grazing and post-grazing leaf:stem ratios and leaf percentages, averaged across three row-spacing treatments.

entire growth stages examined, ranges of leaf:stem ratios in the pre-grazed and residual pastures were 0.51 to 1.63 and 0.40 to 1.18, respectively. The respective ranges of leaf proportions were 33.9 to 61.9% and 28.4 to 52.6%. In the SX-17 data the ranges of leaf:stem ratios within the pre-grazed and residual pastures were 6.2 to 6.8 and 2.7 to 4.2, respectively (Coleman & Horn 1978).

The quality of available and residual pasture as indicated by percentage of CP and IVDMD at the five grazing periods are presented in Table 14. Considering either the pre-grazed or residual pastures, the data support the observation discussed under Experiment I that within a plant morphological component at similar growth stage nutrient constituent did not differ significantly due to pasture row spacing treatment, but differences between the nutrient composition of morphological components (leaf vs. stem) were significant. Additionally, the data in Table 14 indicate the qualitative differences of forage DM between the available and residual pasture as well as between grazing periods. The IVDMD and CP content of leaf and stem forage of the pasture primary growth or secondary regrowth declined in the three treatments as grazing was delayed. Since effects of row spacing were not significant, mean contents of CP and digestible DM of the available and residual pastures are given in Figure 17 to illustrate the patterns of nutrient changes in leaf and stem forages with respect to pasture growth stage and grazing effects. Irrespective of growth stage, the pre-grazed pasture was found to differ in nutrient composition from the residual pasture. At a similar grazing period within leaf or stem percentage IVDMD and CP was higher in the pre-grazed than in the residual forage DM (Figure 17, Table 14).

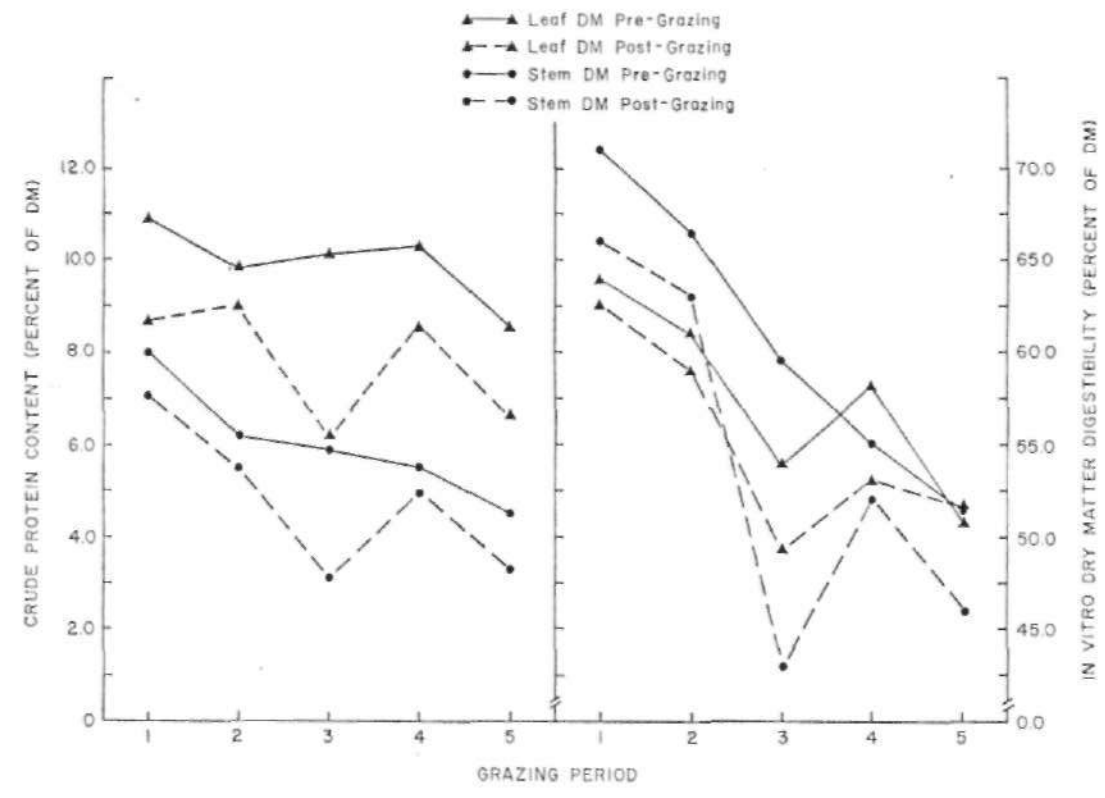


Figure 17. Changes, at various grazing periods, in the nutritive constitution of plant morphological fractions within the pre-grazing and post-grazing forage dry matter of NEB 306F forage sorghum pastures planted at 9.0 kg · ha^{-1} in the semi-arid northeast of Colorado as depicted by percentages of crude protein and *in vitro* dry matter digestibility averaged across three row spacing treatments (grazing periods 1, 2 and 3 are pasture primary growth while 4 and 5 are pasture secondary regrowth following first grazing).

The nutritive composition of the pre-grazed pastures, in general agreement with data discussed under Experiment I, indicates that the stem forage was more digestible than the leaf forage. In fact during the first two grazing periods of the trial the residual stem forage was noted to be more digestible than the pre-grazed leaf forage (Figure 17, Table 14). Nevertheless, the IVDMD of stem declined rapidly to be similar to that of leaf forage at the final grazing period of the trial. Throughout the trial period, the digestibility of leaf or stem forage, other than that recorded at the early pasture primary growth (grazing periods #1 and #2) was below the minimum required forage digestibility quoted by Holt (1977) for productive growth in steers, $\geq$ 270 kg BW. The digestibility was even lower for steers weighing 113 kg BW (Holt 1977). On that basis, the suitability of the NEB 306F forage sorghum in forage-fed beef production would apparently be limited. However, it may also be that in the above-cited study higher standards have been set for forages in forage-fed beef production systems. As will be shown subsequently, quality of forage may not be limiting in this trial as indicated by the daily gains attained by the steers.

Considering the protein composition of pastures (residual or pre-grazed), again in support of the data discussed under Experiment I, CP percentage was consistently higher in leaf than in stem forage (Figure 17, Table 14). Comparatively, the CP percentage in the pre-grazed stem DM was lower than that in the residual leaf DM while the percentage in the residual stem DM was even much lower (e.g., Figure 17). Overall, the data in this trial indicate that CP content of leaf DM was maintained at a satisfactory level throughout the trial period.

approaching the upper limits of the total protein requirement of growing steers (400 kg BW) to gain daily 1 to 1.3 kg (NRC 1976). The CP content of stem DM was adequate to maintain BW at the onset of the trial period but declined gradually to submaintenance level. The CP percentage of stem DM in the pasture secondary regrowth was below the percentage (approximately 6% CP) at which positive response to protein supplementation starts in most grazing trials (e.g., Denham 1977; Corbett & Boyne 1958; Kenney *et al.* 1978; Rittenhouse *et al.* 1970; Weston & Hogan 1968). Nevertheless, since the diet of a grazing animal is a complex mixture of various proportions of leaf and stem forage, it is not likely that protein would be limiting BW gains when the NEB 306F forage is grazed during the pasture growth.

Grazing influenced the nutrient composition of pre-grazed and residual pastures as indicated by the relative percentage IVDMD and CP of leaf and stem forage DM in the pasture secondary regrowth (Table 14). Percentage IVDMD and CP of both pre-grazed and residual leaf forage in the first grazing period of the pasture secondary regrowth were higher than those of leaf forage in the preceding pasture primary growth (Figure 17). This observation also emphasizes the effects of maturity on forage quality. The pre-grazed stem forage, on the other hand, did not show such change in either IVDMD or CP percentages. Paradoxically, however, while the pre-grazed stem forage DM sustained the declining trend of the preceding grazing period, the residual stem DM of the first grazing period of the pasture secondary regrowth showed increases in percentage IVDMD and percentage CP over that of the preceding grazing period of the pasture primary growth. The probable explanation for such increases is that the residual stem

forage DM of the pasture regrowth was comprised of immature basal tillers which were less accessible to the steers at the time of grazing.

Apparent Forage DM Intake

It was, *a priori*, realized in this trial that pre-grazing and post-grazing clipping could not possibly measure accurately the forage consumption of grazing animals. Nevertheless, such clippings should have value in estimating the forage allowance per animal (kg DM forage · BW^{-1}), and hence proper stocking and efficient utilization of the pasture. For reasons to be discussed subsequently, no actual figures of apparent intake or grazing efficiency (kg forage DM intake · kg BW $gain^{-1}$) were reported as originally intended. The apparent forage DM intakes of the steers are, therefore, the tacit differences between the pre- and post-grazing yields of forage DM in Table 14 : the physical composition (leaf and stem DM proportions) of which is illustrated in Figure 16.

The fast growth rate of forage sorghum was found to make it difficult to arrive at reliable estimates of the apparent forage intake of steers by the pre- and post-grazing clipping method. This was noted to be especially the case when estimating the proportion of DM in the apparent intake accounted for by stem forage. Thus, it was observed that when only yields of total forage DM was considered, the post-grazing yield was consistently smaller than that of pre-grazing — the difference of which would have been equated as apparent DM intake of the steers. However, when total DM yields were partitioned by plant morphological portions it was noted that, at times, the post-grazing

standing crop yielded higher stem DM than the pre-grazing standing crop (e.g., Figure 15). This was never observed to be the case with leaf proportion within the total DM yield such that throughout the trial period, the pre-grazing standing crop yielded higher leaf DM than the residual standing crop. Such observation may suggest, as generally stated in most sorghum trials (Aii 1976; Coleman *et al*. 1971; Coleman & Horn 1978; Gangstad 1959, 1964, 1966; Stobbs & Wheeler 1977; Ward *et al*. 1979) that animals prefer leaf and reject stem forage. It may also suggest faster growth and replacement of grazed-off stem DM. The former proposition would certainly be true when mature dried sorghum pasture were the feed on offer. The forage allowance and grazing pressure imposed relative to the available standing crop DM yield as well as the observed feeding habit of the steers while in the vegetative pastures all seem to point out that leaf selectivity and reciprocal stem rejection may not be a satisfactory explanation by itself for the observed data in this trial. It is suggested that further explanation may also reside in the nature of a plant's growth and mechanisms for replenishing DM consumed by grazing animals.

The fast growth of the forage sorghum needs no further emphasis, as may be inferred from the secondary regrowth yield figures illustrated in Figure 15. Physiologically, the plant's vegetative stem is an indeterminant structure while the leaf is a determinante structure (see, e.g., Salisbury & Ross 1978). Thus, in the expanded leaf, DM removed by grazing or otherwise cannot be replenished by regeneration of the decapitated leaf; it must, as a consequence, come from new leaves formed from other leaf primordia. The decapitated stem forage, on the other hand, continues to grow in size simultaneous to grazing while

tillers initiated at axillary and basal buds further contribute towards the stem forage in the residual standing crop. Thus, while the variability for the difference in leaf DM yield between the pre- and post-grazing estimate would reside, to a large extent, on leaf DM yield of tillers formed simultaneous to grazing; the variability for the stem DM component would arise from increase in size of the decapitated stem as well as the amount of stem material added from the new tillers. But in pasture grazing dynamics newly formed tillers also comprise a portion of the grazing animal's diet. The net result of this is that as long as grazing pressure surpasses the plant's capacity to regenerate new tillers leaf forage DM yields will be lower in the residual than in the pre-grazed pastures while the stem forage DM yields may or may not, depending on growth characteristics of the plant as well as grazing intensity, animal's preference and length of grazing period at which the pre- and post-grazing DM estimates were made.

In the lush vegetative forage sorghum pastures employed in the present trial, it was observed that both stem and leaf forage were relished by the steers. At equal forage availability (i.e., accessibility) there was no evidence that the steers selected one over the other. Presumably rapid growth simultaneous to grazing added more stem forage to standing crop than amount removed by the steers. Consequently, the post-grazing standing crop yielded, at times, higher stem forage DM than the pre-grazing standing crop, thereby rendering the apparent DM intake derived by difference of pre- and post-grazing forage yield unreliable.

The net result of the observations is that although the pre- and post-grazing clipping technique would show differences between pre- and post-grazing forage yields and provide estimates of DM intake of grazing livestock, any time such procedure is employed during the vegetative stage of the fast-growth sorghum x sundangrass hybrids, the proportion of the dietary intake accounted for by stem fraction would be, invariably, underestimated. Equally important, the technique would, at times, give misleading animal's preference for certain plant morphological components. The latter would occur especially when sufficient DM allowance is used in the trial.

Animal Performance

The performance of animals within pasture treatments as indicated by mean BW changes of steers while on sorghum pastures is given in Figure 18. A summary of various measures of animal performance is also presented in Table 15. Animal response data included average daily gain (ADG) by grazing period and by season as well as beef production per animal and per hectare. Animal performance measures were not affected by pasture row spacing treatments. This would normally be expected since as stated frequently in this report the various indices of DM intake and utilization were not significantly influenced by the pasture treatments imposed in the grazing trial. However, numerical differences, especially in beef gain per animal and beef production per hectare can be noted in the data reported in Table 15. Average daily gains of steers on pastures of the 25- and 51-cm row spacing treatments were numerically superior to those of steers on pastures of the 76-cm row spacing treatment. The initial gains attained during

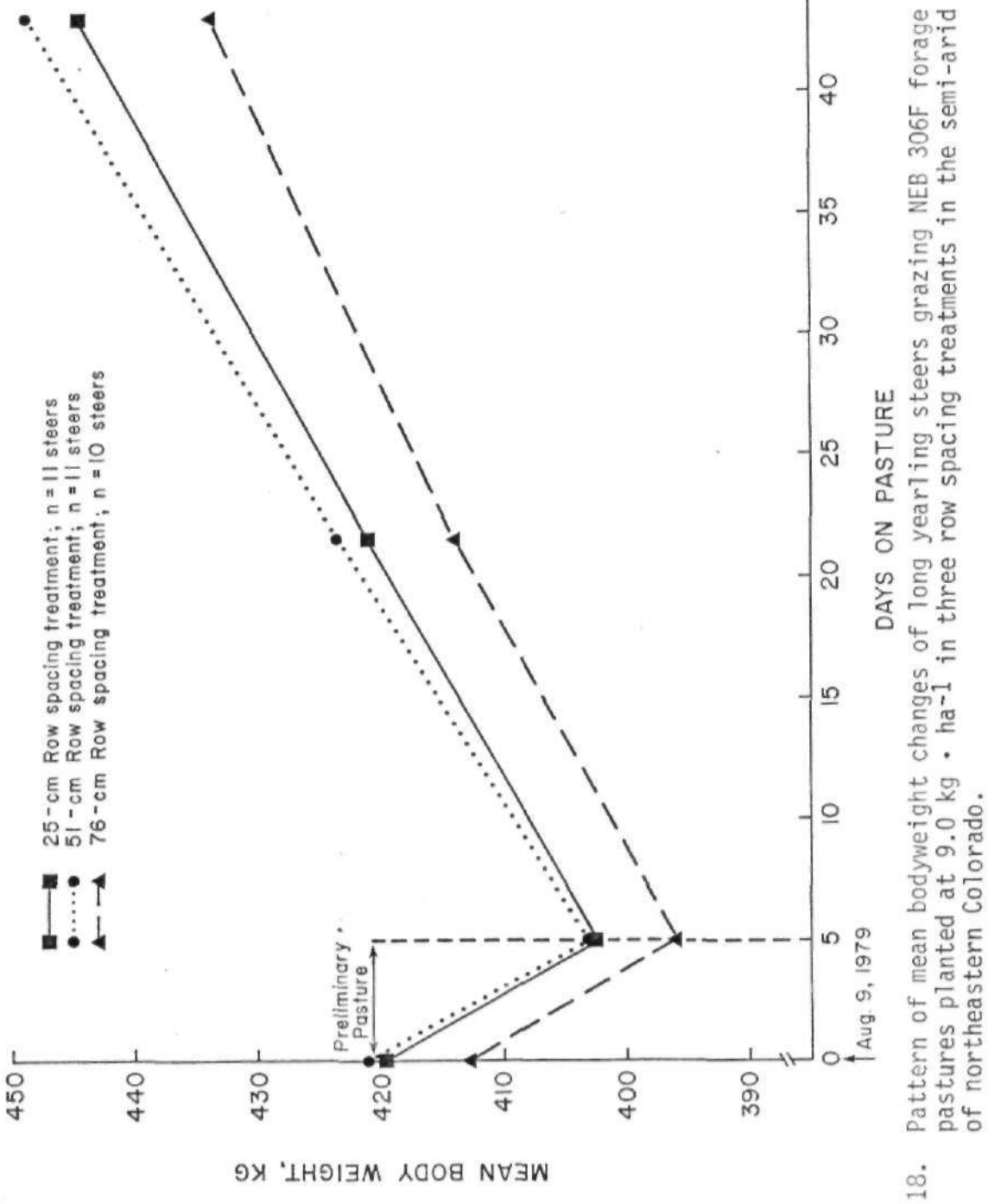


Figure 18. Pattern of mean bodyweight changes of long yearling steers grazing NEB 306F forage sorghum pastures planted at 9.0 kg • ha~1 in three row spacing treatments in the semi-arid conditions of northeastern Colorado.

the first two grazing periods of the trial were not sustained in the later three grazing periods in all treatments. However, the among-grazing period ADG within a treatment did not differ significantly ($p > .10$). Beef gain per animal and beef production per hectare followed a trend similar to animal daily gains (Table 15). For the entire 38-day trial ADG (kg · steer^{-1}) and beef produced (kg · ha^{-1}) in the pastures of 25-, 51- and 76-cm row spacing treatments were: 1.137 and 81.26; 1.230 and 87.95; and 1.005 and 65.33, respectively. Overall mean seasonal productivity of the pastures were daily steer gain of 1.125 kg and beef gain of 78.22 kg · ha^{-1}.

The comparatively lower performance of steers on pastures of 76-cm row spacing treatment relative to steers on the other pasture treatments deserves some comment. It was unlikely that the lower performance was connected to their treatment prior to entering the trial pastures. The group similar to steers in the other two groups were previously grazed on improved pastures of crested wheatgrass (*Agropyron desertorum*) and/or native pastures of prairie sandreed-big bluestem-blue grama (*Calamovilfa longifolia - Andropagon halii - Bouteloua gracilis*) complex during spring and early part of the summer grazing season. Similarly, the three groups of steers spent a five-day conditioning period on forage sorghum pastures before being transferred into the trial pastures. The resulting mean BW changes for the three groups during the five-day period may be noted in Figure 18.

Work by Ferrell *et al.* (1978) indicated that rate of gain favored large-type vs. small-type steers but feed efficiency was similar between the two types. The preliminary reports of current research at the

Table 15. Animal performance data of long yearling steers grazing NEB 306F forage sorghum pastures planted at 9.0 kg·ha^{-1} in three row spacing treatments in the semi-arid Northeast of Colorado.

PERFORMANCE MEASURE	PASTURE ROW SPACING TREATMENTS 25-cm	51-cm	76-cm
Days on trials, Aug. 15 - Sept. 22	38	38	38
Number of test animals	11	11	10
Grazing pressure, # animals · ha^{-1}	2.11	2.11	2.11
Stocking rate, # animals · ha^{-1} · mo^{-1}	1.71	1.71	1.71
Initial liveweight, kg	402.38	403.04	395.90
Daily liveweight gain, kg · head^{-1} · day^{-1}			
Aug. 15 - Aug. 30	1.216	1.278	1.123
Aug. 31 - Sept. 22	1.027	1.140	0.897
Final liveweight, kg	444.44	448.56	433.36
Average daily gain, kg · head^{-1} · day^{-1}	1.137	1.230	1.005
Total beef gained, kg · grazing season^{-1}	462.66	500.77	371.95
Beef production, kg · head^{-1}	42.06	45.52	37.20
Beef production, kg · ha^{-1}	81.26	87.96	65.33

Eastern Colorado Research Centre (Cook *et al*. 1980) also affirms the results in the above-cited study. Nevertheless, in this trial, size as indicated by the initial BW was not sufficiently different among the three steer groups to lower the beef yields of steers in the pastures of the 76-cm row spacing treatment.

Hodgson *et al*. (1977) showed that both quantity and digestibility of forage in the pre-grazed pasture exerted dominant influence on forage intake by steers with intake being 10% greater from pastures of primary growth than from pastures of secondary regrowth. Allden *et al*. (1970) reported that maximum DM intake by sheep was attained at pasture yield of 1800 kg DM · ha^{-1} and that at reduced forage availabilities the sheep tended to compensate by extending the grazing time from 6 to 13 hr · day^{-1}. Marsh (1979) reported that both pasture IVDMD and BW gain of steers fed pasture were influenced by forage allowance (kg forage DM · kg BW^{-1}) with BW gain increasing curvilinearly to an asymptotic point at a forage allowance of about 10.0 kg forage DM · 100 kg BW^{-1}. With regards to data in the present trial, it should be noted that forage DM yield per hectare (Figure 15, Table 14), except the pasture yields in 51-cm row spacing at three grazing periods, was below the yield of maximum DM intake reported by Allden *et al*. (1970). However, it would be erronous to equate the grazing pattern of sheep — which are invariably more selective — with that of cattle. Similarly daily forage DM allowance (calculated at the beginning of the trial to provide for minimum of 14 kg · $steer^{-1}$) was below the asymptotic point in the work of Marsh (1979). Nevertheless, forage DM yield or DM allowance in the 76-cm row spacing was neither above that in the 51-cm or below the one in the 25-cm row spacing treatment. The quality (CP,

IVDMD and physical composition) of the pre-grazed forage, as discussed previously, did not differ among the pasture treatments. Likewise, inferences based on the similarity of physical and nutrient composition of residual forage among treatments suggest that pastures were grazed to the same extent and, presumably DM intake and quality of intake did not differ among the steer groups. Yet, performance of steers in the 76-cm row spacing was lower than in either of the two treatments. Higher stocking rate would have improved the beef gain per hectare but this would have resulted in yet lower individual animal performance.

On the whole, animal responses in this trial conform to data obtained from other sorghum trials (Cook *et al.* 1980) conducted at the Eastern Colorado Research Centre. Thus, for example, in the Cook *et al.* (1980) data during the 1978 summer grazing season ADG recorded for steers pastured on the vegetative forage sorghum was approximately 1.05 kg · day^{-1}. Similarly in concurrence with the data in this trial there was no difference in ADG, beef gain per animal or beef production per hectare among groups grazed in pastures of 25-cm row spacing or those in pastures planted at wider row spacing.

It was pointed out in the literature review section of this report that poor animal performance was generally observed when sorghum forage constitutes the sole diet of the animal. Average daily gain for the grazing season was noted to vary from -0.006 to 0.884 kg · head^{-1} (Archer & Wheeler 1978; Coleman & Horn 1978; Dunavin 1970; Hoveland *et al.* 1971; Lippke 1974; Sheridan *et al.* 1972; Utley *et al.* 1976; Wheeler & Hedges 1972; Yates *et al.* 1964). This would seem to conflict with ADG of 1.005 to 1.140 kg obtained in the present trial. However, for such comparisons to be valid the studies must be evaluated

at similar pasture growth stage. Thus, it was noted, for example in the studies reported by Dunavin (1970), Hoveland *et al.* (1971), Utley *et al.* (1976) and Yates *et al.* (1964) pasture stages grazed by the steer varied from the lush, vegetative to mature, weathered forage. For the entire summer grazing season the ADG recorded in the studies cited was approximately 0.5 kg · steer^{-1}. Utley *et al.* (1976) reported an ADG of 0.884 kg · steer^{-1}. However, it was also noted that during early pasture stages gains were similar to those obtained in the present trial. In the results reported by Hoveland *et al.* (1971) first-month steer daily gains on the forage sorghum pastures were 1.134 kg for the non-supplemented and 1.270 kg for the supplemented groups. Hoveland *et al.* (1971) stated that these responses were not compensatory since the steers, similar to the groups in the present trials, were moved from pastures where they gained satisfactorily (approximately 0.68 kg · steer^{-1} · day^{-1}).

Admittedly, more research information than that reported will be needed to adequately evaluate animal performance and productivity of forage sorghum. Nevertheless, what seems to emerge from the present data as well as the literature reports is that while forage sorghum when utilized in short-duration summer grazing provides for optimum animal performance that could be expected from most high-quality pastures, the forage may be unsuitable for extended grazing season in which the objective is to maximize individual animal productivity. However, its growth rate and DM yield potential provides for high carrying capacity and hence maximum beef production per hectare. To maximize individual animal performance while taking advantage of its high secondary regrowth potential (Figure 15, Table 14) the forage

sorghum may have to be utilized as a complimentary pasture in short-duration grazing when the forage is at mid-vegetative stage. This may be equivalent to the third grazing period of this trial in which higher yields of DM, CP and digestible DM were obtained while the pasture secondary regrowth resulting from such treatment was also equally satisfactory in yield of these indices of animal performance.

The steer performance, as indicated by the ADG (1.005 to 1.140 kg) suggests that neither quantity nor quality of forage DM was limiting in the present trial. Yet, under the semi-arid conditions of the study area, data in this trial compared to data from other studies at Eastern Colorado Research Centre (Denham 1971b; Cook *et al.* 1980) indicate large between-year and seasonal fluctuations in DM yield of the forage sorghum. Generally, forage sorghum yield from the Centre was noted to be lower than that reported from other research centres (Burnside *et al.* 1964; Eilrich *et al.* 1964; Kiesselbach & Anderson 1925; Stickler & Laude 1960; Stickler & Younis 1966) even when their climatic conditions were apparently similar. The large fluctuations in forage yield concomitant with the fast growth of the forage would indeed pose the practical problem of determining proper stocking for optimal animal production. If high production efficiencies are to be achieved from forage sorghum as complementary pastures, emphasis will have to be placed on maintaining DM yield while improving nutrient quality. Certainly, under the marginal conditions of northeastern Colorado when forage sorghum pastures are grazed during the vegetative stage, high forage DM yields would be most beneficial to total animal productivity before quality becomes a limiting factor.

CHAPTER V

SUMMARY

The 'NEB 306F' sorghum x sudangrass, *Sorghum bicolor* x S. *sudanense*, hybrid was used in two trials at Eastern Colorado Research Centre (ECRC), 27.3 km north of Akron, Colorado to evaluate components associated with pasture primary and secondary productivity. Trial I was conducted in two summers (1978 and 1979) to evaluate seeding rate (5.6, 9.0, 11.2 and 16.8 kg · ha^{-1}) and row spacing 25, 51 and 76 cm) effects on forage dry matter (DM) yield components. The effects of row spacing on nutritive quality of DM types was also examined. The DM yield components evaluated were plant height, stem diameter, number of leaves, plant density, yield per plant and leaf content at various stages of physiological maturity. The nutritive quality parameters evaluated were: phosphorus (P), crude protein (CP, netural detergent solubles (NDS), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), hemicellulose (H), cellulose (C), and *in vitro* DM digestibility (IVDMD). The leaf, stem and whole plant forages were analyzed for the nutritive quality components. Samples examined comprised early vegetative (26 to 52-day post-planting) to early reproductive, frosted (93 to 107-day post-planting) forage material. Trial II was conducted in 1979 to evaluate effects of row spacings and plant physiological stages (five grazing periods, starting with active vegetative stage at 48 days post planting) on the performance of 32 long-yearling steers in relation to DM yield, leaf content of DM, and CP and IVDMD of leaf and stem forage. The DM components of both the pre- and post-grazed pastures were examined.

In Trial I:

1. There was no significant seeding rate x row spacing interaction with respect to forage yield components in all cases examined. Hence seeding rate and row spacing effects were examined separately.
2. Components of DM yield within treatment, with exception of leaf content (expressed as % DM or leaf:stem ratio), generally increased as harvest was delayed. Among treatments plant density, leaf number per unit area, and leaf and stem biomass per unit area increased with seeding rates. Maximum yield, plant density and number of leaves were obtained at the 16.8 kg · ha^{-1} seeding rate but yield per plant and stem diameter were smallest at this seeding rate. The latter two forage DM yield components declined linearly with seeding rate (r_i's > - .8000).
3. The proportion of leaf or stem within forage, regardless of the amount of phytomass, appeared to be a constant plant characteristic. It was not influenced by either seeding rate or row spacing manipulations. Similarly, plant height was not influenced by treatments imposed in this trial. The percentages of leaf and stem within the forage DM were, respectively, inversely and directly related with plant growth stages up to cessation of growth at frost.
4. Row spacing effects, in comparison with seeding rate effects, on forage yield components were inconsistent as

plants advanced to physiological maturity. However, in the final harvest lower plant density, and larger stem diameter, yield per plant and phytomass resulted in the 25-cm than in the 51- or 76-cm row spacing. In the initial harvest the largest plant population and forage per hectare were recorded from the 25-cm row spacing, while yield per plant and stem diameter were not different among the row spacings.

5. Simple and multivariate analysis revealed that variations in phytomass were proportionately associated with plant morphology, density, DM per plant as well as leaf and stem biomass. The log-transformed variables resulted in more realistic models of DM yield than the untransformed simple variables. It was suggested that the models, based on the plant morphology, would be more related to the physiology of the pasture and, hence, more accurate in predicting DM yield of standing crop than the ocular and time measures used in forage evaluation techniques.
6. There was no evidence that row spacing had influenced forage quality as determined by P, CP, cell contents, cell wall constituents and IVDMD. However variations *in nutritive quality within DM types (leaf, stem and* whole plant) between years and among physiological stages were significant ($p < .05$). Also, differences among DM types within and among physiological stages were generally significant.

7. Contrary to general concepts of the superiority of leaf nutritive quality over that of stem, the IVDMD and NDS contents of stem were higher or comparable to that of leaf or whole plant forage, while the CP, P, NDF, ADF, ADL as well as the structural polysaccharides were higher in the leaf and whole plant forage. Early in the vegetative stage the CP, P and IVDMD of leaf, stem and whole plant forages were: 18.5, 0.41 and 71.5%; 15.1, 0.37 and 719%; and 14.5, 0.49 and 71.9%, respectively. In the early bloom, frosted sample the CP, and P and IVDMD of the respective DM types were: 9.1, 0.36 and 63.3%; 8.4, 0.29 and 65.0%; and 8.7, 0.36 and 65.1%.
8. The conventional indices of lignification and cell walls, and fiber utilization did not satisfactorily explain the differential or comparative digestibilities of leaf and stem forage. Inferences suggest that the differences in the digestible energy values of leaf and stem forage might not be explained in terms of their contents of NDS and structural constituents, alone, but presumably resulted from the extent of tissue lignification (i.e., distribution of lignified tissues) and differential digestibilities of both hemicellulose and cellulose of each morphological forage type.
9. Generally, the feeding value parameters of whole plant DM were intermediate between those of leaf and stem forage. Leaf or stem percentage, *per se*, was a poor indicator of whole plant feeding quality. Comparatively, the

associative effects of leaf percentage on the nutritive indices of whole plant DM, with the exception of CP and P contents, suggest a depressed digestible energy content of the latter with increasing leafiness. The linear relationship between leaf percentage and CP, P, IVDMD, NDS, NDF, ADF, ADL, C, H and H:C ratio of the whole plant DM were: r = .518*, .472*, .126, -.486*, .486*, .196, .469*, .355 and -.024, respectively.

In Trial II:

1. Results agree with data in Trial I, i.e., row spacing did not influence physical composition of DM or CP content and IVDMD of leaves and stems. Differences within grazing treatment among periods and differences in CP content and IVDMD between leaf and stem were significant in both the pre-grazed and residual pastures. In the pre-grazed pastures the IVDMD of stem was higher than that of leaf despite the higher CP content of the latter fraction. However, in the residual pastures leaf DM was undoubtedly superior in IVDMD and CP values to stem DM. Irrespective of grazing period, the pre-grazed pasture was higher in forage yield, and physical and nutrient composition than the residual pasture.
2. The growth pattern of the forage sorghum made it difficult to arrive at reliable estimate of the "apparent DM intake" of steers by the pre- and post-grazing clipping method. The observation became more apparent

when phytomass was partitioned into leaf and stem propotions, such that, at times, the post-grazing standing crop yielded higher stem DM than the pre-grazing standing crop. The observation was never found to be the case with leaf proportion. Accessibility and indeterminante growth of stem commensurate to grazing agreed more with the observation than the animal's preference for leaf and rejection of stem forage, *per se*.

3. Steer performance suggested that DM yield, DM intake and quality of intake were not limiting. There was no significant difference ($p > .10$) in weight gains among steer groups grazing the three row spacing treatments. The initial gains (ADG) attained by steers (1.22, 1.28 and 1.12 kg for the 25-, 51- and 76-cm row spacing, respectively) on the early vegetative forage were not sustained in the mature forage. However, ADG within treatment among grazing period were not significantly different ($p > .10$). For the entire trial period ADG ($kg \cdot steer^{-1}$) and beef production ($kg \cdot ha^{-1}$) in the 25-, 51- and 76-cm row spacing treatments were: 1.14 and 81.3; 1.23 and 88.0; and 1.01 and 65.4, respectively.

Comparatively, data in this study and previous reports of sorghum trials at ECRC indicate large between-year fluctuations in forage yield. This would pose the practical problem of determining proper stocking if the forage sorghum is used as a complementary pasture in the forage-fed beef production. Likewise, in comparison with reported literature

from other areas, forage yields in the study site were extremely low. However, nutrient quality and animal performance were similar and comparable with any high-quality forage provided the pastures were evaluated at equivalent stages of physiological maturity.

CHAPTER VI

CONCLUSIONS

The observations of this study suggest that heavier seeding rate (11 to 16 kg · ha^{-1}) and narrow row spacing (25-cm) are superior in yields of number of plants and total forage yield per hectare, but also resulted in smaller stem diameter and DM yield per plant. It is not likely that the forage physical (proportions of leaf and stem) and nutrient composition can be modified by management practices such as seeding rate and/or row spacing manipulations. Both feeding value parameters appear to be intrinsic plant characteristics which are markedly influenced by plant physiological stages.

The composition of cell contents and cell wall constituents as well as relation of protein to digestibility of leaf and stem indicate that further research is required in order to establish the "assumed" superiority of leaf feeding value to that of stem forage. Similarly there is need to explain the causes of the abrupt decline in feeding quality of forage with onset of reproduction and/or frost.

Admittedly, more research data will be needed to adequately evaluate animal performance and productivity of forage sorghum. While forage sorghum when utilized in short-duration summer grazing provides for optimal animal performance that may be expected from any high-quality pasture, the forage may be unsuited to extended grazing seasons in which the objective is to maximize individual animal productivity. However, its growth rate and DM yield potential provides for high carrying capacity and hence,maximum beef production per hectare. To optimize harvestible nutrient and individual animal

performance while taking advantage of its high regrowth potential the sorghum may have to be utilized as a complementary pasture in short-duration grazing when the forage is at the mid-vegetative stage (approximately 50-60 days post-planting and/or plant height of *ca* 70 cm). Where secondary regrowth is required the grazing strategy should be such that at least a 2-week rest period is allowed to precede the expected date of frost.

If high production efficiencies are to be achieved from the forage sorghum as complementary pastures in the forage-fed beef, emphasis should be placed in maintaining DM yield while improving nutrient quality. Certainly, under semi-arid conditions when forage sorghums are grazed during the vegetative stage, high forage DM yields would be most beneficial to total animal productivity before quality becomes a limiting factor.

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APPENDIX

Appendix Table I. Changes within row spacing by physiological stage of maturity in forage yield components, chemical and nutritive characteristics of plant parts and intact whole plant of NEB 306F forage sorghum planted at 9 kg · ha^{-1}.

YEAR TREATMENT AND AGE[1] OF PASTURE	HERBAGE YIELD COMPONENTS				CHEMICAL AND NUTRITIVE CONSTITUENTS OF DRY MATTER											
					Crude Protein			Phosphorus			Cell Wall Constituents			Cell Solubles		
	Forage Density	Dry Matter Yield	Leaf:Whole Plant Ratio	Leaf:Stem Ratio	L*	S**	WP***	L	S	WP	L	S	WP	L	S	WP
	X 10^5culm/ha	kg/ha			Percent dry matter											
1978: Overall Year Mean	1.35	2999.46	0.54	1.25	13.26	12.10	11.46	0.380	0.355	0.405	58.98	50.37	54.00	41.02	49.63	46.00
25-cm row spacing																
40 days (Jul. 25)	1.75	1933.03	0.63	1.74	16.19	15.44	15.81	0.359	0.313	0.471	61.56	57.21	57.01	38.44	42.79	42.99
70 days (Aug. 24)	1.90	4546.15	0.52	1.11	11.19	10.83	13.19	0.456	0.417	0.303	59.36	47.05	53.89	40.64	52.95	46.11
93 days (Sept. 16)	2.19	6770.94	0.47	0.89	10.88	10.26	8.44	0.315	0.317	0.274	56.74	48.51	50.08	43.26	51.49	49.92
Mean	1.95	4417.01	0.54	1.25	12.75	12.17	12.48	0.367	0.349	0.349	59.22	50.92	53.66	40.78	49.08	46.34
51-cm row spacing																
40 days (Jul. 25)	0.89	999.44	0.62	1.64	23.44	14.44	10.88	0.417	0.359	0.521	57.93	58.72	59.39	42.07	41.28	40.61
70 days (Aug. 24)	1.25	3077.73	0.49	0.96	11.31	12.01	9.06	0.309	0.344	0.413	60.47	48.62	58.64	39.53	51.38	41.36
93 days (Sept. 16)	1.55	3660.38	0.46	0.84	11.13	10.69	7.50	0.294	0.307	0.413	59.61	45.27	47.90	40.39	54.74	52.10
Mean	1.23	2579.18	0.52	1.15	15.29	12.65	8.81	0.340	0.337	0.449	59.34	50.87	55.31	40.66	49.13	44.69
76-cm row spacing																
40 days (Jul. 25)	0.89	368.03	0.63	1.76	16.00	15.38	16.69	0.458	0.429	0.476	56.20	53.86	55.49	43.80	46.14	44.51
70 days (Aug. 24)	0.77	2203.88	0.57	1.31	10.06	12.81	11.31	0.404	0.385	0.382	60.48	47.27	54.37	39.52	52.63	45.63
93 days (Sept. 16)	0.96	3434.66	0.50	1.00	9.13	6.25	11.81	0.291	0.320	0.389	58.50	46.73	49.27	41.50	53.27	50.73
Mean	0.88	2002.19	0.56	1.36	11.73	11.48	13.27	0.384	0.378	0.416	58.39	49.32	53.04	41.61	50.68	46.96
1979: Overall Year Mean	2.73	2136.13	0.57	1.36	10.22	8.91	10.62	0.410	0.357	0.385	66.22	60.34	63.25	33.78	40.49	36.75
25-cm row spacing																
52 days (Aug. 20)	2.68	1022.22	0.57	1.35	12.69	12.25	14.56	0.471	0.456	0.413	65.29	61.78	58.72	34.71	38.22	41.28
72 days (Sept. 9)	2.04	1358.13	0.63	1.70	9.31	5.75	11.75	0.408	0.395	0.456	69.52	59.26	67.81	30.43	40.74	32.19
102 days (Oct. 9)	2.60	3719.37	0.49	0.95	9.31	9.56	11.16	0.378	0.344	0.418	68.65	55.87	62.61	31.36	44.14	37.40
Mean	2.44	2033.24	0.54	1.24	10.16	9.28	12.16	0.429	0.385	0.426	68.03	58.19	62.94	31.98	41.61	37.07
51-cm row spacing																
52 days (Aug. 20)	1.72	354.42	0.65	1.82	11.31	8.75	13.00	0.399	0.437	0.429	69.99	66.32	66.12	30.10	33.68	33.88
72 days (Sept. 9)	3.24	2134.29	0.56	1.28	9.75	6.56	9.31	0.446	0.339	0.410	71.56	59.32	71.45	28.44	40.68	28.55
102 days (Oct. 9)	3.35	2795.05	0.56	1.29	8.06	8.28	8.41	0.320	0.249	0.289	63.12	58.44	59.15	36.08	41.57	40.86
Mean	2.92	2019.70	0.58	1.42	9.31	7.97	9.78	0.371	0.318	0.354	66.95	60.63	63.97	33.05	39.39	36.04
76-cm row spacing																
52 days (Aug. 20)	2.66	809.38	0.63	1.73	12.56	12.00	13.00	0.489	0.514	0.471	67.52	62.08	65.10	32.48	37.92	34.99
72 days (Sept. 9)	2.61	1744.06	0.58	1.40	12.75	11.19	13.69	0.446	0.409	0.392	69.14	59.81	64.91	30.86	40.20	35.09
102 days (Oct. 9)	2.97	2591.11	0.56	1.29	9.75	7.34	6.50	0.342	0.276	0.320	59.03	63.48	60.76	40.97	41.52	39.24
Mean	2.75	1714.85	0.59	1.47	11.69	10.18	11.06	0.430	0.369	0.376	63.68	62.21	62.86	36.32	40.29	37.14

[1]Days post-planting

*L leaf tissue herbage dry matter

**S stem tissue herbage dry matter

***WP intact whole plant herbage dry matter

††H:C hemicellulose to cellulose ratio

Appendix Table I. Changes within row spacing by physiological stage of maturity in forage yield components, chemical and nutritive characteristics of plant parts and intact whole plant of NEB 306F forage sorghum planted at 9 kg · ha^{-1} (continued).

YEAR TREATMENT AND AGE[1] OF PASTURE	CHEMICAL AND NUTRITIVE CONSTITUENTS OF DRY MATTER																	
	Acid Detergent Fiber			Hemicellulose			Acid Detergent Lignin			Cellulose			*In vitro* Digestibility			H:C Ratio[††]		
	L	S	WP	L	S	WP	L	S	WP	L	S	WP	L	S	WP	L	S	WP
	Percent of dry matter																	
1978: Overall Year Mean	32.06	25.69	29.43	26.92	24.68	24.58	2.68	2.36	2.57	29.38	23.33	26.85	67.74	73.72	71.38	0.92	1.06	0.92
25-cm row spacing																		
40 days (Jul. 25)	31.26	31.79	30.24	30.30	25.42	26.77	2.12	2.76	2.53	29.14	29.03	27.71	74.05	60.25	71.98	1.04	0.68	0.97
70 days (Aug. 24)	32.88	24.44	26.74	26.40	22.61	21.15	2.66	2.87	2.11	30.22	21.57	24.63	65.28	76.54	72.02	0.88	1.05	1.10
93 days (Sept. 16)	31.60	22.80	29.33	25.14	25.71	20.75	2.35	1.96	2.48	29.25	20.84	26.85	61.98	77.91	72.54	0.86	1.23	0.77
Mean	31.91	26.34	28.77	27.31	24.58	24.89	2.38	2.53	2.37	29.54	23.81	26.40	67.10	71.57	72.18	0.93	1.05	0.95
51-cm row spacing																		
40 days (Jul. 25)	30.58	28.95	33.57	27.35	29.77	25.82	2.15	2.44	1.96	28.43	26.51	31.61	68.83	67.43	72.33	0.96	1.12	0.82
70 days (Aug. 24)	33.42	22.59	29.56	27.05	26.03	29.09	3.20	2.49	1.77	30.22	20.10	27.78	66.33	77.50	67.17	0.90	1.30	1.05
93 days (Sept. 16)	29.13	22.60	28.39	30.48	22.67	19.51	3.21	1.49	2.20	25.92	21.11	26.19	69.44	77.56	73.51	1.18	1.07	0.74
Mean	31.04	24.71	30.50	28.29	26.16	24.81	2.85	2.14	1.98	28.19	22.57	28.53	69.20	75.16	71.00	1.01	1.16	0.87
76-cm row spacing																		
40 days (Jul. 25)	33.71	28.28	29.90	22.49	25.58	25.59	2.59	2.12	2.75	31.12	26.16	27.15	71.48	74.95	71.48	0.72	0.98	0.94
70 days (Aug. 24)	32.51	24.11	29.12	27.97	23.26	25.25	2.47	2.34	4.99	30.04	21.77	24.13	65.11	76.68	72.01	0.93	1.07	1.05
93 days (Sept. 16)	33.49	25.63	27.99	25.01	21.10	21.28	3.38	2.78	2.38	30.11	22.85	25.61	67.25	74.68	69.37	0.83	0.92	0.83
Mean	33.24	26.01	29.00	25.16	23.31	24.04	2.81	2.43	3.37	30.42	23.59	25.63	67.95	75.44	70.96	0.83	0.99	0.94
1979: Overall Year Mean	37.51	34.20	34.42	28.70	26.06	28.84	3.76	3.85	3.58	33.76	30.43	30.84	63.13	67.36	66.84	0.86	0.86	0.94
25-cm row spacing																		
52 days (Aug. 20)	36.64	34.80	32.16	28.65	26.98	26.56	3.45	3.35	2.68	33.19	31.45	29.48	66.45	71.20	70.53	0.86	0.96	0.90
72 days (Sept. 9)	40.05	34.61	38.18	29.47	24.65	29.63	2.89	3.46	4.41	37.16	31.15	33.77	67.19	65.13	66.91	0.79	0.79	0.88
102 days (Oct. 8)	38.95	33.71	33.09	29.70	22.16	29.52	4.88	3.40	3.61	34.07	29.31	29.48	59.18	64.85	63.72	0.88	0.76	1.02
Mean	38.65	34.21	34.13	29.38	23.99	28.81	4.02	3.90	3.58	34.62	30.31	30.55	63.00	66.51	66.22	0.86	0.79	0.96
51-cm row spacing																		
52 days (Aug. 20)	40.79	41.39	32.57	29.20	24.93	33.55	4.27	3.85	3.24	36.52	37.54	29.33	61.60	69.07	71.55	0.80	0.66	1.14
72 days (Sept. 9)	40.11	36.22	39.95	31.45	23.10	31.50	3.18	3.65	5.48	36.93	32.57	34.47	57.43	66.07	60.65	0.86	0.77	0.91
102 days (Oct. 9)	36.40	31.68	32.24	26.72	26.76	26.91	3.34	3.41	3.28	33.07	28.27	28.96	64.25	63.03	68.17	0.81	0.96	0.93
Mean	38.43	35.24	34.25	28.52	25.39	29.72	3.53	3.64	3.82	34.90	30.99	30.43	61.88	65.30	67.13	0.82	0.84	0.98
76-cm row spacing																		
52 days (Aug. 20)	39.51	35.63	38.80	28.01	26.45	36.21	3.79	3.97	2.78	35.72	31.66	36.02	65.03	76.06	71.76	0.78	0.84	0.73
72 days (Sept. 9)	37.25	33.68	35.89	31.89	26.13	29.02	3.80	2.63	3.74	33.45	31.05	32.15	60.31	71.13	70.08	0.95	0.84	0.90
102 days (Oct. 9)	32.57	32.15	32.41	26.47	31.33	28.36	3.66	3.51	3.40	28.91	28.64	29.01	66.35	66.97	63.41	0.93	1.09	0.98
Mean	35.47	33.40	34.88	29.21	29.81	27.99	3.73	3.41	3.33	31.75	30.00	30.55	64.51	70.28	67.16	0.90	0.97	0.95

[1] Days post-planting

[*] L leaf tissue herbage dry matter

[**] S stem tissue herbage dry matter

[***] WP intact whole plant herbage dry matter

[††] H:C hemicellulose to cellulose ratio

Appendix Table II. Changes in forage yield components, chemical and nutritive characteristics of plant parts and intact whole plant of NEB 306F forage sorghum planted at 9 kg · ha^{-1} in relation to age of tissue at harvest and row spacing treatment.

YEAR, AGE OF TISSUE† AND TREATMENT	HERBAGE YIELD COMPONENTS				CHEMICAL AND NUTRITIVE CONSTITUENTS OF DRY MATTER											
	Forage Density	Dry Matter Yield	Leaf:Whole plant ratio	Leaf:Stem ratio	Crude Protein			Phosphorus			Cell Wall Constituents			Cell Solubles		
					T*	S**	WP***	L	S	WP	L	S	WP	L	S	WP
	x 10^5 culms/ha	kg/ha			Percent of dry matter											
1978 Overall Year Mean:	1.35	2999.46	0.54	1.25	13.26	12.10	11.46	0.380	0.355	0.405	58.98	50.37	54.00	41.02	49.63	46.00
40 Days (Jul. 25)																
25-cm row	1.75	1933.93	0.63	1.74	16.19	15.44	15.81	0.359	0.313	0.417	61.56	57.21	57.01	38.44	42.79	42.99
51-cm row	0.89	999.44	0.62	1.64	23.44	14.44	10.88	0.417	0.359	0.521	57.93	58.72	59.39	42.07	41.28	40.61
76-cm row	0.89	368.03	0.63	1.76	16.00	15.38	16.69	0.458	0.429	0.476	56.20	53.86	55.49	43.80	46.14	43.51
Mean	1.18	1100.47	0.63	1.71	18.54	15.09	14.46	0.411	0.367	0.489	58.56	56.60	57.30	41.44	43.40	42.70
70 Days (Aug. 24)																
25-cm row	1.90	4686.15	0.53	1.11	11.19	10.81	13.19	0.456	0.417	0.303	59.36	47.05	53.89	40.64	52.95	46.11
51-cm row	1.25	3077.73	0.49	0.96	11.31	12.81	8.06	0.309	0.344	0.413	60.47	48.62	50.64	39.53	51.38	41.36
76-cm row	0.77	2203.88	0.57	1.31	10.06	12.81	11.31	0.404	0.305	0.302	60.48	47.37	54.37	39.52	52.63	45.63
Mean	1.31	3275.92	0.53	1.13	10.85	12.15	10.85	0.390	0.382	0.366	60.10	47.68	55.63	39.90	52.32	44.37
93 Days (Sept. 16)																
25-cm row	2.19	6770.94	0.47	0.89	10.88	10.25	8.44	0.315	0.317	0.274	56.74	48.61	53.08	43.26	51.49	49.52
51-cm row	1.55	3660.38	0.45	0.84	11.13	10.69	7.50	0.294	0.307	0.413	59.61	45.27	47.90	40.39	54.74	52.10
76-cm row	0.96	3434.66	0.50	1.00	9.13	6.25	11.81	0.291	0.320	0.389	58.50	46.73	49.27	41.50	53.27	50.73
Mean	1.57	4621.99	0.48	0.91	10.38	9.06	9.25	0.300	0.315	0.359	58.28	46.84	49.58	41.72	53.17	50.92
1976 Overall Year Mean:	2.73	2136.13	0.57	1.36	10.22	8.91	10.62	0.410	0.357	0.385	66.22	60.34	63.25	33.73	40.49	36.75
52 Days (Aug. 20)																
25-cm row	2.68	1022.22	0.57	1.35	12.69	12.25	14.56	0.471	0.456	0.413	65.23	61.78	58.72	34.71	38.22	41.28
51-cm row	1.72	354.42	0.65	1.82	11.31	8.75	13.00	0.399	0.437	0.429	69.99	66.32	66.12	30.01	33.68	33.88
76-cm row	2.66	809.38	0.63	1.73	12.56	12.09	13.00	0.489	0.514	0.471	67.52	62.08	65.01	32.48	37.92	34.99
Mean	2.35	728.68	0.62	1.36	12.19	11.00	13.52	0.453	0.469	0.438	67.60	63.39	63.28	32.40	36.61	36.72
72 Days (Sept. 9)																
25-cm row	2.04	1358.13	0.63	1.70	9.31	5.75	11.75	0.488	0.395	0.456	61.52	59.26	67.81	38.48	40.74	32.19
51-cm row	3.24	2134.29	0.56	1.28	9.75	6.56	9.31	0.446	0.339	0.410	71.56	59.32	71.45	28.44	40.68	28.55
76-cm row	2.61	1744.49	0.58	1.40	12.75	11.19	13.69	0.446	0.409	0.392	69.14	59.81	64.91	30.86	40.20	35.09
Mean	2.63	1745.49	0.54	1.46	10.63	7.81	11.58	0.460	0.381	0.419	70.07	59.46	68.06	29.93	40.54	31.94
102 Days (Oct. 9)																
25-cm row	2.60	3719.37	0.49	0.95	9.31	9.56	11.16	0.378	0.344	0.418	68.65	55.87	62.61	31.36	44.14	37.40
51-cm row	3.35	2795.05	0.56	1.29	8.09	8.25	8.41	0.320	0.249	0.289	63.12	58.44	59.15	36.88	41.57	40.66
76-cm row	2.97	2791.11	0.56	1.29	9.75	7.31	6.50	0.392	0.276	0.370	59.03	63.48	60.76	40.97	41.52	39.24
Mean	2.97	3035.18	0.54	1.18	9.05	8.37	8.69	0.363	0.290	0.342	63.60	59.26	60.84	36.40	42.41	39.17

†Days post-planting.

*L leaf tissue herbage dry matter.

**S stem tissue herbage dry matter.

***WP intact whole plant herbage dry matter

††H:C hemicellulose to cellulose ratio.

Appendix Table II. Changes in forage yield components, chemical and nutritive characteristics of plant parts and intact whole plant of NEB 306F forage sorghum planted at 9 kg · ha^{-1} in relation to age of tissue at harvest and row spacing treatment (continued).

YEAR, AGE OF TISSUE[1] AND TREATMENT	CHEMICAL AND NUTRITIVE CONSTITUENTS OF DRY MATTER																	
	Acid Detergent Fiber			Hemicellulose			Acid Detergent Lignin			Cellulose			In vitro Digestibility			H:C Ratio[2]		
	L[*]	S[**]	WP[***]	L	S	WP	L	S	WP	L	S	WP	L	S	WP	L	S	WP
	Percent of dry matter																	
1970 Overall Year Mean:	32.06	25.69	29.43	26.92	24.68	24.58	2.60	2.36	2.57	29.38	23.33	26.85	67.74	73.72	71.38	0.920	1.060	0.920
40 Days (Jul. 25)																		
25-cm row	31.26	31.79	30.24	30.30	25.42	26.77	2.12	2.76	2.53	29.14	29.03	27.71	74.05	60.25	71.96	1.040	0.876	0.966
51-cm row	30.58	28.95	33.57	27.35	29.77	25.62	2.15	2.44	1.96	28.43	26.51	31.61	68.83	67.42	72.33	0.962	1.123	0.817
76-cm row	33.71	28.15	29.90	22.49	25.58	25.59	2.59	2.12	2.75	31.12	26.16	27.15	71.48	74.95	71.48	0.723	0.978	0.943
Mean	31.85	29.67	31.24	26.71	26.92	26.06	2.29	2.44	2.41	29.56	27.23	28.82	71.45	67.54	71.93	0.908	0.997	0.909
70 Days (Aug. 24)																		
25-cm row	32.88	24.44	26.74	26.48	22.61	27.15	2.66	2.87	2.11	30.22	21.57	24.63	65.28	76.54	72.02	0.876	1.048	1.102
51-cm row	33.42	22.59	29.55	27.05	26.03	29.09	3.20	2.49	1.77	30.22	20.10	27.78	66.33	77.50	67.17	0.895	1.295	1.047
76-cm row	32.51	24.11	29.12	27.97	23.26	25.25	2.47	2.34	4.99	30.04	21.77	24.13	65.11	76.68	72.01	0.931	1.068	1.046
Mean	32.94	23.71	28.47	27.17	23.97	27.16	2.78	2.57	2.96	30.16	21.15	25.51	65.57	76.91	70.40	0.901	1.137	1.065
93 Days (Sept. 16)																		
25-cm row	31.60	22.80	29.33	25.14	25.71	20.75	2.35	1.96	2.48	29.25	20.84	26.85	61.98	77.91	72.54	0.860	1.234	0.773
51-cm row	29.13	22.60	28.39	30.48	22.67	19.51	3.21	1.49	2.20	25.92	21.11	26.19	69.44	77.56	73.51	1.176	1.074	0.745
76-cm row	33.49	25.63	27.99	25.01	21.10	21.28	3.38	2.78	2.38	30.11	22.85	25.61	67.25	74.68	69.37	0.831	0.923	0.831
Mean	31.41	23.68	28.57	26.88	23.16	20.51	2.98	2.08	2.35	28.43	21.60	26.22	66.22	76.72	71.81	0.955	1.077	0.783
1978 Overall Year Mean:	37.51	34.28	24.42	28.70	26.06	28.84	3.76	3.85	3.58	33.76	30.43	30.84	63.13	67.36	66.84	0.860	0.860	0.940
52 Days (Aug. 20)																		
25-cm row	36.64	34.80	32.16	28.65	26.98	26.56	3.45	3.35	2.68	33.19	31.45	29.48	66.45	71.20	73.53	0.863	0.858	0.901
51-cm row	40.79	41.39	32.57	29.20	24.93	33.55	4.27	3.85	3.24	36.52	37.54	29.33	61.59	69.07	71.55	0.800	0.664	1.144
76-cm row	39.51	35.63	38.80	28.01	26.45	26.21	3.78	3.97	2.78	35.72	31.66	36.02	65.03	76.06	71.76	0.784	0.835	0.728
Mean	38.98	37.27	34.51	28.62	26.12	28.77	3.84	3.72	2.90	35.14	33.55	31.61	64.36	72.11	71.28	0.816	0.786	0.924
72 Days (Sept. 9)																		
25-cm row	40.05	34.61	38.18	29.47	24.65	29.63	2.89	3.46	4.41	37.16	31.15	33.77	67.19	65.13	66.91	0.793	0.791	0.877
51-cm row	40.11	36.22	39.95	31.45	23.10	31.50	3.18	6.35	5.48	36.93	29.87	34.47	57.43	66.07	60.65	0.852	0.773	0.914
76-cm row	37.25	33.68	35.89	31.89	26.13	29.02	3.80	2.63	3.70	33.45	31.05	32.15	60.31	71.13	70.08	0.953	0.842	0.903
Mean	39.14	34.84	38.01	30.94	24.63	30.05	3.29	4.15	4.54	35.85	30.69	33.46	61.64	67.44	65.88	0.866	0.802	0.898
102 Days (Oct. 9)																		
25-cm row	38.98	33.71	33.09	29.70	22.16	29.52	4.88	4.40	3.61	34.07	29.31	29.48	59.18	64.85	63.72	0.894	0.756	1.022
51-cm row	36.40	31.68	32.24	26.72	26.76	26.91	3.34	3.41	3.28	33.07	28.27	28.96	64.25	63.03	68.17	0.810	0.957	0.930
76-cm row	32.57	32.15	32.41	26.47	31.33	28.36	3.67	3.51	3.40	29.91	28.64	29.01	66.35	66.97	63.41	0.933	1.094	0.980
Mean	35.97	32.51	32.58	27.63	26.75	28.26	3.96	3.77	3.43	32.02	28.74	28.82	63.26	64.95	65.10	0.875	0.936	0.977

[1] Days post-planting

[*] L leaf tissue herbage dry matter

[**] S stem tissue herbage dry matter

[***] WP intact whole plant herbage dry matter

[2] H:C homicellulose to cellulose ratio

Appendix III. Matrix of simple linear correlation coefficients[1] between herbage yield components, chemical and nutritive constituents within dry matter of intact whole plant of NEB 306F sorghum and its morphological parts.

	DL[2]	DMS	CPL	CPS	CPP	CWCL	CWCS	CWCP	CSL	CSS	CSP	ADFL	ADFS	ADFP	ADLL	ADLS	ADLP	PL	PS	PP	IVDMDL	IVDMDS	IVDMDP	DMP	L:P	S:P	L:S	HL	HS	HP	CL	CS	CP	H:CL	H:CS
Stem dry matter yield (DMS)	.964																																		
Leaf crude protein (CPL)	-.392	-.378																																	
Stem crude protein (CPS)	-.200	-.196	.735																																
Whole plant crude protein (CPP)	-.464	-.455	.459	.542																															
Leaf cell wall constituents (CWCL)	-.321	-.319	-.291	-.276	.176																														
Stem cell wall constituents (CWCS)	-.569	-.619	.036	-.267	.021	.488																													
Whole cell wall constituents (CWCP)	-.485	-.536	-.073	-.237	.067	.818	.742																												
Leaf cell solubles (CSL)	.321	.319	.291	.276	-.176	-1.000	-.488	-.818																											
Stem cell solubles (CSS)	.622	.650	-.046	.220	-.127	-.597	-.943	-.765	.597																										
Whole plant cell solubles (CSP)	.485	.536	.073	.237	-.067	-.018	-.742	-1.000	.818	.765																									
Leaf acid detergent fiber (ADFL)	-.357	-.318	-.403	-.417	.165	.839	.507	.747	-.838	-.661	-.747																								
Stem acid detergent fiber (ADFS)	-.562	-.585	-.107	-.339	.196	.752	.902	.812	-.752	-.912	-.812	.727																							
Whole plant acid detergent fiber (ADFP)	-.420	-.468	.006	-.171	.014	.737	.616	.857	-.737	-.670	-.857	.599	.671																						
Leaf acid detergent lignin (ADLL)	-.104	-.019	-.436	-.314	-.104	.529	.282	.382	-.529	-.394	-.382	.696	.410	.239																					
Stem acid detergent lignin (ADLS)	-.171	-.199	-.365	-.453	-.083	.713	.512	.761	-.713	-.574	-.761	.784	.673	.817	.593																				
Whole plant acid detergent lignin (ADLP)	-.139	-.219	-.362	-.252	-.036	.580	.239	.587	-.580	-.245	-.582	.477	.360	.561	.235	.579																			
Leaf phosphorus content (PL)	-.543	-.589	.273	.155	.509	.408	.441	.571	-.408	-.470	-.571	.369	.474	.585	-.022	.267	.337																		
Stem phosphorus content (PS)	-.493	-.431	.358	.464	.710	.326	.065	.254	-.326	-.161	-.254	.294	.191	.285	.064	.021	.054	.719																	
Whole plant phosphorus content (PP)	-.690	-.606	.614	.420	.534	.260	.146	.282	-.260	-.262	-.282	.148	.249	.358	-.011	.040	-.045	.423	.525																
Leaf *in vitro* DM digestibility (IVDMDL)	-.142	-.208	.511	.539	.256	-.539	-.207	-.421	.539	.331	.421	-.716	-.353	-.274	-.684	-.656	-.374	-.013	.070	.239															
Stem *in vitro* DM digestibility (IVDMDS)	.170	.225	.197	.496	.143	-.308	-.579	-.402	.308	.619	.402	-.421	-.536	-.232	-.268	-.484	-.140	.023	.488	-.021	.375														
Whole plant *in vitro* DM digestibility (IVDMDP)	-.078	-.014	.435	.433	.414	-.412	-.316	-.649	.412	.309	.649	-.405	-.376	-.511	-.486	-.694	-.510	-.095	.292	.090	.407	.354													
Whole plant DM yield (DMP)	.909	.992	-.388	-.199	-.463	-.323	-.601	-.517	.323	.642	.517	-.339	-.579	-.450	-.058	-.188	-.184	-.573	-.463	-.650	-.179	.202	-.044											
Leaf:whole plant ratio (L:P)	-.780	-.871	.457	.261	.510	.213	.614	.486	-.213	-.635	-.486	.221	.544	.464	.198	.101	.196	.637	.438	.472	.306	-.182	.126	-.836										
Stem:whole plant ratio (S:P)	.700	.871	-.457	-.261	-.515	-.213	-.614	-.486	.213	.635	.486	-.221	-.544	-.464	-.198	-.101	-.196	-.637	-.438	-.472	-.306	.182	-.126	.836	-1.000									
Leaf:Stem ratio (L:S)	-.791	-.859	.483	.280	.547	.210	.593	.464	-.210	-.624	-.464	.227	.536	.440	-.184	.077	.149	.612	.461	.525	.313	-.174	.179	-.836	.992	-.992								
Leaf hemicellulose content (HL)	-.068	-.122	.093	.100	.081	.612	.157	.412	-.612	-.132	-.412	.081	.320	.478	-.042	.167	.368	.210	.169	.259	.054	.047	-.165	-.098	.069	-.069	.054							
Stem hemicellulose content (HS)	-.249	-.318	.281	.023	-.315	-.239	.595	.175	.289	-.446	-.175	-.199	.189	.152	-.121	-.086	-.164	.121	-.208	-.133	.184	-.227	-.073	-.289	.383	-.383	.346	-.239					
Whole plant hemicellulose content (HP)	-.399	-.437	-.134	-.232	.103	.645	.640	.835	-.645	-.623	-.835	.667	.704	.432	.413	.672	.427	.375	.141	.111	-.443	-.455	-.415	-.424	.355	-.355	.342	.210	.144					
Leaf cellulose content (CL)	-.392	-.371	-.348	-.400	.226	.835	.516	.770	-.835	-.665	-.770	.977	.738	.637	.528	.752	.494	.444	.329	.179	-.645	-.418	-.335	-.384	.319	-.319	.323	.108	-.200	.667				
Stem cellulose content (CS)	-.603	-.622	-.035	-.279	.244	.690	.910	.747	-.690	-.907	-.747	.644	.924	.620	.327	.530	.296	.474	.214	.276	-.246	-.555	-.230	-.619	.599	-.599	.598	.327	.238	.645	.665			
Whole plant cellulose content (CP)	-.436	-.466	.118	-.118	.027	.663	.629	.797	-.663	-.688	-.797	.537	.648	.968	.201	.526	.335	.563	.308	.421	-.198	-.222	-.426	-.457	.469	-.469	.455	.433	.223	.361	.075	.616		
Leaf hemicellulose:cellulose ratio (H:CL)	.244	.200	.286	.340	-.150	-.704	-.268	-.300	.204	.414	.300	-.693	-.324	-.359	-.423	-.455	-.126	-.213	-.159	.047	.534	.329	.156	.222	-.213	.213	-.220	.631	-.008	-.356	-.695	-.261	-.142	
Stem hemicellulose:cellulose ratio (H:CS)	.477	.423	.192	.268	-.431	-.803	-.515	-.592	.803	.590	.592	-.706	-.823	-.513	-.375	-.573	-.411	-.408	-.293	-.343	.310	.433	.209	.429	-.353	.353	-.365	-.443	.360	-.489	-.724	-.806	-.459	.230	
Whole plant hemicellulose:cellulose ratio (H:CP)	-.038	-.053	-.217	-.104	.101	.095	.106	.173	-.095	-.043	-.173	.223	.155	-.348	.239	.234	.141	-.047	-.064	-.214	-.271	-.244	-.042	-.046	-.024	.024	-.026	-.150	-.019	.674	.193	.121	-.438	-.242	-.106

[1] $r \geq .4329$ but $< .5487$ significant ($p < .05$).
$r \geq .5487$ but $< .6652$ significant ($p < .01$).
$r \geq .6652$ significant ($p < .001$).

[2] Leaf dry matter yield.