NUTRITIVE VALUE OF SOME SORGHUM (*Sorghum bicolor* (L.) Moench) VARIETIES

By

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This thesis is my original work and has not been presented for a degree in any other University.

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Dedicated to my Beloved Parents

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ABSTRACT

Two experiments were conducted to determine nutritive value of different sorghum varieties through chemical composition and <u>in vitro</u> dry matter digestibility. Using nine varieties of sorghum, experiment I examined (i) differences in nutritive value among varieties. (ii) variation in nutritive value among three morphological plant parts (leaf, stem and head) and (iii) effect of location (place grown) on nutritive value of sorghum. Influence of stage of maturity on nutritive value of the various plant parts was studied in experiment II, with one grain and one forage type sorghum varieties.

In experiment I, nine sorghum varieties (E"1291"; "E5769"; "E5766"; "E6518"; "E1394"; "E6250"; "E1405"; "E1420 and "Hima 547") with varying amounts of grain content (ranging from 5.5 to 43.6 %), as indicated by head dry matter fraction, were grown in replicates in small plots (measuring 5 m x 1 m) under similar cultural practices, at 3 locations having different elevations, soils and climates. Location 1 was at Beef Research Station (BRS), Lanet top farm; location 2 was at BRS Lanet bottom farm and location 3 was at Naivasha. At physiological maturity (hard-dough stage), each variety was harvested, and whole plant, leaf, stem and head samples were taken, dried, ground and saved for analyses.

In experiment II, two sorghum varieties, "E1291" (grain) and "E6250" (forage) were grown at BRS, Lanet bottom farm under similar agronomic and cultural practices as described for experiment I. Plants were harvested at 14-day intervals as growth proceeded, between the 111th and 223rd days post-sowing restulting in a total of nine harvests for each variety. At harvest, plants were dissected into leaf, stem and head samples, dried, ground and saved for analyses.

Samples for both experiments I and II were subjected to chemical analyses, using proximate techniques (AOAC, 1975) and Goering and Van Soest (1970) procedures for fiber fractionation. Dry matter digestibility of sorghum samples was determined in vitro by the procedure of Van Soest, Wine and Moore (1966), a modification of Tilley and Terry (1963) 2-stage in vitro rumen fermentation technique. Bomb calorimeter was used to determine gross energy.

In experiment I, all data were subjected to variance and simple correlation analyses (Steel and Torrie, 1960) and differences between means were compared using Duncan's Multiple Range Test (1955). In Experiment II, simple regression analysis (Steel and Torrie, 1960) was carried out on all data.

In experiment I, chemical composition of the whole sorghum plant varied among the nine varieties with respect to crude protein, cell-wall constituents, cellulose, hemicellulose (P <0.05), acid-detergent fiber and total silica (P <0.01). Crude protein varied from 5.5 to 9.0 %; cell-wall constituents varied from 50.0 to 63.9 %; acid-detergent fiber varied from 31.5 to 42.2 % between the varieties. Cellulose, hemicellulose, permanganate lignin and total silica values ranged from 22.0 to 31.9; 17.7 to 23.0; 5.8 to 8.1 and 3.3 to 5.2 percent respectively. Differences in chemical composition were observed (P <0.01) between the various sorghum plant parts with respect to crude protein, ether-extract, total ash, cell-wall constituents, acid-detergent fiber, hemicellulose, cellulose, permanganate lignin, total silica and soluble silica content. Locational influence on chemical composition of the whole sorghum plant were significant (P <0.01) for cell-wall constituents, acid-detergent fiber and permanganate lignin.

In vitro dry matter digestibility (IVDMD) of sorghum plant showed variation (P <0.01) with respect to variety of sorghum, part of plant and location. IVDMD of sorghum plant varied from 55.5 to 71.7 % in the nine varieties. Dual-purpose varieties appeared to have lower IVDMD values than grain varieties. The leaf, stem and head of sorghum had 67.6; 56.3 and 75.4 percent IVDMD, respectively. Sorghum in vitro dry matter digestibility coefficients at locations 1, 2 and 3 were 60.0; 61.6 and 67.4 percent respectively. The high IVDMD of sorghum plant at location 3 was probably attributed to the relatively low fiber components of sorghum at that location.

IVDMD was negatively correlated with acid-detergent fiber, cellulose ($P < 0.01$) and cell-wall constituents ($P < 0.05$); and insignificantly positively correlated with crude protein. Grain content of sorghum (as indicated by head dry matter fraction) was not correlated with IVDMD.

In experiment II, chemical composition of both grain and forage varieties was significantly affected by maturity (days post-sowing), where crude protein decreased ($P < 0.01$) in leaf and stem. Cell-wall constituents and acid-detergent fiber increased in the stem of a grain variety "E1291" ($P < 0.01$) and leaf and stem of forage variety "E6250" ($P < 0.01$) with advancing stage of maturity. Hemicellulose decreased in the leaf ($P < 0.05$) and head ($P < 0.01$) of grain variety "E1291". Cellulose increased in the stem of grain variety "E1291" ($P < 0.01$) and stem of forage variety "E6250" ($P < 0.05$) with advancing stage of maturity; and decreased in the head of grain variety ($P < 0.01$).

IVDMD of leaf and stem of grain variety decreased ($P < 0.01$), while that of leaf ($P < 0.05$) and stem ($P < 0.01$) of forage variety also declined with advancing stage of maturity. IVDMD of sorghum head increased slightly in both sorghum varieties, since fiber components of sorghum head decreased with advancing stage of maturity.

In grain variety "E1291" the influence of maturity on IVDMD of leaf and stem were expressed by the equations: Y = 112.2 - 0.2931X, ($r = -0.97$; $P < 0.01$) and Y = 109.92 - 0.2742X, ($r = -0.96$; $P < 0.01$), respectively, while in forage variety "E6250" comparable changes with maturity were expressed by the equations Y = 99.70 - 0.1767X; ($r = -0.75$; $P < 0.05$) and Y = 104.32 - 0.2595X, ($r = -0.87$; $P < 0.01$), respectively, where Y is % *in vitro* true dry matter digestibility and X is maturity in days post-sowing. IVDMD of individual parts in both sorghum varieties was explained by the changes in chemical composition with advancing stage of maturity.

INTRODUCTION

Kenya has a land area of about 569,000 square kilometres, and a human population of approximately 13 million with an economy based mainly on agriculture. Less than twenty percent of the land area is high-potential, receiving rainfall of 750 mm or more and suitable for intensive agriculture. The remaining majority of the land is dry, receiving less than 500 mm and is of low agricultural potential. Areas receiving between 500 and 750 mm suitable for commercial ranching occupy about 54% of Kenya's land. Cattle population in 1973 was estimated at 9.7 million comprising 650,000 dairy cattle, 900,000 beef cattle on large scale farms and in settlement areas, and 8.2 million beef cattle in pastoral or nomadic areas or small scale holdings.

Kenya's beef production is based on the national herd which is in the hands of pastoral or nomadic producers and the various breeds of the East African shorthorn zebu. The zebu comprises 93% of the national herd and most of the carcasses from the lower grades at the Kenya Meat Commission (KMC) are from this source, since they are usually either too old, or unfinished immatures when sold to KMC. KMC and local butchers compete to sell beef on the local market, while export market is virtually the exclusive concern of the KMC. At the level of initial pastoral or ranch producer, KMC and local butchers meet competition from graziers and feeders (feedlots) for purchase of stock. Normally, seasonal drought forces pastoralists, nomadic producers and some ranchers to sell stock which would otherwise die due to drought. Feedlots and graziers' objective is to increase the weight and improve the meat quality before sale to either KMC or local butchers.

In 1976, KMC slaughtered 228,505 heads of cattle and this was only 30% of the total market. Of these, 43,617 were high grade cattle suitable for export mostly coming out of feedlots. Kenya has increasingly earned foreign exchange from export of chilled and frozen beef cuts and quarters to Europe, Middle-East and African countries, a development basically made possible by the establishment of feedlots in this country in the last 10 years. Feedlots produce high quality tender beef, and they meet the strict veterinary regulation requirements of such importers of beef from Kenya, as well as supplying the local market with high quality meat. Commercial feedlots have assumed an important place in the beef industry in the country and by 1976 total feedlots production was equivalent to 20% of beef of all grades and 60% of high grade meat marketed through the KMC. Feedlots depend on their supply of immatures from pastoral and nomadic areas where the Zebu is the major breed of cattle available. Improved Boran and Crossbreds which are crosses between the local Zebu and large-framed temperate (Bos taurus) breeds are mainly obtained from ranches. It has been shown that the local zebu animals respond well to intensive feeding in feedlots (Creek and Squire, 1976).

The United Nations Development Programme (UNDP), Food Agriculture Organization (FAO), Kenya Beef Industry Development Project was started at Lanet (Nakuru) in 1968, and it was from this project that feedlot operations began, and by 1974 there were about a dozen commercial feedlots in the country. Maize has been the major forage crop used in the development of feedlot rations, and most commercial feedlots have used maize as the sole source of roughage in fattening cattle. However, due to various social and economic reasons, and partly because the FAO project had as one of its terms of reference to study alternative forage crops which would be productive in marginal areas where cattle feeding (feedlots) would ultimately be situated, a forage research programme was also started. In the final phase of the Beef Industry Development Project, work was intensified on alternative forage crops and sorghum was selected as a suitable drought resistant crop. Sorghum varieties from high-altitude areas of Uganda and Ethiopia which consistently produced good yields comparable with or better than maize are now increasingly adopted by the commercial beef cattle finishing sector.

Of introductions in the first screening trials, only 25 cold-tolerant sorghum lines could perform well at the site of the project, the Beef Research Station (BRS), Lanet (Arkel. 1975). A further screening trial was conducted in 1975 using nine varieties selected from the previous year (1974) based on high dry matter yields or high quality dry matter production. For these sorghum varieties, the agronomic requirements and practices were fully established. However, critical nutritive evaluation of these varieties is still lacking. Ward, Brethour, Duitsman, Ely, Smith and Boren (1969) pointed out that several factors influence the nutritive value of forage sorghums including dry matter content, stage of maturity at harvest, grain content of the variety and management of the sorghum forage at harvest.

Nine sorghum varieties identified at Lanet as suitable for forage production with varying grain content were selected to study:-

(i) the effect of grain content and location on the nutritive value of sorghum varieties and;

(ii) the influence of stage of maturity at harvest on nutritive value of sorghum varieties.

REVIEW OF LITERATURE

A. CHEMICAL COMPOSITION

The proportions of chemical constituents of forage sorghum vary widely, and are related to the inherent characteristics such as the grain proportion in the forage, the stage of maturity (Ward et al., 1969), and the environmental conditions (location), including climate (rainfall and temperature), soil fertility and season (Ward et al., 1969; Arora, Luthra and Das, 1975). Ensiling as well as processing methods have been shown to influence the chemical composition of sorghums (Danley and Vetter, 1973; McNeill, Potter, Rigg and Rooney, 1975). Chemical composition of forage sorghums have been shown to favour their use as fodder and silage in ruminant feeding (Wall and Blessin, 1970). Maize and sorghum forage compositions are fairly similar, although greater grain content in maize forage accounts for its slightly higher level of crude protein and lower contents of crude fiber (Nordquist and Rumery, 1967; Wall and Blessin, 1970).

1. Influence of sorghum variety on chemical composition

Owen and Webster (1963) noted that there was lack of adequate information on the comparative chemical composition of genetically different sorghums. Chemical composition of sorghums used in feeding trials by Reames, Stallcup and Thurman (1961); and Owen, Kuiken and Webster (1962), showed that the hybrids had higher crude protein values than varieties. However, sorghum varieties were found to contain more nitrogen-free extracts than the hybrids.

Silage made from sorghum varieties with high grain content was slightly lower in crude protein than that made from forage varieties, but chemical composition was otherwise very similar among different sorghum varieties (Reames, Stallcup and Thurman, 1961; Owen, Kuiken and Webster, 1962). Owen and Webster (1963) reported significant differences in dry matter, crude protein, nitrogen-free extract, and crude fiber contents among sorghum varieties, while ash and ether extract did not show any significant variation. Deosthale and Mohan (1970) reported differences in protein content of sorghum grain among various sorghum varieties. Arora and Luthra (1974) showed that the protein content of sixty seven sorghum varieties differed considerably. However, Danley and Vetter (1973) did not find any significant difference in crude protein content between two forage sorghum varieties.

Arora et al. (1975), using eight sorghum varieties in India, observed significant differences in levels of crude protein, neutral-detergent fiber and acid-detergent fiber. Danley and Vetter (1973) showed that differences in soluble carbohydrate content between two forage sorghum varieties were significant. Fiber content also showed significant differences between forage sorghums with respect to acid-detergent fiber, neutral-detergent fiber, cellulose and lignin content. Hardy (1975) working with two Israeli grain sorghums ("Hezera 610", "726"), reported that moisture content was related to sorghum variety, and that chemical characteristics such as volatile fatty acids and soluble carbohydrates content of silage was dependent on the sorghum variety.

Different sorghum varieties showed variation in the ability to accumulate selenium, nitrogen, phosphorus and sulphur from various soils (Mahenora, 1975), whereas different sorghum varieties contained varying amounts of molybdenum (Doesthale and Gopalan, 1974). Vitamin A precusor, carotene, occurs in differing amounts in sorghums depending on the variety (Landi and Antongiovanni, 1973). Other minor substances with adverse effects on nutritive value such as tannins and cyanides have been found to differ in their concentrations in sorghum (McCullough and Cummins, 1974; Arora et al., 1975; Hunt and Taylor, 1976). Although sorghums vary widely in their tannin content (Arora and Luthra, 1974), bird resistant grain sorghums have a relatively higher tannin content and reduced digestibility than non-bird resistant varieties (McCullough and Cummins, 1974; Amstrong, Rogler and Featherson, 1974; Dreyer and Nierkerk, 1974). Sorghums with high tannin contents resulted in silages with low digestible crude protein (McCullough and Cummins, 1974). On the other hand, sorghum varieties developed for grain or silage production had higher hydrogen cyanide contents than those developed for fresh forage (Hunt and Taylor, 1976).

Garret and Worker (1965) studied the chemical composition of two sorghums, a grain type and a forage type and reported little and inconsistent differences in crude protein, ether extract, crude fiber, lignin, ash and dry matter percentages between the varieties, and similar feeding value of the two sorghums.

2. Influence of stage of maturity on chemical composition

Forage constituents most affected by advancing maturity are proteins, soluble and structural carbohydrates. Generally there is a decrease in total nitrogen and soluble carbohydrates and an increase in cellulose, hemicellulose and lignin content as the sorghum plant matures (Waite, 1963).

Studying the influence of stage of maturity on Atlas sorghum silage, Owen (1962) observed a decrease in crude fiber, crude protein, and ether extract; and an increase in nitrogen-free extract content with maturity from the milk to the hard seed stage. Webster (1963) showed that crude protein content was highest in immature "Atlas" sorghum plants but decreased with age. Dry matter percent increase from first bloom to mature grain stage was faster, in "Atlas" sorghum variety than in sterile sorghums; and the final dry matter at the hard seed stage was higher for "Atlas" than sterile sorghums (Webster, 1963). Dry matter increase with stage of maturity is greater for forage than grain sorghum varieties (Browning and Lusk, 1967). A higher increase in dry matter with stage of maturity was found for "Atlas", which is a forage variety (Webster, 1963), while

Browning and Lusk (1967), showed a lower increase in dry matter with "RS 610" a grain variety, with advancing maturity.

Owen and Webster (1963) studied the influence of maturity on chemical composition of "Atlas" and "Rox" varieties and hybrids "RS 301F" and "RS 303F" and reported negative significant linear regressions of moisture, crude protein, and crude fiber content on maturity (days after bloom), and a positive significant linear regression of nitrogen-free extracts on maturity. Although the change in moisture content with increasing maturity was small, it reflected a fifty percent increase in dry matter content (Owen and Webster, 1963) The decrease in fiber level and increase in nitrogen-free extract with increasing maturity should reflect an improvement in nutritive quality, but the decrease in crude protein with maturity may lower nutritive value of sorghum forage when fed to certain classes of livestock (Owen and Webster, 1963). With advancing maturity, from heading to ripe seed stage, sorghums generally declined in crude protein, crude fiber and ash, and increased in nitrogen-free extracts (Owen, 1967). A grass-type forage sorghum increased in cellulose upto the early-milk stage, then declined, but was much higher in fibrous constituents in late maturity than a grain-type sorghum (Owen, 1967). Owen (1967) noted that a rapid increase in nitrogen-free extracts takes place during the period when starch is being deposited in the seed, from milk to hard seed stage, with a reciprocal dilution of the crude fiber content.

Bahtia, Sing, Dogra and Dua (1975) studied changes in cell-wall carbohdyrates content at different growth stages in sorghums and observed that cellulose and hemicellulose in the stems increased with plant age. Prates, Leboute and Roffer (1975) reported that crude protein content was higher in earlier cuts of forage sorghum than in later cuts. In Japan, Aii (1975) observed that lignin and silica contents increased with increasing maturity in both first growth and regrowth of sorghums.

Danley and Vetter (1973), using two forage sorghum varieties, showed that advancing maturity had no significant effect on soluble carbohydrate content, while crude protein content declined with advancing maturity. Although, hemicellulose was little affected, the increase in neutral-detergent fiber, acid-detergent fiber, cellulose and lignin with advancing maturity were not significant. There was a significant maturity x forage interraction for dry matter, acid-detergent fiber, cellulose, hemicellulose, lignin and crude protein. Advancing maturity does not appear to have same effects on chemical composition of forages of different species, for the magnitude of changes in chemical composition which accompany maturity is not always significant, and interspecific differences between forage species are larger than intraspecific comparisons between varieties within a forage species (Danley and Vetter, 1973). Carotene content and hydrogen cyanide concentrations decreased as maturity progressed (Landi and Antongiovanni, 1973; Hunt and Taylor, 1976).

3. Influence of environmental (locational) conditions on chemical composition

Environment and temperature have been shown to have considerable influence on quality of forages (Wilson and Ford, 1971; Deinum and Dirven, 1972). Chemical composition was modified by climate and other unidentified factors, and levels of crude protein and ash mostly depend on availability of elements in the soil (Ward et al., 1969). Recently, Arora et al. (1975) evaluated eight sorghum varieties under four different locations with varying agro-climatic conditions. Crude protein content varied with location and locational differences were observed for percent of neutral-detergent fiber, and acid-detergent fiber, which were due to environment, as the same genotype (variety) behaved differently at different locations (Arora et al., 1975). Deinum and Dirven (1972) observed that temperature had a direct positive effect on percentages of crude fiber particularly in leaves and stems, causing poor quality forage in warm climates.

Ward et al. (1969) reported that crude protein, crude fiber, ether extract, nitrogen-free extract and ash content of sorghums produced in two locations in the USA showed variation. Although the average values for crude protein, crude fiber, ether extract, nitrogen-free extract and ash for sorghum silages were similar for two different locations, the range of the values differed in the two locations.

Chemical composition, forage and grain yields have been found to show close correlation with amounts of rainfall (Denman, 1976), and with seasonal changes in years (Owen, Miles, Cowsert and Lusk, 1957). Arora _et al._ (1975) noted that dry matter production varied from location to location for eight sorghum varieties.

Tannin, which has been observed to be a negative factor for nutiritive value of any sorghum genotype (Dreyer and Nierkerk, 1974; McCullough and Cummins, 1974 and Arora _et al._, 1975) was shown to be significantly influenced by locational variation probably due to differences in soil fertility (Arora _et al._, 1975).

(i) Influence of fertilization on chemical composition

Fertilizer application is generally an essential practice in the cultivation of sorghum forages to obtain economic yields (Owen, 1967). Nitrogen fertilization is usual, and Thangamuthu and Sundram (1975), in fertilizer trials with sorghum cultivars observed that nitrogen application gave higher yields of fresh fodder, dry matter, crude protein and ash contents. Perry and Olson (1975) reported increased dry matter yield of sorghum grain and increased nitrogen content in sorghum forage with higher rates of nitrogen application in the soil. Mahenora (1975) also reported increased dry matter and crude protein yield in sorghums with application of nitrogen fertilizer.

Owen (1967) noted that, in general, nitrogen fertilization had a minor effect on silage quality, although crude protein content may be increased in varying amounts, other chemical constituents are not affected. Phosphorus content in sorghums declined with the higher rates of nitrogenous fertilization (Thangamuthu and Sundram, 1975).

(ii) Influence of ensiling on chemical composition of sorghums

Danley and Vetter (1973) observed no differences in dry matter content between the fresh and ensiled sorghum forages, although the reduction in soluble carbohydrates due to ensiling was significant. Acid detergent fiber, cellulose and lignin contents of ensiled forages were significantly higher than those of fresh forages. Water-soluble-nitrogen and soluble non-protein nitrogen were not affected by ensiling (Danley and Vetter, 1973).

B DIGESTIBILITY OF SORGHUM

The relationship between grain content of sorghum to nutritive value has received considerable study due to the concern over the poor digestibility of the seed when sorghums are fed to animals (Owen, 1967). The faecal sorghum seed losses were high and the excreted seed appeared not to have been used appreciably by the animal. Hence, the use of forage sorghum varieties (low-grain content) was adopted to minimize the grain utilization problem. Pearl millet compared to sorghum varieties gave a higher dry matter yield and *in vitro* digestibility, as well as a higher digestible crude protein. However, differences in *in vitro* digestibility and protein content between eight sorghum varieties were not significant (Freitas and Saibro, 1976). Guinea grass and sorghum were found to be similar in vitro digestibility while in vitro digestibility of Napier grass was higher than that of sorghums (Ugarte, Rabago and Domeniguez,1975). A digestion trial revealed that the digestibility coefficients for dry matter and gross energy were greater for maize than sorghum. The digestible crude protein values of maize and a grain sorghum variety "RS 610" were higher than that of a forage sorghum, "Hegari" (Browning and Lusk, 1966). Results obtained using two sorghum varieties and two maize varieties showed that forage sorghum had a lower in vitro digestibility than maize (Danley and Vetter, 1973).

Several factors influence the digestibility of sorghum forages including varieties and grain content (Browning and Lusk, 1966); stage of plant maturity (Browning and Lusk, 1966; Owen, 1967; Danley and Vetter, 1973; Aii, 1975); location and environment (Arora et al., 1975); sorghum parts (Fribourg,Duck and Culvahouse 1976); and other factors such as tannin content (Green, 1974), fiber proportion (Marten, Goodrich, Jordan, Schmid and Meiske, 1976), and supplementation during feeding (McCullough and Cummins, 1974).

1. Sorghum variety (or grain content) and digestibility

Work done in the USA has shown that digestibility of the grain and forage sorghum varieties does not differ significantly (Garrett and Worker, 1965; Owen, 1967 and Balwani, Johnson, McClure and Denority, 1969). A sorghum variety with a very high grain content, "RS 610", was only slightly more digestible than "Tracy" which had little grain (Owen, 1967). In digestion trials, using cows and steers, Ward, Boren, Smith and Brethour (1967) found digestible energy of silages made from sorghums varying widely in grain contents to be remarkably similar. Garret and Worker (1965) feeding Hereford steers on two sorghum varieties, a grain type and a forage type, noted that there was no significant difference in digestible energy content of the two forages. Balwani et al., (1969) fed to sorghum types, one grain type and the other forage to sheep, and reported that the two were quite similar in digestibility, although the grain sorghum had a higher protein content. Danley and Vetter (1973) found similar *in vitro* digestibility for two varieties of forage sorghum. In digestion trials, Browning and Lusk (1966) compared a series of grain and forage type sorghums and reported greater voluntary intake of silage dry matter for the grain than for the forage type. The protein digestion coefficients were shown to be significantly greater for the grain type sorghums (Browning and Lusk, 1966). "Rox", a grain sorghum was more digestible than "Atlas", a forage sorghum (Kuhlman and Owen, 1962). At Lanet, Nakuru, Arkel et al. (1977) showed that *in vitro* digestibility of forage sorghum "E 6518" was lower than that for grain sorghum "E 1291", although maize had a higher *in vitro* digestibility than both sorghum varieties.

2. Stage of maturity and sorghum digestibility

Browning and Lusk (1967) reported that digestion coefficients for crude protein and crude fiber declined significantly with advancing maturity in sorghums. Danley and

Vetter (1973) found a significant decrease in *in vitro* dry matter digestibility of two sorghum forages with advancing maturity, while estimated digestible energy and estimated total digestible nutrients also showed a similar significant decline. Aii (1975) noted that the *in vitro* digestibility of sorghum leaf varied little with advancing maturity, when that of the stem decreased significantly. Helm and Leighton (1960) reported a decline in digestibility for crude fiber, nitrogen-free extract and protein while other workers (Owen, 1967), found no significant differences in dry matter or energy digestibility for "Tracy", a forage sorghum variety, with advancing maturity.

A forage type sorghum, "Atlas", showed a drop in dry matter digestibility from milk to hard-seed stage, whereas "Rox" and "RS 610" grain sorghums were equally well digested at the three stages of maturity (Kuhlman and Owen, 1962; Owen, 1967). There was an adverse effect of maturity on digestibility of low-grain sorghums which was absent in high-grain varieties (Owen, 1967). The rapid increase in the amount of highly digestible starch during maturation in the high-grain sorghums more than compensated for the decline in cellulose digestion, and the higher faecal seed (grain) losses (Owen, 1967).

3. Influence of location on sorghum digestibility

Arora *et al.* (1975) observed that *in vitro* dry matter digestibility for eight sorghum varieties grown in four locations was influenced by environment. The lowest *in vitro* dry matter digestibility at one location was mainly due to the highest dry matter production, a higher tannin and lower protein content which contributed towards the low *in vitro* dry matter digestibility value.

4. Digestibility of sorghum parts

Fribourg *et al.* (1976) studied *in vitro* digestibility of forage sorghum genotypes using the nylon bag *in vivo* technique, and showed the digestibility of sorghum stem was lower than that of the leaf; and that leaf digestibility was lower at flowering than at vegetative stages. Aii (1975) observed that the digestibility of the sorghum stem decreased sharply, while that of the leaf remained fairly constant during growth.

5. Tannin content and sorghum digestibility

Bird resistant sorghum varieties have high levels of tannin content (Maxon, Shirley, Bertrand and Palmer, 1973). Metabolizable energy (ME) and net energy (NE) content of a high-tannin content (bird-resistant) sorghum was found to be lower than that of a low tannin (non-bird-resistant) variety. Green (1974) showed that eight grain sorghum hybrids had high *in vitro* organic matter digestibility and low tannin contents, while twenty-three sorghum hybrids had a low *in vitro* organic matter digestibility and high tannin contents; although there was no relationship between tannin content and grain yield among the sorghum varieties. The very low digestibility values of high-tannin content, bird-resistant varieties, were not worth the grain saved from bird damage where sorghum is grown on a large scale (Green, 1974).

6. Fiber content and digestibility of sorghum

In digestion trials with sheep, dry matter intake and crude protein content, were positively correlated with *in vivo* digestible dry matter, whereas cell-wall constituents, acid-detergent fiber, crude fiber and cellulose accounted for over sixty percent of the variation in intake of sorghum silage (Marten *et al.*, 1976). Acid-detergent fiber was the best predictor of sorghum silage dry matter digestibility (Marten *et al.*, 1976). Danley and Vetter (1973) observed a negative correlation between percent cell-wall constituents, lignin and acid-detergent fiber with *in vitro* dry matter digestibility for two sorghum forages and silages. Both *in vitro* dry matter digestibility and *in vivo* (nylon bag) digestibility of sorghums were significantly negatively related to crude fiber and positively related to crude protein (Aii, 1975).

7. Effect of supplementation on sorghum digestibility

Digestion trials with Hereford steers fed six sorghum varieties differing in grain to forage ratios showed that protein and nitrogen free-extract digestibility was low in these silages given alone without supplementation (McCullough and Cummins,. 1974). Owen (1967) and Ward *et al.* (1969) also noted that there was a need to supplement sorghum protein in animal feeding for increased digestibility of sorghum crude protein and sorghum utilization.

C. DAIRY AND BEEF ANIMALS PERFORMANCE ON SORGHUM FORAGES

Sorghum has received a considerable attention as a feedstuff for dairy and beef animals (Wall and Blessin, 1970). Its potential as a fodder crop has been studied extensively (Hunt, Cummings and Lusk, 1972; Marchi and Giraudo, 1973; Singh and Rekib. 1974; Ugarte *et al.*, 1975, Roverso, Cuhna and Silva, 1975; Cuhna, Montagnini, Roverso and Silva, 1973; Prates, Leboute and Roffler, 1975; Bolsen, 1976; Saibro, Maraschin and Barreto, 1976; Freitas and Saibro, 1976; Swingle and Waymack, 1977). In silage production for intensive dairy and beef cattle industry, studies have mainly concentrated on comparing the value of maize with sorghum (Owen, Miles, Cowsert, Lusk, Custer and Cardwell, 1957; Owen, Kuiken and Webster, 1959; Owen, Kuiken and Webster, 1962; Lance, Foss, Krueger, Boumgardt and Niedermeier, 1964; Browning and Lusk, 1966; Nordquist and Rumery, 1970; Cummings, Watson, Hunt and Lusk, 1971; Lucci, Paiva and Freitas, 1972; Cuhna *et al.*, 1973; Danley and Vetter, 1973; Balwani *et al.*, 1969; Stallcup, York and Flynn, 1975).

1. Sorghum as roughage or fodder

Straw of sorghum was of good quality when conserved in combination with turnips, providing a good substitute for green fodder (Singh and Rekib, 1974). In Argentina, Marchi and Giraudo (1973) used a commercial hybrid sorghum, "Hayden 35", to determine the effect of time of starting to graze sorghum on weight gains of Aberdeen Angus steers. When grazed early sorghum contained more protein and less total sugars than with late grazing. Weight gains were best when forage sorghum was grazed at pre-flowering stage (Marchi and Giraudo, 1973).

In Brazil, Saibro et al. (1976) using a fodder production or a grazing system compared various sorghum varieties with pearl millets and maize varieties reporting that dry matter production varied among varieties. Sorghum yielded lower than pearl millet, but late maturing sorghum varieties gave higher yields than early maturing ones (Saibro et al., 1976). In a three-year grazing trial in the Rhone Valley, sorghum gave the lowest dry matter and crude protein yields as compared to several fodder crops. However, sorghum had an advantage when used for silage allowing two to three extra cuts (Plancquaert et al., 1976). Chemical composition and in vitro digestibility of Guinea grass and sorghum from pastures were similar; although daily milk production was higher for animals grazed on Guinea grass supplemented with concentrates than for animals on sorghum or Guinea grass pastures alone (Ugarte et al., 1975; Ugarte, Domeniquez and Rabago, 1976). Roverso et al. (1975) compared sorghum and Napier grass silage in feeding pregnant cows and observed no statistical differences in liveweight of cows, fertility rate and calf weight at birth. Cuhna, Silva and Tundisi, (1975) fed sorghum and Napier grass silage and observed that sorghum was slightly better than Napier grass in maintenance of animal weights. Hunt, Cummings and Lusk (1972) compared an intermediate sorghum type with a Sudan grass cross as a green chop in a lactation study, and reported no differences in milk production. Dry matter intake of sorghum stover by steers was higher than that of wheat straw when both roughages were supplemented with non-protein-nitrogen (Swingle and Waymack, 1977).

2. Maize and sorghum silage in cattle feeding

Nordquist and Rumery (1967) compared maize with three forage sorghums and noted that sorghum produced the highest dry matter while maize gave the highest grain yield. Since differences in crude protein and crude fiber were insignificant, excellent milk production could be obtained from cows receiving either maize or forage sorghum (Nordquist and Rumery, 1967). Cuhna et al. (1973) compared sorghum with maize grains in fattening cattle and showed that sorghum had a slightly better feed conversion efficiency; while Balwani et al. (1969) observed that the dry matter digestibility of maize silage was higher than that of either grain or forage sorghum silage. Lucci, Paiva and Freitas (1972) fed lactating cows on diets containing either maize, or grain or forage sorghum silage and reported that maize and forage sorghum gave higher daily milk yields; and that feed conversion efficiency was better for maize than for the sorghum silages. When good quality maize and sorghum silages were given to dairy heifers, average daily gains were variable but insignificant (Cummings et al., 1971). Stallcup, York and Flynn (1975) compared maize and sorghum as silages for dairy cows and observed that milk production was significantly higher for forage sorghum silage than maize. One "Leafmaster-43", a forage sorghum, gave higher milk production than another forage sorghum "Funks G-102F" which in turn gave higher milk yield than grain sorghum "Taylor-Evans Y-101" (Stallcup, York and Flynn, 1975).

In Mississipi experiments, sorghum consistently outyielded maize although maize was better for milk production, silage consumption and body weight gains as compared to sorghum silages (Owen <u>et al</u>., 1957). At Nebraska, maize was superior to a sterile sorghum and a standard forage sorghum as the sole silage roughage for lactating cows in terms of milk production and intake, but not in body weight gains (Owen, Kuiken and Webster, 1959). A grain sorghum "Axtell" had a higher dry matter intake than maize when fed to lactating cows although the milk production was better for cows on maize silage. Weight gains and milk fat content were not significantly different for maize, grain sorghum or forage (sterile hybrid) sorghum (Owen, Kuiken and Webster, 1962). At Wisconsin, maize silage was higher in crude protein and silage dry matter consumption than grain sorghum silages; and fat corrected milk (FCM) production, digestibility of crude protein, energy and dry matter were higher for maize silage than sorghum silage (Lance <u>et al</u>., 1964). Browning and Lusk (1966) showed that dry matter consumption and average daily gain were significantly greater for dual-purpose sorghum type "RS 610" than for maize, while observing no significant difference in average milk production between cows fed sorghum or maize silages.

3. <u>Factors influencing the utilization of sorghum by dairy and beef animals</u>:

Efficiency of utilization of sorghum varies greatly, and animals response to sorghum silage depends on class of animals fed, the amount of silage consumed and available nutrients. Dry matter content, stage of maturity at harvest, grain content and management of sorghum at harvest are some important factors affecting sorghum nutritive value (Ward *et al.*, 1969).

(i) Effect of dry matter content of sorghum on cattle response

Percentage dry matter content in sorghum silage is the most important single factor related to animal response (Ward *et al.*, 1969). Cattle consume more dry matter in silages which contain greater proportions of dry matter (Ward, Boren and Smith, 1966; Browning and Lusk, 1967; Ward *et al.*, 1969). Ward, Boren, Smith and Brethour (1966) examined the relationship between sorghum silage dry matter and *ad libitum* intake by lactating cows and beef calves at one station using nineteen sorghum silages and by Hereford beef steers at another station using twenty one sorghum silages. Dry matter consumption was greater with drier silage, and this relationship held despite differences among sorghum varieties, animals fed, location, years and treatments of the sorghum silages. It was therefore necessary to compare silages at similar moisture content for feed intake and animal performance measurements (Ward *et al.*, 1966). Response by cattle fed on sorghum silage with different characteristics and treatments showed that weight gains were closely related to silage dry matter content, and that the dry matter content of ensiling forage was a better indicator of expected results than was variety or hybrid (Ward _et al._, 1967). Later Ward _et al._ (1969) confirmed that silage dry matter was closely related to weight gains when calves fed on drier sorghum silages had better average daily gains, as differences in dry matter percentage of the silage accounted for more than eighty-five percent of the variation in weight gain.

With milk production, the relationship between sorghum silage dry matter and amounts of milk produced is not so clear, although lactating cows also consumed more silage dry matter in drier silages (Owen, 1967; Ward _et al._, 1969). When dry matter content of silage increased from twenty-three to forty-six percent, consumption of drier sorghum was sixty percent higher than a lower dry matter silage, but milk production and body weight changes were not affected; while an increase of fourty percent in dry matter of another sorghum silage only produced eight percent increase in milk production (Owen, 1967).

(ii) Effect of stage of maturity of sorghum at harvest on its utilization

Stage of maturity and dry matter content are closely related, and advancing maturity in sorghum increases consumption, although there is an optimum upper limit of thirty-five percent dry matter content in ensiled sorghum silage (Ward _et al._, 1969). Animal response to sorghum silage was accounted for by differences in dry matter percentages of silages made from forages cut one week after bloom to the hard-dough stage (Ward et al., 1969). A switch back milk production study with eighteen lactating cows showed that the daily dry matter intake by cows increased with advancing maturity while daily fat corrected milk production, and milk fat were not affected (Browning and Lusk, 1967). Greater intakes of dry matter with more mature silages without corresponding increase in milk production was observed by Owen (1962) using Atlas, a forage type sorghum; and by Marshall et al. (1966) using a grain sorghum type. Owen,Kuiken and Webster (1962), using Atlas sorghum silages harvested at three stages of growth as roughages in feeding lactating cows noted that with advancing maturity, consumption of dry matter increased and fat corrected milk (FCM) production decreased, while milk fat percentage and body weight changes were not significantly affected. It was therefore advantageous to harvest sorghum at the hard-seed stage when acreage yields were near maximum (Owen, Kuiken and Webster, 1962). There were small differences in milk production when two sorghum varieties "Tracy" and "Hegari", harvested at different maturity stages, were fed to cows (Helm and Leighton, 1960). Owen (1965) compared the effect of Atlas silages harvested at four stages of growth in two experiments and reported that fat corrected milk production was nearly the same for all stages of maturity, although dry matter intake was progressively higher for each later stage. Aii (1975) showed that intake by cows decreased with increasing lignin and crude fiber during growth.

(iii) Influence of sorghum variety and grain content on its utilization

Sorghum varieties and hybrids that are available vary widely in height, juiciness, sweetness, leafiness and grain production (Ward et al., 1969). The proportion of grain in the forage has two influences: heavily seeded forages tend to have a higher dry matter content, and increased readily available carbohydrates (Ward et al., 1969). Although claims had been made on the superiority of different sorghum varieties or hybrids, data from controlled experiments was lacking or limited for judging the accuracy of these claims (Ward et al., 1969).

Sherrod, Albin and Furr (1969) reported that feedlot performance and carcass data showed average daily gains to be similar for steers fed a regular sorghum or another new hybrid with waxy endosperm although feed intake was slightly lower and feed conversion efficiency higher for the waxy sorghum than the regular one. At Kansas, USA, Ward et al. (1965) pointed out that the loss of undigested seed in the faeces of cattle fed sorghum silage could be an important factor when choosing a variety since sorghum varieties had variable proportion of their dry matter as seed. And Owen (1962) noted that a limitation of using sorghums for silage was the relative indigestibility of the seed. When the nutritive value of several grain sorghum varieties were compared with sterile hybrids which set no seeds, the total intake by cows of silage was not different between a grain type sorghum "Axtell" and a forage hybrid "RS 303F". However, on dry matter basis "Axtell" grain sorghum consumption was significantly higher; but there was no significant difference in milk production between the grain or the forage sorghum-fed cows (Owen, 1962). Silages made from sorghums without grain were approximately equal in nutritional value to grain-bearing varieties for lactating cows. Therefore, since grain-content was a poor indicator of nutritional quality, it should not be used as a criterion for judging nutritive value in sorghums (Owen, 1962; 1967).

Weight gains for beef steers were practically the same for two silages, one made from a high-grain and the other a low -grain sorghum (Owen, 1962). When sorghums with low medium, or high grain contents were compared in different experiments, weight gain by calves and steers were similar for the various silages (Owen, 1967). Garret and Worker (1965) used two sorghum varieties, "Brawley" a forage and "De Kalb FS 22" a grain variety, to feed Hereford calves and steers. Average daily gains and silage dry matter intake did not differ significantly for the animals on the two types of sorghum silages. However, "Brawley", the forage sorghum tended to deposit more fat on the carcass. And when "FS1a", a very high yielding hybrid sorghum was also fed to beef calves, significantly greater average daily gains were observed. Despite the difference in grain: forage ratios in the two sorghums, 1:2 for the grain type, and 1:5 for the forage type, on dry matter basis, the sorghums were similar in feed value when fed as silages to beef steers (Garret and Worker, 1965). In feedlot trials at Lanet Nakuru, Arkel, Creek and Squire (1976) evaluated two sorghum varieties "E 1291", a grain type, and "E6518" a forage type using zebu (Boran) steers and crosses of zebu with large-framed beef breeds. Average daily liveweight gain, feed conversion efficiency and carcass characteristics were better with the grain sorghum than the forage type. Browning, Lusk and Miles (1961) reported that lactating cows receiving grain sorghum "RS610", produced more milk and consumed more dry matter compared to cows which received a forage type sorghum, "NK300". A forage sorghum "FS-22" produced less milk than either an intermediate "Atlas" or grain type "FS-1a" (Owen, 1967). Ward et al. (1969) reported that grain was considerably drier than the leaf and stem portion of the silage and could contain fifty percent dry matter. The proportion of grain in sorghum can vary from zero to over fourty percent of the dry matter depending on variety, but the grain content of sorghum apparently exerted little influence on the nutritive value as measured by either growth or milk production (Ward et al., 1969).

The class of animals fed sorghum silage determines how efficiently animals utilize it; and it has been observed that growing beef calves utilize sorghum silage much better than lactating dairy cows (Ward et al., 1969). Supplementation of high sorghum silage rations with adequate protein was an important aspect determining the efficiency of utilization of its energy and protein (Owen 1967).

MATERIALS AND METHODS

A MATERIALS

EXPERIMENT I

To study the nutritive value of nine different varieties of sorghum with varying grain content.

Forage samples

Forage samples analysed in Experiment I were obtained from the Forage Screening Trial conducted at the Beef Research Station in 1975. Nine sorghum varieties varying widely in grain content, as indicated by the head dry matter fraction, which included "E1291", "E5769", "E5766", "E6518", "E1394", "E6250, "E1405", "E1429" and "Hirna 547", were grown at three sites (locations) described later. At physiological maturity (hard-dough seed stage) for each variety, plants were harvested; some were dissected into leaf, stem and head samples, while whole plant samples were also taken simultaneously. Leaf sample comprised the whole plant leaf blade and midrib, but excluded the leaf sheath at the base; stem sample included the whole plant column from the base upwards together with attached leaf sheath, stopping about 1 cm. from head, while head sample was composed of whole plant ear (head) starting about 1 cm. from base of the head. After harvest, samples were oven-dried at 90^{0}C and ground to pass through 1 mm Willey mill. Three replicates of ground samples each of whole plant, leaf, stem and head for each variety of sorghum at each of the three locations were sub-sampled and finally the total 108 samples obtained were individually saved in plastic bags for laboratory analysis.

Description of sorghum varieties

"E1291"

This was a very short variety, non-tillering with low leaf percentage and short growth period. It had very high grain yield (over 40%) as indicated by the head dry matter fraction. The head was "semi-compact elliptic" (Rao and House, 1978), having red coloured grain, ¼-covered with black glumes.

"E5769"

The variety which was medium in height, non-tillering with low leaf percentage had medium maturity period and a medium total dry matter yield. Its grain content was high (over 30%) as indicated by head dry matter fraction. The head was "semi-compact elliptic" (Rao and House, 1978), with the grain having a reddish-brown colour and ¼-covered with glume, light-brown to reddish brown in colour.

"E5766"

Variety "E5766" was closely similar to "E5769", but was taller, having a medium-to-high total dry matter yield. Its grain content was high (over 30%) as indicated by the head dry matter fraction. The head was "semi-compact elliptic" (Rao and House, 1978), with red grain, ¼-covered with glume which was reddish-brown in colour.

"E6518"

This sorghum variety which was very tall, multi-tillering with thick stems was very late maturing and high dry matter yielding. Its grain content was intermediate (over 20%) as indicated by the head dry matter fraction. The head was composed of "semi-loose stiff branches" (Rao and House, 1978), with the grain having a light-red colour and ¼-covered with reddish-brown glume.

"E1394"

This was a tall, non-tillering variety with medium-to-late maturity and high total dry matter yields. Grain content was intermediate (over 20%) as indicated by head dry matter fraction. The head was composed of "semi-loose stiff branches" (Rao and House, 1973) with red grains, ¾-covered with black glumes.

"E6250"

A very tall sorghum variety, "E6250" was multi-tillering, having thin stems, medium-to-late maturity and fairly high yielding. Grain content was intermediate (over 20%) as indicated by head dry matter fraction. The head was comprised of "loose-stiff branches" (Rao and House, 1978) with light-brown grain, ¾-covered with light-brown glumes.

"E1405"

This sorghum variety was of medium height, non-tillering, with medium maturity period and high total dry matter yield. Its grain content was low (less than 20%) as indicated by the head dry matter fraction. The head was "semi-compact oval" (Rao and House, 1978) and the reddish-brown grain was ½-covered with reddish-brown glumes.

"E1429"

A tall multi-tillering sorghum variety, "E1429" was late maturing giving very high dry matter yield. Its grain content was low (about 10%) as indicated by head dry matter fraction. The head had "loose-stiff branches" (Rao and House, 1978) and the reddish-brown grain was ¾-covered with partly straw/black glumes.

"Hirna 547"

"Hirna 547" was tall, multi-tillering, late maturing with high dry matter yield. Its grain content was very low (about 5%) as indicated by head dry matter fraction. The head was "compact oval" (Rao and House, 1978) and the light brown grain was ¾-covered with brown glumes.

Locations

Location 1

Location 1 is situated at the top farm (Field 16) of the Beef Research Station, Lanet (BRS 1) at an elevation of 1920 m. It has a deep sandy loam soil with good water holding capacity. The total rainfall during the growing season (March-November 1975) was 953 mm. The trial site is approximately 35 km south of the equator. It had maximum and minimum temperatures of 24.1°C and 10.0°C respectively.

Location 2

Location 2 was at bottom farm (Field 2) Lanet, (BRS 2) 5 km to the south of location 1 at an elevation of 1860 m. It has a soil of recent volcanic origin with a very shallow top-soil over-lying a murrum bed. The soil here is porous with low moisture holding capacity and is deficient in nitrogen, and low in phosphorus and potassium. The total rainfall for the season was 780 mm; with maximum and minimum temperatures of 23.3°C and 9.5°C respectively.

Location 3

Location 3 is at Naivasha with an elevation of 1850 m and is approximately 77 km south of the equator. It has a soil of recent geological origin composed of lake deposits with a clearly developed morphology. This soil is deep, well drained with excellent water holding capacity Rainfall at this site was about 420 mm during the growing season, and mean air temperature of 19.5°C.

Cultural practices

The sorghum plants were grown in small plots measuring 5 m x 1 m at a spacing of 70 x 10 cm. At planting all plots received fertilizer application of 30 kg. N and 90 kg. P_2O_5 per hectare equivalents. After two and half months top-dressing was done with 50 kg. N per hectare equivalent. Plots were weeded manually. Plants in guard rows were discarded at harvest.

EXPERIMENT II

To study the effect of stage of maturity on the nutritive value of sorghum varieties.

Forage samples

Two sorghum varieties "E1291" and "E6250", were used in this experiment. The sorghum varieties differed in their growth characteristics and grain content as described in Experiment I. While "E1291" had over 40 % grain, "E6250" contained only about 20 % grain as indicated by the head dry matter fraction. These sorghums were grown at the Beef Research Station, Lanet in 1974 at location 2, (BRS 2). The plants were harvested at two-week intervals beginning from the period just before head formation, upto the hard dough seed stage. The plants were harvested fortnightly between the 111th day and 223rd day after planting date. At harvest the plant was dissected into leaf, stem and head samples, oven-dried at 90°C, and ground to pass through a 1 mm Willey mill (see experiment 1).

Ground samples of leaf, stem and head of each variety from the five replicates were composited, sub-sampled and saved in plastic bags for analysis.

Cultural practices

Plants were grown in small plots measuring 5 m x 1 m at a population of 133,000 plants per hectare. Similar fertilizer treatments were applied with all the plots receiving 40 kg. N per hectare and 80 kg. P_2O_5 per hectare broadcast over seedbed at planting. The plots were kept weed-free throughout by hand-weeding. At harvest, plants in guard rows were discarded.

B. METHODS

PROXIMATE ANALYSES

Dry matter determination

About 0.5 g of forage material was weighed in duplicate into aluminium dishes and oven-dried at 105°C overnight. Dry matter was determined as:

$$\frac{\text{Weight after drying}}{\text{Original sample weight}} \times 100$$

Crude Protein

The Kjeldahl method for the determination of crude protein content was used. About 100 mg. of the sample was weighed in duplicates into Kjeldahl flasks (A third flask served as blank). Catalyst selenium (Se) tablet and concentrated 10 ml sulphuric acid (H_2SO_4) were added to the flasks. The contents were boiled to oxidize nitrogen into ammonium sulfate $(NH_4)_2SO_4$. Ammonia was distilled off using aliquots of 50% NaOH into a measured amount of boric acid, which was then titrated against a standard acid. The amount of nitrogen obtained was multiplied by the factor 6.25 and the crude protein content expressed as a percentage.

Ether extract

About 2.0 g of material weighed in duplicate were transferred into paper Soxhlet thimbles. The thimbles and contents were placed into a Soxhlet extractor and previously tared collecting flasks attached. Continous extraction by di-ethyl ether proceeded for 12 hours after which thimbles were removed. The ether in the flasks was allowed to evaporate before the flasks were oven dried at 105°C for about 2 hours, then cooled and weighed. Ether-extract was expressed as a percentage of the original dry weight of the sample.

GROSS ENERGY

The gross energy was determined by a Gallen Kamp Adiabatic Bomb Calorimeter.

The bomb was initially calibrated to determine the effective heat capacity. Samples of about 1 g were weighed in duplicates tabletted and placed in the cup of the bomb. A nickel fuse wire was fixed across the electrodes, and a 9 cm piece of cotton was draped down to touch the tablet. One ml of distilled water was added to the bomb chamber, after which it was assembled and charged with 25 atmospheres of oxygen. The bomb was then placed in the Calorimeter jacket, sorrounded by 2.1 L of distilled water. The stirrer was started and when the temperature became constant, the charge was ignited electrically and readings taken on the thermometer to record the maximum rise. Corrections were made for the fuse wire, and cotton thread. The temperature rise per gram dry matter was multiplied by the thermal capacity of the bomb metal parts and water to give the number of calories produced by the burning sample.

VAN SOEST ANALYSES

Cell-wall constituents (CWC)

About 1.0 g of forage was placed in a refluxing Berzelius 600 ml beaker and 100 ml of cold neutral detergent solution, 2 ml decalin and 0.5 g sodium sulfite were added. The mixture was heated to boil in 5-10 minutes, refluxed for one hour and filtered into previoulsy tared Gooch porcelain crucibles with glass wool. The residue was washed twice with hot water and twice with acetone, after which the crucibles were oven dried at 100°C overnight, cooled and weighed. Yield of neutral-detergent fiber was reported as weight of residue expressed as a percentage of original dry sample weight.

Insoluble silica

The residue from the determination of cell-wall constituents (CWC) was ashed in a muffle furnance at 550°C for about 4 hours, cooled and weighed. Insoluble silica was calculated as residue weight after ashing expressed as a percentage of original dry matter sample weight.

Acid-detergent fiber (ADF)

About 1.0 g of the forage sample was placed in a refluxing Berzelius 600 ml beaker, 100 ml cold acid detergent solution, and 2 ml decalin were added, heated to boil in 5-10 minutes and refluxed for one hour. The mixture was filtered into previously tared 50 ml sintered glass crucibles with coarse porosity. Crucible contents were first washed twice with hot water, then with acetone, and oven-dried at 100^{0}C overnight, cooled and weighed. Acid-detergent (ADF) was calculated as the weight of the residue expressed as a percentage of original dry sample weight.

Hemicellulose (HC)

Hemicellulose was calculated as the difference between cell-wall constituents (CWC) and acid-detergent fiber (ADF).

Permanganate Lignin (PL)

Crucibles containing acid-detergent residues were placed into a shallow enamel pan. About 25 ml of combined saturated potassium permanganate ($KMnO_4$) and buffer solution (in the ratio 2:1 v/v) was added into each crucible. A short glass rod in each crucible was used to break up lumps and stir contents. At the end of 90 minutes the crucibles were removed from the pan, filtered without washing; then filled with demineralising solution twice, lasting about 5 minutes each. The contents were washed twice with 80% ethanol, and twice with acetone. Crucibles were oven-dried at 100^{0}C overnight, cooled and weighed. Lignin was calculated as loss in weight from acid-detergent fiber expressed as a percentage of the original dry sample weight.

Cellulose (C)

The contents of crucibles after determination of permanganate lignin were ashed at 550°C for about 4 hours in a muffle furnace. Crucibles were then cooled and weighed. Cellulose was calculated as the loss in organic matter upon ashing expressed as a percentage of original dry sample weight.

Total silica and soluble silica

To the crucible contents, after determining cellulose was added about 4 ml of 48% hydrobromic acid. Acid was filtered off after four hours and contents washed with acetone and filtered, before oven-drying at 100°C for about 8 hours, placed in muffle furnace for 2 hours at 550°C, cooled and weighed. Total silica was calculated as the weight of the residue after hydrobromic acid treatment and expressed as a percentage of the original dry sample weight. Soluble silica was calculated as the difference between total and insoluble silica.

IN VITRO DIGESTIBILITY OF DRY MATTER

Dry matter digestibility of sorghum samples was determined *in vitro* by the procedure of Van Soest, Wine and Moore (1966) which is a modification of the Tilley and Terry (1963) two-stage *in vitro* rumen fermentation technique. *In vitro* digestion of cell-walls was used to estimate true dry matter digestibility.

Rumen Fluid

Rumen fluid was obtained from a healthy Friesian-cross cow, fitted with a permanent rumen fistula based at the University Farm, Kabete. The cow was about seven years old. Rumen liquor was collected on Mondays. The animal was fed on good quality Chloris gayana hay in the morning about three hours before rumen liquor collection was done.

Rumen ingesta drawn from the animal was transferred into a two-liter Thermos Flask, previously flushed with warm (40°C) water. Finally the rumen ingesta was transferred to the forage evaluation laboratory of the Department of Animal Production, University of Nairobi.

In the laboratory cheese-cloth was used to squeeze rumen fluid from the ingesta into a beaker kept in a water-bath at 40°C, and carbon dioxide (CO_2) was bubbled gently through the rumen fluid.

Artificial saliva and innoculum

Mc Dougall's artificial saliva was prepared in two parts: first part was made by dissolving in one liter of distilled water 9.8 g sodium bicarbonate ($NaHCO_3$); 7.0 g disodium hydrogen orthophosphate ($NaHPO_4 . 7H_2O$); 0.57 g potassium chloride (KCl); 0.47 g sodium chloride (NaCl) and 0.12 g manganese sulphate ($MgSO_4 . 7H_2O$). The second part was prepared by dissolving 4.0 g calcium chloride ($CaCl_2$) in 100 ml. Just before use, 1 ml of the 4% $CaCl_2$ solution was added per litre of the buffer.

Artificial saliva and rumen fluid were mixed in a ratio of 4.1 (v/v) in a flask connected to carbon dioxide

(CO_2) cylinder. Carbon dioxide was bubbled through the media continously.

In vitro digestion

To about 0.5 g of forage sample weighed in duplicate and placed into a 100 ml rumen fermentation test-tube, 2 ml of distilled water was added to wet all particles. Fifty ml of rumen inoculum was added from the dispensing burette, after which the tube was flushed with carbon dioxide and closed with the rubber stopper fitted with Bunsen valve for gas release. Tubes were shaken to mix the media with forage particles and transferred into an oven set at 40°C for incubation for 48 hours. The contents were shaken 3-4 times during the incubation period. After incubation tubes were removed, 2 ml of toluene added and placed in refregirator to stop any further digestion.

The contents of each tube were analysed for CWC as outlined before. In vitro true dry matter digestibility was calculated as 100 % - % cell-walls after digestion. Cell-wall digestibility was calculated by subtracting the percent cell-wall after in vitro digestion from percent cell-wall in original sample and expressing this value as a percentage of the original sample cell-walls.

STATISTICAL ANALYSES

All data in Experiment I were subject to analysis of variance (Steel and Torrie, 1960) and differences between means were compared using the Duncan's multiple range test (1955). Simple correlation coefficients between chemical constituents, gross energy, cell-wall digestibility and *in vitro* dry matter digestibility values were calculated. Data from Experiment 2 were subjected to simple regression analysis (Steel and Torrie, 1960), where chemical constituents, digestibility coefficients and gross energy (Kcal/g) were regressed on maturity (days post-sowing).

RESULTS AND DISCUSSION

EXPERIMENT I

DRY MATTER YIELD AND PHYSICAL COMPOSITION OF NINE SORGHUM VARIETIES

Table 1 gives the figures for total dry matter yield, head fraction percentage, stem length, leaf to stem ratio and days to physiological maturity for nine sorghum varieties used in Experiment I, and cut at 15 cm above ground. Grain content of sorghum varieties, as indicated by the head dry matter fraction, varied from 5.5% to 43.6%. Grain varieties had 30.3 to 43.6 % head fraction of dry matter, dual-purpose varieties had 20.8 to 22.8 %, while forage varieties had 5.5 to 17.9% head fraction of dry matter. Total dry matter yields ranged from 10.9 to 20.8 tons/ha in the nine varieties of sorghum. Generally, grain sorghum varieties yielded less total dry matter than either dual-purpose or forage varieties. Height of the plant (stem length) varied from 144 to 302 cm in the nine sorghums, with grain varieties being comparatively shorter than dual-purpose or forage sorghum varieties. Days to physiological maturity (hard-dough seed stage) ranged from 177 to 209 days in nine sorghum varieties, with grain varieties being more early maturing than either dual-purpose or forage varieties. Arkel (1977) observed comparable varietal differences among various sorghum varieties with respect to the same parameters.

TABLE 1. DRY MATTER YIELD, HEAD DRY MATTER FRACTION, STEM LENGTH, LEAF: STEM RATIO AND DAYS TO MATURITY OF NINE SORGHUM VARIETIES

Sorghum variety	Total DM yield (tons/ha)	Head DM fraction (%)	Stem length (CM)	Leaf: stem ratio	Days to physiological maturity	Remarks[2]
"E1291"	12.5(±5.6)[1]	43.6(±2.7)	144(±26)	0.33	177	"Grain - sorghum"
"E5769"	10.9(±2.2)	38.0(±5.2)	190(±21)	0.20	194	"
"E5766"	12.7(±7.1)	30.3(±3.5)	236(±22)	0.21	178	"
"E6518"	20.8(±6.5)	22.8(±6.0)	302(±46)	0.36	208	"Dual purpose sorghum"
"E1394"	19.2(±4.6)	21.8(±2.5)	272(±68)	0.23	206	"
"E6250"	16.9(±4.6)	20.8(±7.0)	274(±7.0)	0.26	202	"
"E1405"	19.2(±5.4)	17.9(±4.5)	245(±27)	0.23	194	"Forage sorghum"
"E1429"	20.7(±2.0)	10.9(±5.2)	262(±47)	0.29	206	"
"Hirna 547"	17.4(±4.0)	5.5(±2.2)	270(±56)	0.28	209	"

[1]Standard deviation

[2]Classification into grain, dual-purpose or forage variety was based on presented data where % head dry matter fraction was used as a criterion to estimate grain content.

CHEMICAL COMPOSITION AND IN VITRO TRUE DRY MATTER DIGESTIBILITY OF WHOLE PLANTS OF NINE SORGHUM VARIETIES

Crude protein

Crude protein was significantly different ($P<0.05$) among the nine varieties of sorghum with the values ranging between 5.9 and 9.0 % (Table 2, Figure 1). Grain sorghum variety "E1291" had 9.0% crude protein, dual-purpose variety "E1394" had 5.9% while forage variety "Hirna 547" had 7.9% crude protein. "Hirna 547", although a forage sorghum, had higher crude protein content than some dual purpose varieties ("E6518", "E1394" and "E6250"). Variation in crude protein content of different varieties of sorghum had been reported in literature (Reames, Stallcup and Thurman, 1961; Owen, Kuiken and Webster, 1962; Owen and Webster, 1963; Arora and Luthra, 1974). Arkel *et al.* (1977) working at Lanet, Nakuru, found that crude protein content of grain sorghum variety "E1291" was higher than that of a dual-purpose sorghum variety "E6518". In this study, crude protein was not related to grain content, but it was negatively correlated ($P<0.05$) with cell-wall constituents, acid-detergent fiber, cellulose and total silica content (Table 3). Although crude protein had a positive relationship with *in vitro* true dry matter digestibility, this was not significant. Marten *et al.* (1976) found that crude protein was positively correlated with *in vivo* dry matter digestibility. Ali (1976) reported that crude protein was positively related to both *in vivo* and *in vitro* digestibility of sorghums.

Fiber components

Fiber content of sorghum varieties as measured by cell-wall constituents and acid-detergent fiber varied significantly ($P<0.05$ or $P<0.01$) among the nine varieties of sorghum. Cell-wall constituents ranged from 50.0 to 63.9%, while acid-detergent fiber ranged from 31.5 to 42.2% (Table 4, Figure 2). Grain sorghum variety "E1291" had 50.0 % cell-wall constituents dual-purpose variety "E6250" had 63.9% while forage sorghum "Hirna 547" had 62.1 % cell-wall constituents. Grain sorghum variety "E1291" contained 31.5% acid-detergent fiber, dual-purpose variety "E6250" had 42.2 % while "Hirna 547" had 40.2% acid-detergent fiber. Danley and Vetter (1973) and Arora _et al_.. (1975) found significant variation in cell-wall constituents and acid-detergent fiber between different varieties of sorghum. Cell-wall constituents was positively related ($P < 0.01$) to acid-detergent fiber and cellulose, and negatively related ($P< 0.05$) to _in vitro_ true dry matter digestibility (Table 3). Marten _et al_. (1976) and Danley and Vetter (1973) reported that percent cell-wall constituents of sorghum was negatively correlated to _in vivo_ and _in vitro_ dry matter digestibility. Acid-detergent fiber was positively and negatively related ($P< 0.01$) to cellulose, and to _in vitro_ true dry matter digestibility, respectively. Aii (1976) reported that crude fiber was negatively related to _in vivo_ and _in vitro_ digestibility. Marten _et al_. (1976) observed that acid-detergent fiber was negatively correlated with _in vivo_ dry matter digestibility, and that acid-detergent fiber was the best predictor of sorghum dry matter digestibility of all the fibrous fractions.

Hemicellulose, cellulose and permanganate lignin contents varied significantly (P <0.05) among the nine varieties of sorghum. Hemicellulose values ranged from 17.7 to 23.0%, cellulose ranged from 22.0 to 31.9% while permanganate lignin ranged from 5.8 to 8.1% (Table 2 Fig. 1 and 3). Grain sorghum variety "E1291" had 18.5% hemicellulose, dual-purpose variety "E6250" had 21.6% while forage variety "Hirna 547" contained 21.7%. Cellulose content of grain-variety "E1291" was 22.0%, that of dual-purpose variety "E6250" was 31.9% while forage sorghum variety "Hirna 547" had 28.2%. Grain-sorghum variety "E1291" had 5.8% permanganate lignin, dual-purpose variety "E6250" had 6.4% while forage variety "Hirna 547" had 8.1%. In this study sorghum cellulose content was negatively correlated with grain content (P< 0.05) and highly negatively correlated (P< 0.01) with _in vitro_ true dry matter digestibility. Marten _et al._ (1976) found cellulose to be negatively related to _in vivo_ digestibility of sorghums. The correlations between hemicellulose and permanganate lignin with both grain content and _in vitro_ true dry matter digestibility was negative but insignificant (Table 3).

Total Silica

Total silica content varied significantly (P< 0.01) with variety of sorghum, and ranged between 3.3 and 5.2% (Table 2, Figure 1). Grain sorghum variety "E1291" had 5.2% dual-purpose sorghum variety "E6250" had 4.2% while forage variety "Hirna 547" also had 4.2% total silica. Total silica showed a negative but non-significant correlation with in vitro dry matter digestibility (Table 3).

In vitro true dry matter digestibility

In vitro true dry matter digestibility varied significantly ($P < 0.01$) among the nine varieties of sorghum, with values ranging between 55.5 and 71.7% (Table 4 and Figure 2). Grain sorghum variety "E1291" had 66.4% in vitro true dry matter digestibility, dual-purpose sorghum variety "E6250" had 55.5 % while forage sorghum variety "Hirna 547" showed 61.4 % in vitro true dry matter digestibility. The relatively high cell-wall constituents, acid-detergent fiber and cellulose content, and low crude protein, were probably the reasons for the lower in vitro true dry matter digestibility observed in dual-purpose sorghum variety "E6250", since cell-wall constituents ($P < 0.05$), acid-detergent fiber and cellulose ($P < 0.01$) were negatively correlated with in vitro true dry matter digestibility (Table 3). Arkel et al. (1977) working at Lanet, Nakuru reported that in vitro digestibility of grain sorghum variety "E1291" was higher than that of a dual-purpose sorghum variety "E6518". Kuhlman and Owen (1962) also reported that a grain sorghum "Rox" had a higher in vitro digestibility than a forage type sorghum "Atlas". In this study, it was observed that although "E1429" was a forage sorghum variety, its in vitro true dry matter digestibility was nearly equal to that of "E1291" a grain variety with about four times as much grain, as indicated by head dry matter fraction (Table 4). This probably could have been caused by differences in silica content. The total silica content of "E1291" was 5.2% while that of "E1429" was 4.1 %. Owen (1967) reported that a grain sorghum "RS 610" had only slightly higher in vitro digestibility than forage variety

"Tracy". Garret and Worker (1975) and Balwani *et al.* (1969), in separate studies, found similar *in vivo* digestibility between grain and forage sorghum types. Danley and Vetter (1973) reported similar *in vitro* digestibility for two forage varieties of sorghum, whereas Ward, Boren and Smith (1967) found similar *in vivo* digestible energy contents among silages made from varieties of sorghum varying widely in grain content.

Dry matter yield and grain content

Dry matter yield was positively related to cell-wall constituents, acid-detergent fiber ($P < 0.05$) and cellulose ($P < 0.01$). The relationship between dry matter and both crude protein and *in vitro* true dry matter digestibility was negative but not significant (Table 3). Arora *et al.* (1975) reported that dry matter yield of sorghum was negatively related to crude protein content and *in vitro* digestibility. Grain content was negatively correlated with dry matter yield, acid-detergent fiber, cellulose ($P < 0.05$) and cell-wall constituents ($P < 0.01$). It was, however, not related to *in vitro* true dry matter digestibility. Some workers (Kuhlman and Owen, 1962; Arkel *et al.*, 1977) observed higher *in vitro* digestibility of grain sorghum as compared to forage sorghum while the majority of workers (Garret and Worker, 1965; Owen, 1967; Ward, Boren and Smith, 1967; and Balwani *et al.*, 1969) found no significant difference between grain and forage sorghum in their digestibility. Ward *et al.* (1969) noted that grain content exerted little influence on nutritive value of sorghums.

TABLE 2. CRUDE PROTEIN, CELLULOSE, HEMICELLULOSE, PERMANGANATE LIGNIN AND TOTAL SILICA CONTENT (PERCENT OF DRY MATTER) OF NINE VARIETIES OF SORGHUM

Sorghum Variety	Grain Content[1] %	Crude Protein[2] %	Cellulose[2] %	Hemicellulose[2] %	Permanganate Lignin[2] %	Total Silica[2] %
"E1291"	43.6	9.0	22.0	18.5	5.8	5.2
"E5769"	38.0	7.3	24.1	19.4	6.8	4.0
"E5766"	30.[illegible]	7.4	23.3	20.5	6.2	4.1
"E6518"	2[illegible].8	6.9	28.5	17.9	6.8	4.9
"E1[illegible]34"	21.8	5.9	29.8	17.7	6.9	4.0
"E6230"	20.8	6.5	31.9	21.6	6.4	4.2
"E1405"	17.9	5.9	30.2	23.0	6.6	3.3
"E1429"	10.9	6.6	28.9	20.6	6.4	4.1
"Hirna E47"	5.5	7.9	28.2	21.7	8.1	4.2
Range	5.5-43.6[b]	5.9-9.0[a]	22.0-31.9[a]	17.7-23.0[a]	5.8-8.1[a]	3.3-5.2[b]

[1] Grain content, % sorghum head of total dry matter.

[a] Variation among varieties of sorghum significant at $P<0.05$

[b] " " " " " at $P<0.01$

[2] Values obtained for whole sorghum plant.

TABLE 3. SELECTED SIMPLE CORRELATION COEFFICIENTS AMONG CHEMICAL COMPONENTS AND IN VITRO DRY MATTER DIGESTIBILITY VALUES FOR NINE SORGHUM VARIETIES

	GC[1]	DMY	CP	CWC	ADF	HC	CEL	PL	TS
GC	-	-	-	-	-	-	-	-	-
DMY	-0.72[a]	-	-	-	-	-	-	-	-
CP	0.47	-0.63	-	-	-	-	--	-	-
CWC	-0.82[b]	0.70[a]	-0.70[a]	-	-	-	-	-	-
ADF	-0.77[a]	0.79[a]	-0.70[a]	0.95[b]	-	-	-	-	-
HC	-0.48	0.12	-0.25	0.56	0.30	-	-	-	-
CEL	-0.75[a]	0.80[b]	-0.78[a]	0.95[b]	0.97[b]	0.37	-	-	-
PL	-0.65	0.29	-0.11	0.52	0.53	0.17	0.35	-	-
TS	0.43	-0.18	-0.71[a]	-0.56	-0.37	-0.68[a]	-0.45	-0.06	-
IVDMD	0.49	-0.64	0.51	-0.79[a]	-0.87[b]	-0.11	-0.85[b]	-0.30	-0.12

[a] correlation coefficient significant at $P<0.05$
[b] " " " " $P<0.01$

[1] GC, Grain content; DMY, Dry matter yield; CP, Crude protein; CWC, Cell-wall constituents; ADF, Acid-detergent fibre; HC, Hemicellulose; CEL, Cellulose; PL, Permanganate lignin; TS, Total silica.

TABLE 4 CELL-WALL CONSTITUENTS, ACID-DETERGENT FIBER, IN VITRO TRUE DRY MATTER DIGESTIBILITY (DRY MATTER BASIS) AND TOTAL DRY MATTER YIELD (TONS/HA) OF NINE VARIETIES OF SORGHUM

Sorghum Variety Name	Grain Content[1] %	Dry-matter[2] Yield (tons/ha)	Cell-wall[2] Constituents %	Acid-detergent[2] Fiber %	*In vitro*[2] true dry matter digestibility (%)
"E1291"	43.6	12.5	50.0	31.5	66.4
"E5769"	38.0	10.9	52.7	34.1	70.0
"E5766"	35.3	12.7	53.9	33.4	71.7
"E6518"	22.8	20.8	58.2	40.3	61.4
"E1394"	21.8	19.2	60.3	40.7	56.9
"E6250"	20.8	16.9	63.9	42.2	55.5
"E1405"	17.9	19.2	63.2	40.3	60.7
"E1429"	10.9	20.7	58.6	37.9	66.0
"Hirna 547"	5.5	17.4	62.1	40.2	61.4
Range	5.5-43.6[b]	10.9-20.8[a]	50.0-63.9[a]	31.5-42.2[a]	55.5-71.7[b]

[1] Grain content, % sorghum head of total dry matter.

[a] Variation among varieties of sorghum significant at $P<0.05$
[b] " " " " " " " $P<0.01$

[2] Values obtained for whole sorghum plant.

Figure 1: Crude protein, Permanganate lignin and total silica content of nine sorghum varieties.

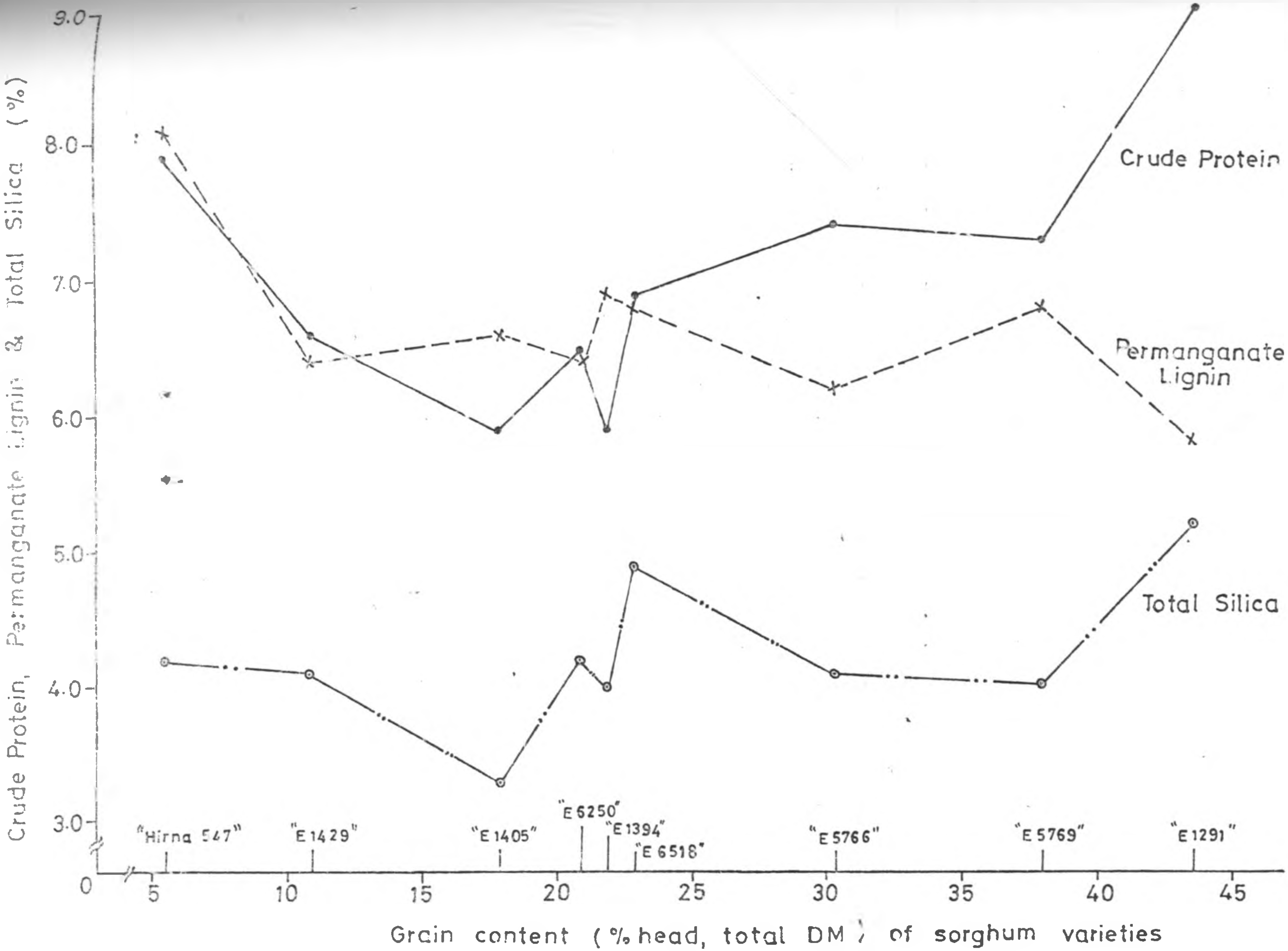

Crude Protein, Permanganate Lignin & Total Silica (%)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
0
5
10
15
20
25
30
35
40
45
Grain content (% head, total DM) of sorghum varieties
Crude Protein
Permanganate Lignin
Total Silica
"Hirna 547"
"E 1429"
"E 1405"
"E 6250"
"E 1394"
"E 6518"
"E 5766"
"E 5769"
"E 1291"

Figure 2: *In vitro* true dry matter digestibility, cell-wall constituents and acid-detergent fiber of nine sorghum varieties

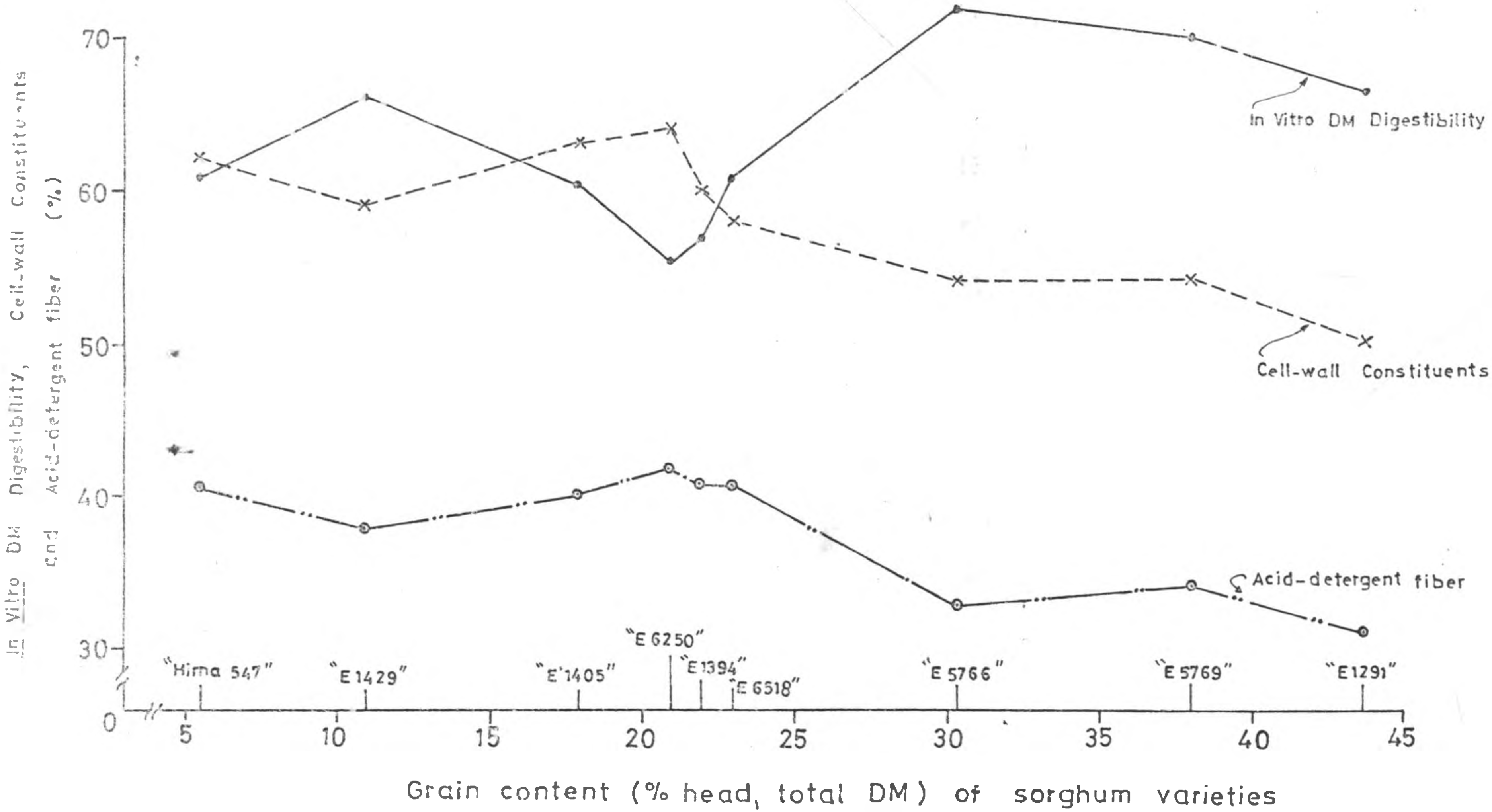
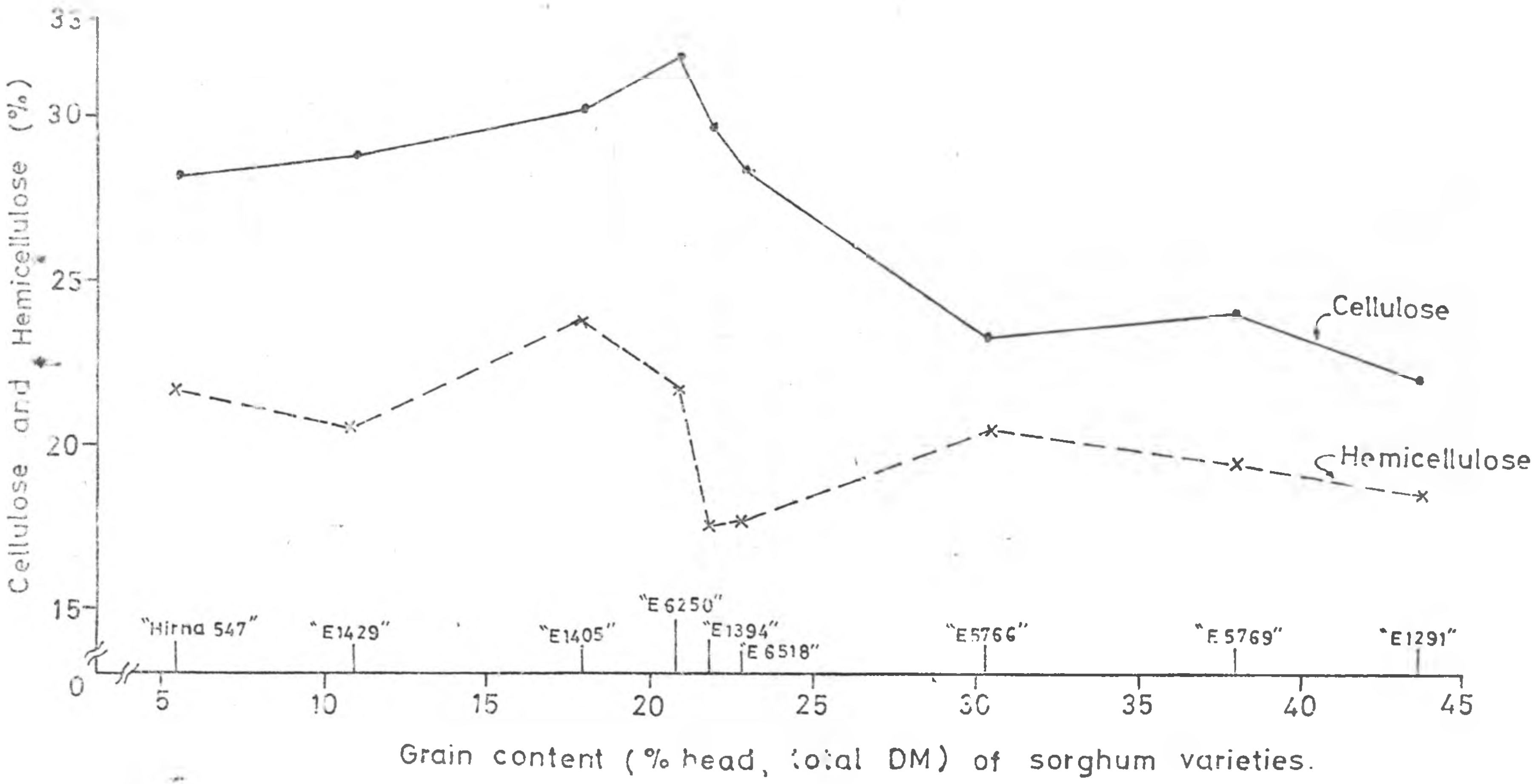

In Vitro DM Digestibility, Cell-wall Constituents
and Acid-detergent fiber (%)
70
60
50
40
30
0
In Vitro DM Digestibility
Cell-wall Constituents
Acid-detergent fiber
"Hirna 547"
"E 1429"
"E 1405"
"E 6250"
"E 1394"
"E 6518"
"E 5766"
"E 5769"
"E 1291"
5
10
15
20
25
30
35
40
45
Grain content (% head, total DM) of sorghum varieties

Figure 3: Cellulose and hemicellulose content of nine sorghum varieties


Cellulose and Hemicellulose (%)
Cellulose
Hemicellulose
"Hirna 547"
"E1429"
"E1405"
"E6250"
"E1394"
"E6518"
"E5766"
"E5769"
"E1291"
Grain content (% head, total DM) of sorghum varieties.

CHEMICAL COMPOSITION AND IN VITRO TRUE DRY MATTER DIGESTIBILITY OF VARIOUS PLANT PARTS (LEAF, STEM AND HEAD) OF NINE SORGHUM VARIETIES

Crude protein

Crude protein content of sorghum was significantly different ($P < 0.01$) between the various plant parts. Sorghum leaf had 10.7 %, stem had 4.7 %, while sorghum head contained 9.3 % crude protein (Table 5, Figure 4).

Fiber components

Fiber content of sorghum plant as measured by cell-wall constituents, acid-detergent fiber, cellulose and permanganate lignin showed significant variation ($P < 0.01$) between the various plant parts (Table 5). Sorghum leaf contained 61.7 % cell-wall constituents, stem had 67.3 %, while sorghum head had 37.4 %. Acid-detergent fiber content was 40.1 % in leaf, 46.0 % in stem and 19.2 % in sorghum head. Sorghum leaf contained 23.9 %, stem had 35.8 % while head contained 12.8 % cellulose (Figure 5). Permanganate lignin content of leaf was 6.3 %, that of stem was 7.7 %, while that of sorghum head was 4.6 % (Figure 6).

Total silica and soluble silica

Total and soluble silica significantly varied ($P < 0.01$) between the various plant parts. Sorghum leaf had 10.4 %, total silica stem had 3.3 %, while head contained 1.8 % (Table 5). Soluble silica,content of leaf was 0.6 %, that of stem was 1.8 % while that of sorghum head was 0.4 %.

In vitro true dry matter digestibility

In vitro true dry matter digestibility was significantly different (P<0.01) in the various plant parts. Sorghum leaf showed 67.6 % *in vitro* true dry matter digestibility, stem had 56.3 %, while head had 75.4 % (Table 5, Figure 7). The lower *in vitro* true dry matter digestibility observed in the sorghum stem could probably be attributed to the lower crude protein, and higher fiber content as measured by cell-wall constituents, acid-detergent fiber, cellulose and permanganate lignin, as well as higher soluble silica content of stem, when compared to leaf and head. Also, cell-wall digestibility of stem was lower than that of leaf and head (Table 5). Aii (1975) reported that *in vitro* digestibility of sorghum stem declined sharply while that of leaf remained fairly constant during growth. Fribourg *et al.* (1976) observed that sorghum stem had lower *in vitro* digestibility than sorghum leaf in various forage sorghums. Aii (1975) reported that crude protein content of sorghum was positively correlated with *in vitro* digestibility, while Marten *et al.* (1976) and Danley and Vetter (1973) reported that cell-wall constituents, acid-detergent fiber, cellulose and lignin were negatively correlated with both *in vivo* and *in vitro* digestibility of sorghum. Van Soest and Jones (1967) reported the adverse effect of soluble silica on digestibility of forages.

The interaction between variety and part of the plant was significant (P< 0.05 or P< 0.01) with respect to cell-wall constituents, acid-detergent fiber, cellulose, total ash, total silica, insoluble silica, energy content and in vitro dry matter digestibility. Cell-wall constituents, acid-detergent fiber, cellulose and total silica levels in sorghum heads of the grain varieties, "E1291", "E5769", and "E5766", were significantly (P <0.05) lower than those of the forage sorghum varieties, "E1405", "E1429", and "H 547" (Table 6). In vitro dry matter digestibility of sorghum head of the high grain variety "E1291" was significantly (P< 0.05) higher than that of the forage variety "H 547". Total silica content in sorghum leaf of the grain varieties was significantly (P< 0.05) higher than that of the forage varieties. High grain variety "E1291" contained significantly (P< 0.05) higher level of total silica in the stem than all the other varieties. In vitro dry matter digestibility of sorghum stem of the dual-purpose varieties, E1394", "E6518", and "E6520" was significantly (P< 0.05) lower than that of grain varieties "E5769", and "E5766", and forage variety "E1429.

TABLE 5: CHEMICAL COMPOSITION (PERCENT DRY MATTER) GROSS ENERGY (Kcal) CONTENT, PERCENT *IN VITRO* TRUE DRY MATTER DIGESTIBILITY AND CELL-WALL DIGESTIBILITY OF LEAF, STEM AND SORGHUM HEAD OF NINE SORGHUM VARIETIES[1]

Quality Parameter	Part of sorghum plant		
	Leaf (range)	Stem (range)	Head (range)
Crude protein, %	10.7 (9.2-12.8)	4.7 (3.6-6.6)	9.3 (7.1-11.3)
Ether-extract , %	4.4 (3.2-5.8)	3.1 (2.2-3.9)	4.5 (2.9-5.5)
Total ash, %	14.3 (11.5-15.8)	5.2 (4.2-7.0)	3.3 (2.1-4.0)
Cell-wall constituents, %	61.7 (56.6-66.5)	67.3 (59.0-70.9)	37.4 (29.7-52.2)
Acid-detergent fiber, %	40.1 (37.0-42.0	46.0 (39.7-50.7)	19.2 (13.9-28.6)
Hemicellulose, %	21.6 (15.4-25.4)	21.3 (17.4-24.0)	18.2 (14.3-23.9)
Cellulose, %	23.9 (21.5-26.6)	35.8 (30.8-40.9)	12.8 (8.1-18.4)
Permanganate lignin, %	6.3 (5.4-7.9)	7.7 (6.6-8.7)	4.6 (4.1-5.8)
Total silica, %	10.4 (6.1-13.2)	3.3 (2.5-6.2)	1.8 (1.2-2.9)
Soluble silica, %	0.6 (0.4-0.7)	1.8 (0.9-2.6)	0.4 (0.1-0.7)
Gross energy, Kcal/g	4.2 (3.9-4.7)	4.2 (3.9-4.5)	4.4 (4.2-4.6)
Cell-wall digestibility, %	46.5 (34.2-57.5)	36.1 (24.4-49.5)	37.6 (28.4-49.2)
In vitro true DM-digestibility, %	67.6 (63.3-73.6)	56.3 (45.4-68.1)	75.4 (67.8-80.9)

[1]part of plant had significant effect on all parameters at $P<0.01$.

Table 6: Cell-wall constituents, acid-detergent fiber, cellulose, total silica and in vitro dry matter digestibility of leaf, stem or head of nine varieties of sorghum[1]

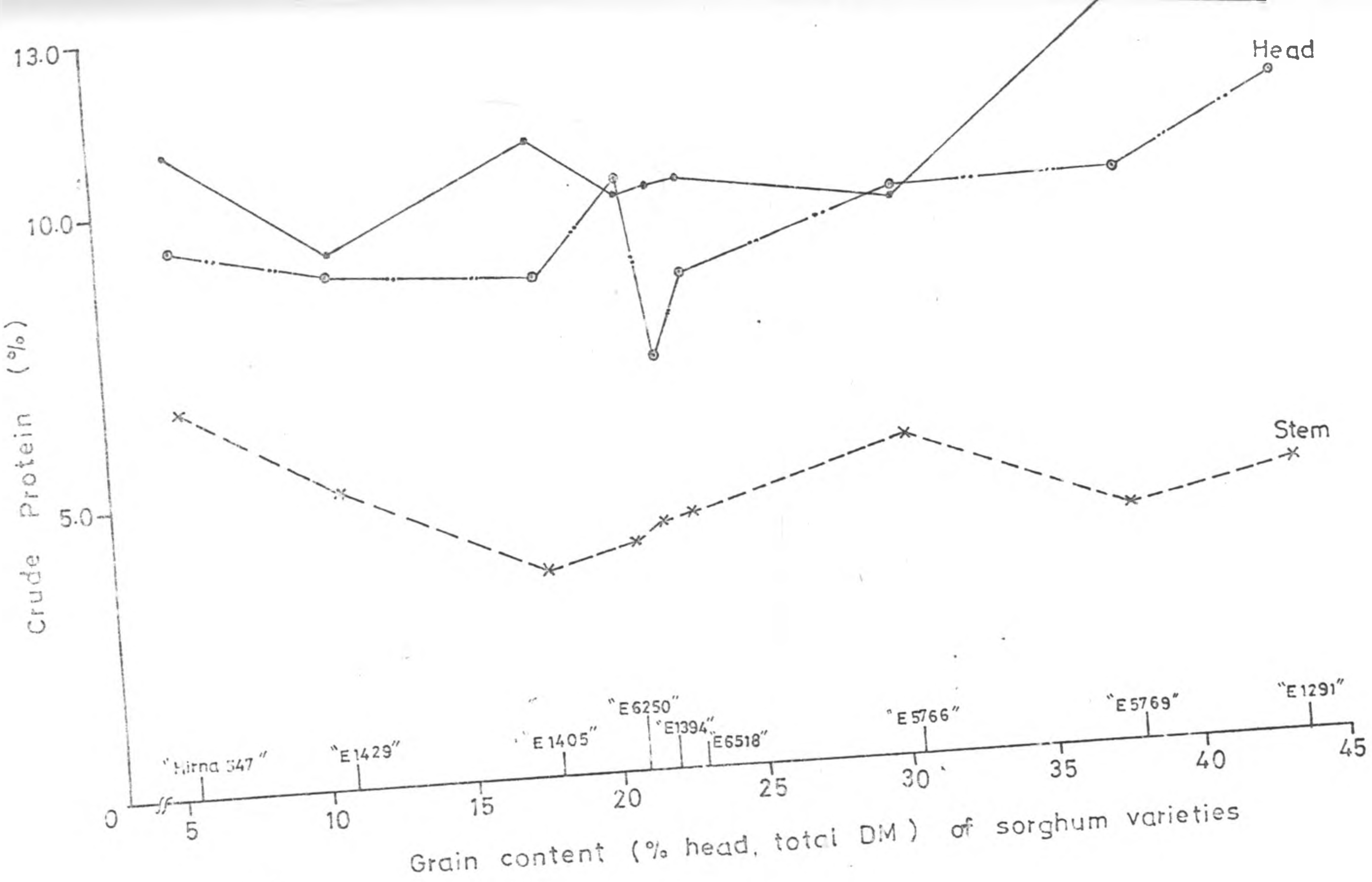
Sorghum[2] Variety	CWC[3]	ADF[3]	Cellulose		Total silica			IVDMD[3]	
	Head	Head	Stem	Head	Leaf	Stem	Head	Stem	Head
"E1291"	32.0^{a}	14.4^{a}	36.8^{ab}	8.9^{a}	13.0^{b}	6.2^{b}	1.2^{a}	57.1^{abd}	75.8^{bcd}
"E5769"	28.2^{a}	13.9^{a}	37.0^{ab}	8.1^{a}	13.2^{b}	3.7^{a}	1.4^{a}	63.0^{cd}	80.9^{d}
"E5766"	29.7^{a}	15.2^{a}	30.8^{a}	9.0^{a}	13.0^{b}	3.2^{a}	1.6^{a}	68.1^{bd}	79.0^{bd}
"E6518"	33.3^{b}	17.0^{ad}	39.2^{ab}	11.0^{ac}	11.6^{bc}	2.7^{a}	1.6^{a}	51.1^{ac}	78.3^{bd}
"E1394"	32.4^{a}	17.5^{ad}	38.2^{ab}	11.8^{ac}	11.6^{bc}	2.5^{a}	1.9^{b}	[illegible] ^{a}	76.5^{bcd}
"E6250"	41.4^{b}	21.5^{cd}	40.9^{b}	15.6^{bd}	10.5^{bc}	3.1^{a}	1.5^{a}	45.4^{a}	73.9^{bc}
"E1405"	39.6^{b}	20.0^{cd}	37.0^{ab}	13.9^{cd}	6.1^{a}	2.9^{a}	1.8^{b}	53.1^{a}	73.8^{bc}
"E1429"	47.7^{b}	24.3^{bc}	31.7^{ab}	18.3^{bc}	8.6^{ac}	2.7^{a}	1.9^{b}	63.6^{bc}	72.4^{ac}
"Hirna 547"	52.6^{b}	28.6^{b}	30.9^{a}	18.4^{bc}	5.8^{a}	2.7^{a}	2.9^{b}	59.0^{abd}	67.8^{a}

[1] Means with one or more common letters (in each column) are not significantly different at $(P < 0.05)$

[2] Sorghum varieties arranged in decreasing grain content order.

[3] CWC = Cell-wall constituents; ADF = Acid-detergent fibre; IVDMD = *in vitro* true dry matter digestibility.

Figure 4: Crude protein content of leaf, stem, and head of nine sorghum varieties.



Head
Stem
13.0
10.0
5.0
Crude Protein (%)
0
5
10
15
20
25
30
35
40
45
"Hirna 347"
"E1429"
"E1405"
"E6250"
"E1394"
"E6518"
"E5766"
"E5769"
"E1291"
Grain content (% head, total DM) of sorghum varieties

Figure 5: Cellulose content of leaf, stem and head of nine sorghum varieties.

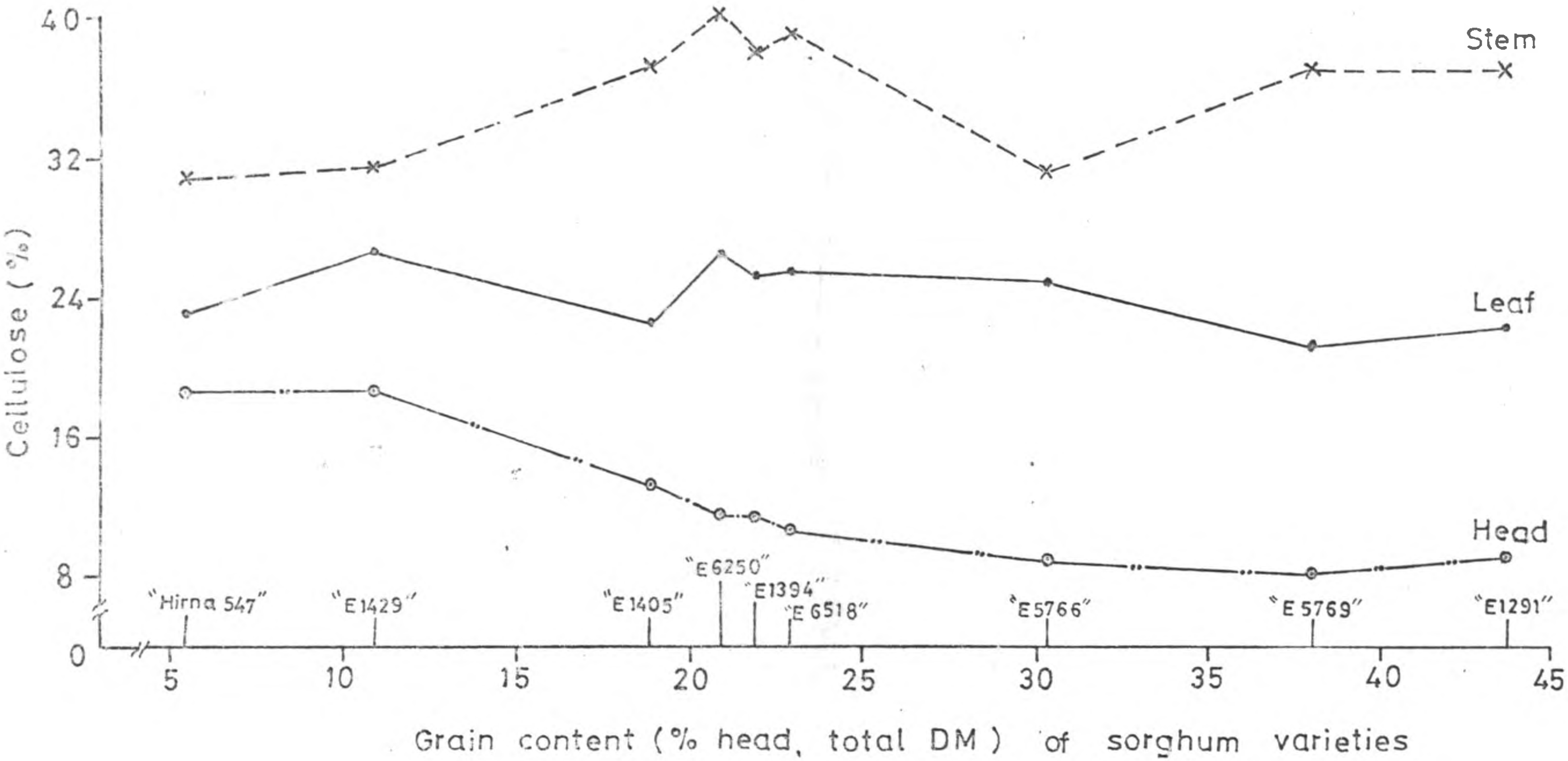

Stem
Leaf
Head
Cellulose (%)
40
32
24
16
8
0
"Hirna 547"
"E1429"
"E1405"
"E6250"
"E1394"
"E6518"
"E5766"
"E5769"
"E1291"
5
10
15
20
25
30
35
40
45
Grain content (% head, total DM) of sorghum varieties

Figure 6: Permanganate lignin content of leaf, stem and head of nine sorghum varieties.

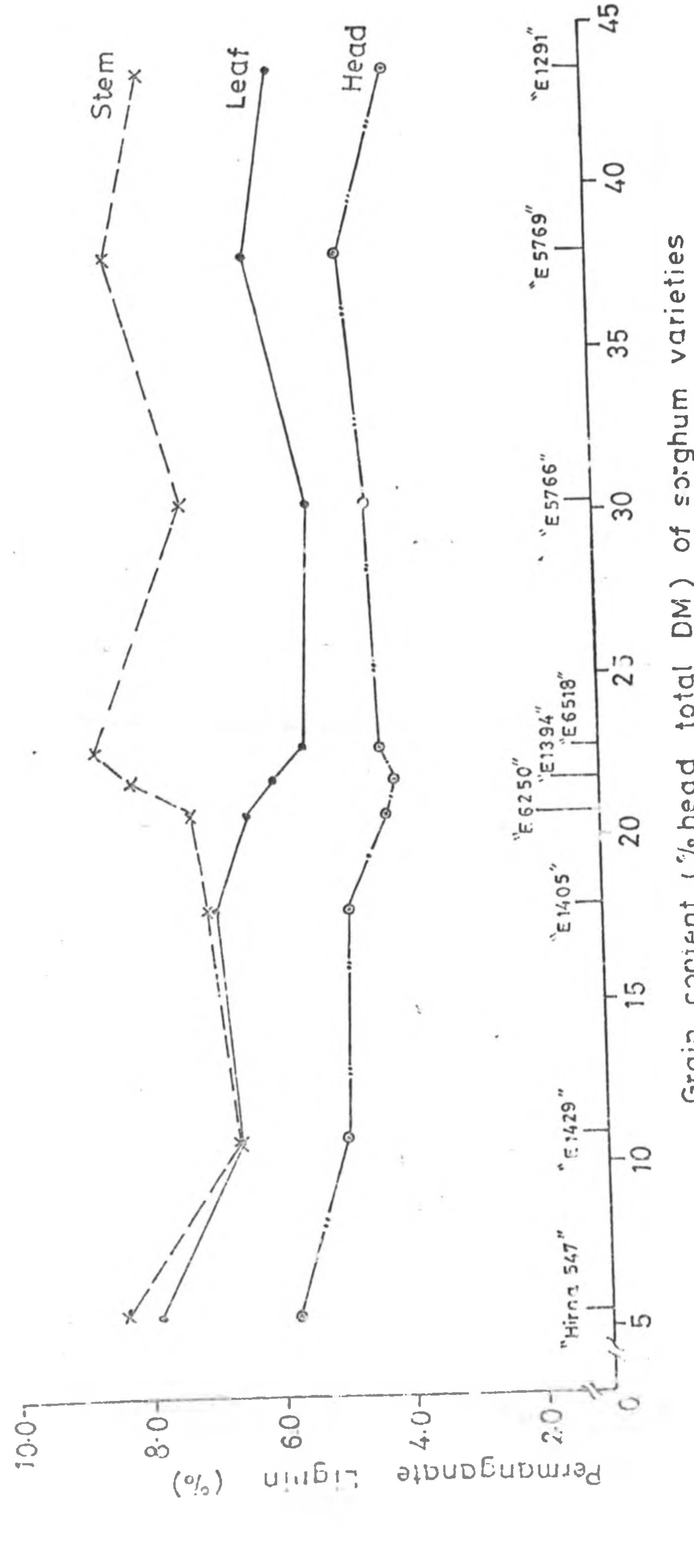
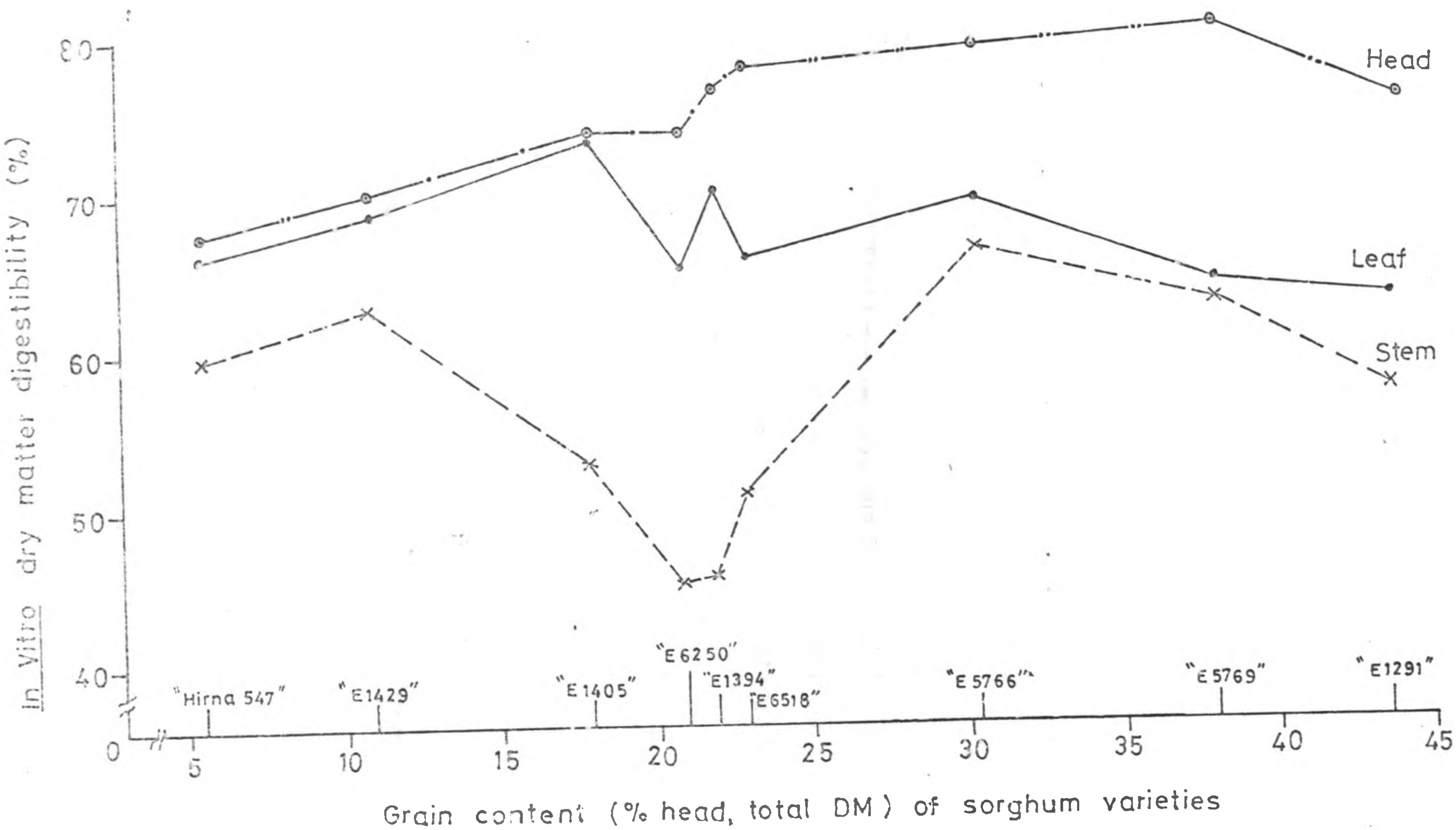

Stem
Leaf
Head
"Hirna 547"
"E1429"
"E1405"
"E6250"
"E1394"
"E6518"
"E5766"
"E5769"
"E1291"
Grain content (% head, total DM) of sorghum varieties
Permanganate Lignin (%)
10.0
8.0
6.0
4.0
2.0
0
5
10
15
20
25
30
35
40
45

Figure 7: In vitro true dry matter digestibility of leaf, stem and head of nine sorghum varieties.



In Vitro dry matter digestibility (%)
80
70
60
50
40
0
5
10
15
20
25
30
35
40
45
Head
Leaf
Stem
"Hirna 547"
"E1429"
"E1405"
"E6250"
"E1394"
"E6518"
"E5766"
"E5769"
"E1291"
Grain content (% head, total DM) of sorghum varieties

LOCATIONAL VARIATION IN CHEMICAL COMPOSITION AND IN VITRO TRUE DRY MATTER DIGESTIBILITY OF NINE SORGHUM VARIETIES

There were significant locational variations ($P < 0.01$) with respect to cell-wall constituents, acid-detergent fiber, permanganate lignin and in vitro true dry matter digestibility (Table 7).

Fiber components

Mean cell-wall constituents of nine sorghum varieties was 62.4 % at location 1 (Beef Research Station, Lanet, Field 16 - BRS 1), 62.6 % at location 2 (Beef Research Station, Lanet, Field 2 - BRS 2), and 50.0 % at location 3 (Naivasha) (Table 7). Location 3 showed a significantly lower value ($P < 0.05$) of sorghum cell-wall constituents than locations 1 and 2.

Mean acid-detergent fiber of nine varieties of sorghum was 41.0 % at location 1, 40.2 % at location 2 and 34.7 % at location 3 (Table 7). Location 3 showed a significantly lower value of acid-detergent fiber ($P < 0.05$) than the other two locations.

Permanganate lignin content of sorghum was 7.8 % at location 1, 7.1 % at location 2 and 4.8 % at location 3 (Table 7). Location 3 showed a significantly lower value of permanganate lignin content of sorghum ($P < 0.05$) than the other two locations.

In vitro true dry matter digestibility

Mean in vitro true dry matter digestibility coefficients of nine sorghum varieties was found to be 60.0 % at location 1, at location 2 it was 61.6 % and at location 3 it was 67.4 % (Table 7). Significantly higher ($P < 0.05$) in vitro true dry matter digestibility of sorghum varieties was observed at location 3 compared to locations 1 or 2.

Significant interaction between location and variety of sorghum was obtained for permanganate lignin ($P < 0.01$), but not with respect to cell-wall constituents, acid-detergent fiber or in vitro true dry matter digestibility. Interaction between location and part of plant was significant ($P < 0.01$) for crude protein, acid-detergent fiber and in vitro true dry matter digestibility (Table 8).

In this study, the higher in vitro true dry matter digestibility obtained at location 3 as compared to the other two locations, was probably a result of the lower fiber content of sorghums, as measured by cell-wall constituents, acid-detergent fiber and permanganate lignin at location 3. These observations are in agreement with those of Arora et al. (1973) who studied locational variation in chemical composition and in vitro dry matter digestibility of eight sorghum varieties at four locations in India, and reported locational influence on cell-wall constituents, acid-detergent fiber and in vitro dry matter digestibility. Differences in soil type, moisture and temperature at the three locations in this experiment could have contributed to the observed differences in chemical composition and in vitro true dry matter digestibility of sorghum varieties. Arora _et al_., (1975) reported that tannin content of sorghum varieties, although not investigated in this study, was significantly influenced by locational differences, while high levels of tannin in sorghum reduced _in vitro_ organic matter and dry matter digestibility of sorghum varieties (Green, 1974, Arora _et al_., 1975).

Table 7 Chemical composition (dry matter) and in vitro true dry matter digestibility of nine sorghum varieties at three different locations[1]

Forage Quality Parameter	BRS 1			BRS 2			Naivasha		
	Mean	Range	SE[2]	Mean	Range	SE	Mean	Range	SE
Cell-wall constituents, %	62.4[a]	51.1-71.1	6.2	62.6[a]	55.9-67.6	4.7	50.0[b]	42.6-54.5	3.4
Acid-detergent fiber, %	41.0[a]	33.9-47.6	4.2	40.2[a]	31.8-44.2	4.3	34.7[b]	28.8-43.0	4.4
Parmanganate lignin, %	7.8[a]	7.2-8.8	0.2	7.1[a]	4.7-8.3	1.6	4.8[b]	2.2-6.3	0.2
In-vitro-true DM digestibility, %	60.0[a]	53.0-69.1	5.3	61.6[a]	54.4-68.3	4.8	67.4[b]	57.7-77.6	7.0

[1]Means with one common letter across the row are not statistically different at $P < 0.05$.
[2]SE, standard error.

Table 8: Crude protein, acid-detergent fiber and in vitro true dry matter digestibility of leaf, stem and head of sorghum at three locations

	Crude protein, %			Acid-detergent fiber, %			In-vitro true dry digestibility, %		
Location	1	2	3	1	2	3	1	2	3
Leaf	11.5[k][1]	10.7[km]	9.8[m]	42.0[e]	40.8[e]	37.6[d]	64.3[a]	66.9[a]	71.6[b]
Stem	3.6[n]	4.3[n]	6.1[p]	50.0[f]	48.5[f]	39.6[g]	52.7[a]	53.2[a]	63.1[b]
Head	8.9[q]	9.7[a]	9.2[q]	19.4[hj]	20.6[h]	17.4[j]	75.7[a]	76.1[a]	74.2[a]

[1]Values with one or more common letters (across the row under each parameter) are not statistically different at $P < 0.05$.

EXPERIMENT 2

INFLUENCE OF STAGE OF MATURITY AT HARVEST ON CHEMICAL COMPOSITION AND IN VITRO TRUE DRY MATTER DIGESTIBILITY OF GRAIN SORGHUM VARIETY "E1291" AND FORAGE VARIETY "E6250"

Dry matter yield

Figures of total dry matter yield, and contribution of leaf, stem and head of two types of sorghum are presented in Table 9. "E1291" was a high-grain yielding variety with over 40.0 percent sorghum head of total dry matter (grain-content), while "E6250" was a forage type sorghum variety with less than 20.0 percent head (Table 1). Sorghum varieties "E1291" and "E6250" are hereafter referred to as "grain variety" or "forage variety", respectively.

Simple correlation coefficients between chemical components and *in vitro* true dry matter digestibility with stage of maturity for leaf, stem and head of two sorghum varieties are shown in Table 10.

Crude protein

Percent crude protein content of leaf and stem of both grain sorghum variety "E1291" and forage variety "E6250" was negatively correlated ($P < 0.01$) with stage of maturity of sorghum plant at harvest between the 111th and 223rd days post-sowing. In grain sorghum "E1291", crude protein content of leaf and stem decreased from 16.8 to 7.2 percent, and from 10.4 to 5.4 percent, respectively; while in forage sorghum variety "E6250", crude protein of leaf and stem decreased from 18.7 to 9.0 percent and from 18.4 to 3.5 percent,

Table 9 Dry matter yield for leaf, stem and head of grain sorghum "E1291" and forage sorghum "E6250" at different stages of maturity

Days post-sowing	Total dry matter yield (tons/ha)							
	Grain sorghum variety "E1291"				Forage sorghum variety "E6250"			
	Leaf	Stem	Head	Total	Leaf	Stem	Head	Total
111	1.2	2.2	0.2	3.6	0.6	1.0	-	1.6
125	1.5	3.5	0.3	5.3	1.9	1.9	-	3.8
139	1.5	4.9	0.5	6.9	3.0	4.2	0.4	7.6
153	1.6	6.2	1.0	8.8	2.9	6.0	0.6	9.5
167	1.5	6.3	2.0	9.8	3.8	8.2	1.0	13.0
181	1.4	5.2	3.0	9.6	2.4	8.8	1.7	11.6
195	1.5	5.9	4.2	11.6	3.9	10.2	1.6	15.7
209	1.3	5.0	4.3	10.6	2.4	12.6	2.6	17.6
223	1.4	4.6	4.1	10.1	2.6	11.2	2.6	16.4

respectively (Table 11). In grain and forage sorghum varieties "E1291" and "E6250" the adverse effect of maturity on crude protein content was most severe in the leaf of "E1291" and stem of "E6250" where the linear decrease in crude protein with maturity could be best expressed by equations $Y = 27.17 - 0.0819 X$, $(r = -0.94)$ and $Y = 33.08 - 0.1470 X$, $(r = -0.91)$, respectively, where Y is percent crude protein and X is maturity in days between the 111th and 223rd days-post-sowing (Table 16). In both sorghum varieties, changes in crude protein of the head with advancing maturity were insignificant. Owen (1962) and Webster (1963) observed a decrease in crude protein with advancing maturity from the milk to hard seed stage in a forage sorghum, "Atlas". Owen and Webster (1963) found a negative significant linear regression of crude protein on maturity (days after bloom) while working with "Atlas" and "Rox" varieties, and "RS301F" and "RS303F" hybrids, representing both forage and grain types of sorghum. Prates, Leboute and Raffer (1975) noted that earlier cuts of forage sorghum had higher crude protein contents than later cuts. Aii (1975) reported that crude protein in stem and leaf sheath decrease with maturity.

Cell-wall constituents

In both grain and forage sorghum varieties "E1291" and "E6250", percent cell-wall constituents significantly $(P < 0.01)$ increased within stem, and decreased within head of sorghum plant, with advancing stage of maturity between the 111th and 223rd day post-sowing; while that of leaf increased $(P < 0.01)$ only in forage variety "E6250", but not in grain variety "E1291". In grain sorghum variety "E1291" cell-wall constituents increased

Table 10 : r-values calculated for the simple correlation between forage quality parameters and stage of maturity at harvest (days post-sowing) for grain sorghum "E1291" and forage sorghum "E6250"

Forage quality parameter	High-grain sorghum variety "E1291"			Forage sorghum variety "E6250"		
	Leaf	Stem	Head	Leaf	Stem	Head
	r-values					
Crude protein, (%)	-0.94**	-0.88**	-0.61	-0.98**	-0.91**	0.65
Gross-energy, (Kcal)	0.11	-0.25	0.42	-0.47	0.47	-0.17
Ether-extract, (%)	-0.21	-0.29	-0.25	-0.70*	-0.66*	0.05
Total ash, (%)	0.95**	-0.25	-0.93**	-0.69*	-0.91**	-0.55
Cell-wall constituents, (%)	0.16	0.91**	-0.89**	0.82**	0.93**	-0.93**
Acid-detergent fiber, (%)	0.74*	0.98**	-0.83**	0.96**	0.94**	-0.90**
Hemicellulose, (%)	-0.70*	0.46	-0.84**	-0.58	0.20	-0.77*
Cellulose, (%)	-0.33	0.98**	-0.83**	0.58	0.67*	-0.57
Permanganate lignin, (%)	0.92**	0.89**	-0.40	0.65	0.85**	0.86*
Total silica, (%)	0.93**	0.73*	-0.55	0.55	-0.71*	-0.45
Soluble silica, (%)	0.66*	0.88**	0.28	0.42	-0.02	-0.58
Cell-wall digestibility, (%)	-0.95**	-0.55	-0.81**	-0.84**	-0.88**	-0.75*
In vitro true DM digestibility, (%)	-0.97**	-0.96**	0.49	-0.75*	-0.87**	0.31

** Significant at $P < 0.01$

* Significant at $P < 0.05$

Table 11: Crude protein content leaf, stem and head of grain sorghum "E1291" and forage sorghum "E6250" at different stages of maturity

Days post-sowing	% crude protein					
	High-grain sorghum variety "E1291"			Forage sorghum variety "E6250"		
	Leaf	Stem	Head	Leaf	Stem	Head
111	16.8	10.4	15.6	18.7	18.4	-
125	17.5	8.6	11.2	17.3	18.5	-
139	17.9	7.3	15.7	18.2	12.0	4.4
153	14.7	6.1	9.9	16.7	6.5	11.8
167	14.3	5.8	10.6	14.8	5.9	10.5
181	13.4	5.0	10.9	12.7	5.1	10.7
195	11.1	4.0	10.8	11.8	3.4	10.8
209	10.2	4.5	10.9	10.4	3.4	11.0
223	7.2	5.4	10.7	9.0	3.5	12.3

linearly from 51.5 to 69.5 percent in stem and decreased from 57.8 to 22.2 percent in head; while in forage sorghum variety "E6250", it increased in leaf and stem from 56.0 to 63.6 percent and from 48.9 to 69.0 percent, respectively, and declined in the head from 60.7 to 46.0 percent (Table 12). Although, there was an increase in cell-wall constituents of the stem in both grain and forage varieties with advancing maturity, in the case of forage sorghum the increase was greater than that observed in grain sorghum, (Y = 36.38 + 0.1517X, (r = 0.93) and Y = 33.87 + 0.1477X, (r = 0.91), where Y is percent cell-wall constituents and X is maturity in days post-sowing), suggesting a more adverse effect of maturity on stem of forage sorghum (Table 16). Head of the grain variety "E1291" on the other hand showed a marked linear decrease in cell-wall constituents with advancing maturity where Y = 108.05 - 0.3709X, (r = -0.89). Joo (1965) observed that as maturity progressed a grass-type forage sorghum became much higher in fibrous contents than a grain sorghum. Danley and Vetter (1973), however, found the increase in cell-wall constituents of two forage sorghum varieties to be insignificant.

Acid-detergent fiber

In both grain and forage sorghum varieties, acid-detergent fiber content of leaf increased significantly ($P < 0.05$ or $P < 0.01$) with maturity, while that of stem and head of both grain and forage varieties were positively and negatively correlated ($P < 0.01$), respectively, with maturity (days post-sowing) between the 111th and 223rd day. In grain variety "E1291", acid-detergent fiber increased from

36.3 to 50.4 percent in leaf, from 34.4 to 49.3 percent in stem and declined from 28.8 to 16.1 percent in head (Table 13). In forage sorghum variety "E6250", acid-detergent fiber content increased from 34.4 to 44.0 percent in the leaf; from 22.9 to 52.4 percent within the stem and decreased in head from 34.4 to 25.4 percent. It was observed from these results that the increase in acid-detergent fiber of stem in the case of forage sorghum variety "E6250" with advancing maturity, expressed by an equation:

$Y = 20.14 + 0.1451 X$, ($r = 0.94$), was greater than the corresponding increase in stem of grain variety, expressed by another equation:

$Y = 20.63 + 0.1229 X$, ($r = 0.98$), where Y is percent acid-detergent fiber and X is maturity in days post-sowing (Table 16). Within each variety, the stem was more affected by advancing maturity than was leaf with respect to accummulation of percent acid-detergent fiber. Danley and Vetter (1973) found the increase in acid-detergent fiber of two forage varieties of sorghum to be insignificant.

Cell-wall digestibility

Linear regression of cell-wall digestibility of leaf and head of grain sorghum variety "E1291", and that of leaf and stem of forage sorghum variety "E6250", on maturity (days post-sowing) was negative and significant ($P<0.01$); while cell-wall digestibility of forage sorghum head also decreased significantly ($P<0.05$) with advancing stage of maturity. Cell-wall digestibility of leaf, stem and head of grain variety

"E1291" declined from 60.4 to 13. 4 percent, 62.6 to 30.3 percent and from 45.1 to 21.4 percent, respectively (Table 14). In forage variety "E6250", it decreased from 67.8 to 29.3 percent in leaf, from 52.3 to 21.0 percent in stem and from 56.2 to 31.3 percent in head. From the results of this experiment it was observed that stage of maturity had an adverse effect on cell-wall digestibility of all parts of sorghum plant-leaf, stem and head - of both grain and forage varieties. Although, in both varieties leaf cell-wall digestibility was more adversely affected than that of stem or head, grain sorghum variety "E1291" showed a marked reduction in cell-wall digestibility with advancing stage of maturity in its leaf which could be best expressed by an equation: Y = 112.8 - 0.4548 X, (r =-0.95), where Y is percent cell-wall digestibility and X is maturity in days post-sowing (Table 16). Although percent cell-wall constituents of leaf of "E1291" did not increase with maturity its cell-wall digestibility decreased markedly. However, in the forage variety percent cell-wall constituents of leaf increased and cell-wall digestibility also declined with maturity (Table 16). Browning and Lusk (1967) reported that digestibility of fibrous components of sorghum declined significantly with maturity in sorghum.

In vitro true dry matter digestibility

In vitro true dry matter digestibility of leaf and stem of grain sorghum variety "E1291" and that of stem of forage sorghum variety "E6250" decreased significantly ($P< 0.01$) with advancing stage of maturity between the 111th and 223rd day post-sowing,

Table 12: Cell-wall constituents of leaf, stem and head of grain sorghum "E1291" and forage sorghum "E6250" at different stages of maturity

Days post-sowing	% cell-wall constituents					
	High-grain sorghum variety "E1291"			Forage sorghum variety "E6250"		
	Leaf	Stem	Head	Leaf	Stem	Head
111	65.4	51.5	57.8	56.0	48.9	-
125	55.8	55.1	63.8	54.5	55.8	-
139	60.0	55.1	67.8	61.0	59.9	60.7
153	52.2	53.9	58.3	57.0	62.2	58.1
167	56.0	53.4	36.3	58.8	62.0	59.0
181	59.5	59.8	35.0	60.7	65.9	56.7
195	58.6	64.1	40.9	61.3	64.6	51.5
209	59.8	64.5	33.1	60.4	57.1	44.0
223	64.1	69.5	22.2	63.6	69.0	46.0

Table 13: Acid-detergent fiber of leaf, stem and head of grain sorghum "E1291" and forage sorghum "E6250 at different stages of maturity

	% Acid-detergent fiber					
Days	High-grain sorghum variety "E1291"			Forage sorghum variety "E6250"		
post-sowing	Leaf	Stem	Head	Leaf	Stem	Head
111	36.8	34.4	28.8	34.4	32.9	-
125	35.3	36.7	34.7	33.7	38.0	-
139	39.0	38.5	35.5	35.7	42.2	34.4
153	36.5	38.4	32.2	35.3	43.7	30.3
167	33.0	40.0	18.0	39.5	47.4	33.0
181	39.2	42.5	15.5	39.3	47.8	29.2
195	41.9	44.9	14.5	40.2	46.8	26.5
209	42.4	45.6	16.3	41.5	48.2	22.8
223	50.4	49.3	16.1	44.0	52.4	25.4

while *in vitro* true dry matter digestibility of leaf of "E6250" was also negatively correlated ($P < 0.05$) with maturity. *In vitro* true dry matter digestibility of head showed insignificant increase with advancing maturity for both varieties. In grain sorghum variety "E1291", *in vitro* true dry matter digestibility declined from 74.1 to 44.5 percent in leaf, from 80.7 to 51.6 percent in stem and increased from 68.3 to 82.6 percent in head (Table 15). In forage sorghum variety "E6250", *in vitro* true dry matter digestibility of leaf decreased from 81.9 to 63.7, that of stem declined from 67.3 to 48.5 percent, while that of head increased from 71.2 to 72.7 percent. Marked influence of maturity on *in vitro* dry matter digestibility was observed in leaf and stem of grain variety "E1291" and could be best expressed by two equations: $Y = 112.2 - 0.2930X$, ($r = -0.97$) for change in leaf; and $Y = 109.92 - 0.2742\,X$, ($r = -0.96$) for change in stem respectively, where, Y is percent *in vitro* true dry matter digestibility and X is maturity (days post-sowing) (Table 16). In forage sorghum variety "E6250", *in vitro* true dry matter digestibility was more affected in the stem and could best be expressed by an equation: $Y = 104.32 - 0.2595X$, ($r = -0.87$), where Y is percent *in vitro* true dry matter digestibility and X is maturity (days post-sowing). These observations were in agreement with those of Aii (1976) and Hanna, Monson and Burton (1977) who reported that *in vitro* digestibility of sorghum stem decreased sharply, while that of leaf varied little during growth. Danley and Vetter (1973) found a significant decrease of in vitro dry matter digestibility of two forage sorghum varieties with advancing maturity, while Kuhlman and Owen (1962) and Owen (1967) reported that a forage sorghum "Atlas" decreased in digestibility when grain sorghum "RS610" was equally well digested with advancing maturity from milk to hard-seed stage. Owen (1967) commented on the more adverse effect of maturity on digestibility of low-grain (forage) sorghum as compared to that of grain-types, explaining that rapid accummulation of highly digestible starch with maturation within the high-grain sorghum varieties more than compensated for the decline in fiber digestion, especially that of cellulose.

The relationship between total ash, ether-extract, total silica, soluble silica, cellulose, hemicellulose, permanganate lignin and gross-energy content of leaf, stem and head of the two sorghum varieties with stage of maturity are given by the regression equations in Appendix A, Tables A1 and A2.

Table 14: Cell-wall digestibility of leaf, stem and head of grain sorghum "E1291" and forage sorghum "E6250" at different stage of maturity

Days post-sowing	% cell-wall digestibility					
	High-grain sorghum variety "E1291"			Forage sorghum variety "E6250"		
	Leaf	Stem	Head	Leaf	Stem	Head
111	60.4	62.6	45.1	67.8	52.3	-
125	64.4	41.1	39.3	67.9	59.6	-
139	43.0	50.6	25.4	58.2	53.3	56.2
153	49.5	16.2	42.0	53.2	57.8	56.3
167	43.5	35.9	35.0	51.4	53.6	51.8
181	38.6	40.1	31.4	23.7	33.7	33.3
195	18.1	40.7	16.2	26.3	34.1	53.1
209	10.5	30.0	16.1	46.0	34.5	39.8
223	13.4	30.3	21.4	29.3	21.0	31.3

Table 15: *In vitro* true dry matter digestibility of leaf, stem and head of grain sorghum "E1291" and forage sorghum "E6250" at different stages of maturity

Days post-sowing	% in vitro true DM digestibility					
	High-grain sorghum variety "E1291"			Forage sorghum variety "E6250"		
	Leaf	Stem	Head	Leaf	Stem	Head
111	74.1	80.7	68.3	81.9	67.9	-
125	80.0	76.5	73.0	82.6	77.5	-
139	71.3	72.8	65.2	74.4	72.0	71.2
153	72.0	66.9	66.2	72.8	73.7	71.2
167	64.5	61.6	77.2	66.3	55.1	64.4
181	57.2	55.6	75.4	53.7	52.0	66.3
195	56.1	62.0	65.7	68.8	52.7	75.8
209	46.4	49.5	72.2	67.5	50.0	71.0
223	44.5	51.6	82.6	63.7	48.5	72.7

Table 16: Linear regression equations of % chemical components and in vitro true dry matter digestibility on maturity (days post-sowing) for leaf, stem and head of grain sorghum "E1291" and forage sorghum "E6250"

Quality Parameter	Plant part	Grain sorghum "E1291" Linear Equation	r-value	Forage sorghum "E6250" Linear Equation	r-value
Crude Protein	leaf	Y = 27.17 - 0.0819X[1]	-0.94**	Y = 29.57 - 0.0908X	-0.98**
	stem	Y = 14.30 - 0.0476X	-0.88**	Y = 33.08 - 0.1470X	-0.91**
	head	Y = 17.64 - 0.0349X	-0.61	Y =-0.1284 + 0.0571X	0.65
CWC[2]	leaf	Y = 56.38 + 0.0162X	0.16	Y = 48.84 + 0.0624X	0.82**
	stem	Y = 33.87 + 0.1477X	0.91**	Y = 36.38 + 0.1517X	0.93**
	head	Y = 108.08 - 0.3709X	-0.89**	Y = 90.56 -0.2036X	-0.93**
ADF	leaf	Y = 24.33 + 0.0914X	0.74*	Y = 23.31 + 0.0890X	0.96**
	stem	Y = 20.63 + 0.1229X	0.98**	Y = 20.14 + 0.1451X	0.94**
	head	Y = 56.27 - 0.1958X	-0.83**	Y = 51.19 - 0.1237X	- 0.90**
Cell-wall Digestibility	leaf	Y = 112.88 - 0.4548X	-0.95**	Y = 109.34 - 0.3726X	-0.84**
	stem	Y = 70.10 - 0.1886X	-0.55	Y = 96.72 - 0.3131X	-0.88**
	head	Y = 68.81 - 0.2310X	-0.81**	Y = 95.10 - 0.2714X	-0.75*
IVDMD	leaf	Y = 112.0 - 0.2931X	-0.97**	Y = 99.70 - 0.1767X	-0.75*
	stem	Y = 109.92 - 0.2742X	-0.96**	Y = 104.32 -0.2595X	-0.87**
	head	Y = 59.34 + 0.0750X	0.49	Y = 63.21 + 0.0395X	0.31

[1] Y = % quality parameter; X = maturity (days post-sowing, between the 111th and 223rd day)

[2] CWC = cell-wall constituents; ADF = acid-detergent fiber; IVDMD = *in vitro* true dry matter digestibility.

*Significant at $P < 0.05$

** " " $P < 0.01$

CONCLUSIONS

Within the limits of the experimental conditions and procedures employed, the results of this study lead to the following conclusions:

Experiment I

Significant differences existed among the nine sorghum varieties studied with respect to levels of crude protein cell-wall constituents, acid-detergent fiber, cellulose, hemicellulose, permanganate lignin and *in vitro* dry matter digestibility. There were significant variations in chemical composition, gross energy content and *in vitro* dry matter digestibility of leaf, stem and head of the sorghum varieties. Location had a significant influence on nutritive value of sorghum varieties with regard to cell-wall constituents, acid-detergent fiber, permanganate lignin and *in vitro* dry matter digestibility. Grain content of the nine sorghum varieties studied was not related to either crude protein content or *in vitro* dry matter digestibility. *In vitro* dry matter digestibility was negatively correlated with cell-wall constituents, acid-detergent fiber and cellulose content.

Experiment II

Crude protein content decreased significantly in the leaf and stem of both grain and forage sorghum varieties with advancing stage of maturity. In the grain variety

"E1291", cell-wall constituents, acid-detergent fiber and cellulose content increased significantly in the stem, but decreased in the head. Permanganate lignin also increased in the stem. In vitro dry matter digestibility declined significantly in leaf and stem of the grain variety with advancing stage of maturity. In the forage variety "E6250", cell-wall constituents and acid-detergent fiber content significantly increased in stem and leaf; and decreased in the head with advancing stage of maturity. Permanganate lignin significantly increased in the stem and head, whereas in vitro dry matter digestibility of leaf and stem of the forage sorghum variety decreased significantly with advancing stage of maturity.

SCOPE OF FURTHER STUDY

Further study on the nutritive value of sorghum varieties available locally in Kenya should be carried out using the following guidelines:

1. Determination of tannin levels of sorghum varieties and the relation of tannin content to digestibility.
2. Levels of hydrogen cyanide of the different varieties of sorghum and its effect on animal performance.
3. Comparative studies between maize and sorghum silages as sources of roughage for:
   (i) growing and finishing beef steers and
   (ii) lactating dairy cows.
4. Performance of poultry and pigs on diets based on sorghum grain of different sorghum varieties.

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Appendix A

Table A1: Simple regression equations and r-values calculated for % total ash, ether-extract, total and soluble silica on maturity (days post sowing) for leaf, stem and head of grain sorghum "E1291" and forage sorghum "E6250"

Quality Parameters	Plant part	Grain sorghum "E1291"		Forage sorghum "E6250"	
		Linear equation	r-value	Linear equation	r-value
Total ash	leaf	[1]Y = 8.07 + 0.0517X	0.95**	Y = 17.20 - 0.0224X	-0.69*
	stem	Y = 8.82 - 0.0062X	-0.25	Y = 28.89 - 0.0899X	-0.91**
	head	Y = 10.46 - 0.0393X	-0.93**	Y = 7.97 - 0.0140X	-0.55
Ether extract	leaf	Y = 6.67 - 0.0090X	-0.21	Y = 10.65 - 0.0286X	-0.70*
	stem	Y = 4.92 - 0.0087X	-0.29	Y = 6.71 - 0.02136X	-0.66*
	head	Y = 6.96 - 0.0150X	-0.25	Y = 5.39 - 0.0020X	-0.05
Total silica	leaf	Y = 1.75 + 0.0756	0.93**	Y = 4.46 + 0.0168X	0.55
	stem	Y =0.53 + 0.0115X	0.73*	Y = 4.07 - 0.0100X	-0.71*
	head	Y =3.23 - 0.0095X	-0.55	Y = 3.82 - 0.0082X	-0.45
Soluble silica	leaf	Y = 1.37 + 0.0194X	0.66*	Y = 0.33 + 0.0104X	0.42
	stem	Y = 1.20 + 0.0126X	0.88**	Y = 1.07 - 0.0002X	-0.02
	head	Y = 0.05 + 0.0013X	0.28	Y = 1.40 - 0.0056X	-0.58

[1]Y = % quality parameter; X = maturity (days post sowing)

* Significant at P< 0.05
** " " P< 0.01

Table A2. Simple regression equations and r-values calculated for % fiber components and gross energy (Kcal/g) on maturity (days post sowing) for leaf, stem and head of grain sorghum "E1291" and and forage sorghum "E6250"

Quality Parameter	Plant part	Grain sorghum "E1291"		Forage sorghum "E6250"	
		linear equation	r-value	Linear equation	r-value
Cellulose	leaf	[1]Y = 20.65 - 0.0417X	-0.33	Y = 13.29 + 0.0351	0.58
	stem	Y = 17.65 + 0.0788X	0.98**	Y = 16.91 + 0.0994	0.67*
	head	Y = 44.92 - 0.1650X	-0.83**	Y = 45.96 - 0.1276	-0.57
Hemicellulose	leaf	Y = 32.15 - 0.0758X	-0.70*	Y = 24.51 - 0.0217X	-0.58
	stem	Y = 13.25 + 0.0249X	0.46	Y = 16.18 + 0.0069	0.20
	head	Y = 52.63 - 0.1781X	-0.84**	Y = 51.76 - 0.1561X	-0.77*
Permanganate lignin	leaf	Y = 0.25 + 0.0927X	0.92**	Y = 6.83 + 0.0296X	0.65
	stem	Y = 1.03 + 0.0362X	0.89**	Y = 1.35 + 0.0371X	0.85**
	head	Y = 6.81 - 0.0121X	-0.40	Y = 1.65 + 0.0316X	0.86**
Gross energy	leaf	Y = 3.93 + 0.0006X	0.11	Y 4.70 - 0.0025X	-0.47
	stem	Y = 4.35 - 0.0011X	-0.25	Y = 2.98 + 0.0081X	0.47
	head	Y = 3.62 + 0.0039X	0.42	Y = 4.51 - 0.0005X	-0.17

[1]Y = % quality parameter (or kcal/g, gross energy); X = maturity (days post-sowing)
*Significant at $P < 0.05$
** " " $P < 0.01$