PLANTING SYSTEM AND STAGE OF MATURITY AS FACTORS AFFECTING YIELD AND CHEMICAL COMPOSITION OF ATLAS FORAGE SORGHUM

by

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INTRODUCTION

Forage sorghum is an important crop in the Great Plains. A major reason for their popularity is their yield advantage over corn, especially under drought conditions. Sorghums grown for silage are adapted to a wide range of soil and climatic conditions. Atlas forage sorghum is widely grown because of its sweet juicy stalk and high yield potential.

The nutritive value of sorghum silage may be affected by stage of maturity at harvest, row width, plant population, and other cultural factors. Of major concern in growing sorghums for silage is the stage of maturity at which to harvest. Some farmers believe that forage sorghum should be cut at the early dough stage to obtain maximum livestock utilization. Others feel that harvest should be delayed to increase dry matter, protein, and carbohydrate yields. Still others suggest that although harvesting at a more mature stage will increase dry matter yield, the digestibility and palatability of the silage may be decreased. The relative levels of protein, carbohydrates, and fiber are major factors affecting digestibility.

Other major factors influencing yield in forage sorghum are plant population and row width. Most ensilage harvesting machinery has been designed to operate in 30- to 40-inch rows. Recently, interest has been shown in producing sorghum for silage in narrow rows. In some areas, 20-inch rows and solid stands in 8 or 10-inch rows are becoming popular. Drilled sorghum does not require cultivation and may have an advantage over 40-inch rows under certain conditions, but yield may be reduced under drought conditions due to a much higher population density. Although sorghum does adjust for population differences, more information is needed on the effect of plant population on the yield components of forage sorghum.

This investigation was undertaken to determine the trends in accumulation of protein, fiber, carbohydrates, and dry matter, and their relation to row width, plant population, and stage of maturity of forage sorghum.

REVIEW OF LITERATURE

Results of feeding trials indicate that sorghum silage is inferior to corn silage in several nutrient components (25,27,29,39). Most sorghum silages are lower than corn in crude and digestible protein and in total digestible nutrients (18,31,39). However, the silage yield per acre is often considerably higher from forage sorghum than from corn especially under drought conditions (18,22,27). Sorghums are of more value in regions of uncertain rainfall because they resist wilting and can remain practically dormant during periods of drought and resume growth when moisture becomes available (18). The increased dry matter yield from forage sorghum often more than offsets its lower nutritive value.

Many investigators have demonstrated a consistent and rapid decrease in protein percentage in young forage sorghum plants from the seedling to the heading stage (5,47,49,51,52). Webster et al. (51) have shown that protein contributes one-sixth to one-fifth of the dry weight of young sorghum plants. Webster and Davies (47) found that protein percentage decreased rapidly from this high level in early stages of growth to about 7% at heading. The protein percentage remains nearly constant or decreases slightly from heading to maturity (5,17,23,24,26,38,39,47,50,54). Protein percentage is high during the early stages of growth because the plant builds up its cellular structure of fiber, protein, and minerals. Protein percentage decreases during later stages of growth as the cellular structure is diluted by carbohydrates (54). Further decrease may occur due to deterioration of the leaves.

Thurman et al. (39) have shown that protein percentage of the leaf blade is 4 times greater than the leaf sheath, about 2 times greater than the heads, and over 6 times greater than the culms. Long (17) indicated that protein percentage was highest in the heads; followed by the leaves and stalks, respectively.

Long (17) found a continuous increase in crude protein yield per acre with advancing maturity. The stalks are low in protein percentage and they tend to control the percent protein found in the silage since they contribute from 45 to 80% of the green weight yields of forage sorghum. Much of the increase in silage yields in good seasons is due to increased stalk weight. Thus, the higher the forage yield, generally the lower the percent protein, but the higher the yield of crude protein in pounds per acre (39). On this basis, Nevens and Kendall (22) suggest delaying harvest until sorghum reaches 25 to 30% dry matter to increase protein yield. However, some results have shown that the protein in the stalks is largely undigestible (31,39). Thurman et al. (39) pointed out that the digestibility coefficient of protein in the stalks and leaf sheath was only .07, and most of the digestible protein was found in the leaf blades. Removal of the heads did not reduce the protein content or digestibility of the resultant silage (31). The greatest effect of harvest date appears to be a decreased digestibility of protein (30). Several workers have indicated that this is due to the indigestibility of the sorghum seed as a large percentage of mature seed passes through the bovine digestive system intact (24,39,31). Certain sterile forage sorghum hybrids have been shown to be 1 to 2 percentage points higher in protein than Atlas sorgo or Rox (26,53).

Several workers have indicated that Atlas sorgo will accumulate a fairly large amount of non-protein nitrogen (10 to 15% of the total nitrogen) (38,50, 54). This is present primarily as amides and alpha-amino acids and perhaps as nitrate.

The percent of crude protein is not significantly affected by frost (1,9). Studies by Webster and Davies (47) have shown that protein content is lower in wet years than in dry years. As leaf growth is relatively constant under most conditions (39), the protein percentage would increase in dry years due to a decrease in stalk growth. This would probably account for the increase in protein shown by Webster and Davies (47).

Most studies have indicated that fiber accumulation is more variable than protein accumulation in sorghum. In contrast to most grasses, forage sorghum generally decreases in fiber percentage with maturity (5,17,23,24,26,41). This decrease occurs at about the same rate as the increase in soluble carbohydrates (54). Investigations by Webster and Davies (47) indicate that although crude fiber percentage generally decreases, there is a brief period of increase culminating about the time of heading. This study indicated that fiber reaches a minimum percentage about the time of grain maturation with a slight but consistent increase until frost; after which there is a sharp increase due to weathering of the more soluble fractions of the plant (9,47).

Although fiber percentage decreases in the plant, there is an increase in fiber accumulation per culm (41) and per acre (17) as the season progresses. Long (17) indicated that high populations produced the greatest amount of fiber per acre while low populations made the greatest relative increase in fiber yield per plant. Leaves were highest in fiber, followed by the culms and heads respectively. This accounts for the higher crude fiber percentage found in silages made from sterile hybrids (26).

Digestibility of cellulose and fiber decreases with maturity (30,38). Fiber and cellulose were found to be fairly digestible at early stages before they became highly lignified (38). Sullivan (38) reported significant negative correlations of -.65 between fiber content and digestibility of dry matter at maturity and -.90 between lignin and dry matter digestibility.

Researchers have shown that total solids in sorghum decrease from an initial high point when the plants are small and then increase as heading is approached (44,45,48,52). As the plant advances toward maturity, total sugars make up a greater proportion of total solids (45). Several studies have indicated that nitrogen free extract (which is positively correlated with carbohydrates) increases rapidly prior to heading and then somewhat slower thereafter (26,47,51,54). As maturity progresses, total sugar percent increases consistently, particularly until the grain matures; a greater increase occurring between the dough and dead ripe stage than between the milk and dough stages (14,24,41,45,48,49,52).

The content of reducing sugars is highest in the immature stages and decreases with maturity (34,41,45,46,48). Webster and Heller (49) reported an increase in reducing sugars until heading when they began to decrease. Glucose exceeds fructose at all stages of maturity (6,45). Generally, nonreducing sugars (primarily sucrose) increase greatly with advancing maturity until they exceed the amount of reducing sugars present in the plant at a mature stage (14,34,44,45,46,48,49,54). Very little sucrose is ever present in sorgos until after heading (49,52). Atlas is an exception to most forage sorghums because the sucrose concentration does not increase rapidly after heading, and total accumulation is not as great as in most sorgos (52).

Starch content of forage sorghum plants increases after heading and continues to increase until frost (17,24,46). Researchers have found the starch content of sorghum juice to vary from .4 to 1.8% at harvest; with from 14 to 21% starch in the leaves and from 65 to 70% in the heads (16,34). The decrease in reducing sugars after heading is due to a conversion to non-reducing sugars and starch, and to use in metabolic activities (34,41). Long (17) reported the leaves to be highest in total sugars, while the heads were much higher in acid hydrolyzable carbohydrates than the culms and leaves, and in his study, highest yields of carbohydrates were obtained from the high population densities.

After heading, but prior to physiological maturity of the grain, the products of photosynthesis are translocated to the developing seed and are deposited as starch (41,54). After physiological maturity, the photosynthate is stored in the culm primarily as sucrose and secondarily as crude fiber (41). Thus forage sorghums will accumulate carbohydrates until frost. After frost, the percentage of sucrose in the plant decreases with a corresponding increase in glucose concentration (1,10).

Daily variations in sugar percentages occur within the plant. Total sugar increases throughout the day until noon to 3 p.m. when they decrease rapidly until 9 to 10 p.m. Non-reducing sugars make up the greatest percentage of this increase as reducing sugars show little change throughout the day (20,49). Again the increase in sucrose is not as great in Atlas as it is in other sorgos. Sucrose apparently is not an active metabolic form of sugar in this variety (49). The composition of carbohydrate fractions in the plant does not change much during the process of ensiling (19).

The proximate analysis of sorghum changes after heading due to an increase in dry matter (51). The highest yield of green weight is obtained when the sorghum is harvested with the grain in the dough stage (24). However, most investigators have shown an increase in dry matter accumulation until frost (17,24,47). Owen (24) reported a 93% increase in dry matter from bloom to a very mature stage. Thus from the standpoint of dry matter yield, the highest yields can be obtained by delaying harvest until the grain is mature. Long (17) reported that high plant populations produced significantly higher dry matter yields. However, in a one-year study, Stickler and Laude (36) failed to show any effect of population on yield.

Several studies have indicated that narrow row spacing will result in increased forage yields (7,33,35,37). However, in drilled rows, lodging tends to increase with decreased spacing (7,18,37,55). Sullivan (37) and Martin (18) have stated that drilled rows resulted in decreased diameter of culms, reduced leaf size, plant height, and grain yield per plant, and increased fiber content. No cultivation was necessary in their drilled forage sorghum.

Long (17) reported that the culm contributed about 50% of the final dry matter yield, the leaves about 20%, and the heads about 30%. The culm increased in its contribution to dry weight until 15 days after bloom, when further increase in dry weight was due to filling of the head. After physiological maturity of the grain, the culm again increased in dry weight due to an accumulation of sugars (41).

The time of maximum forage yield varies with the season, but Webster and Davies (47) suggest that the hard dough stage is probably the best time to harvest. According to Ramsey _et al_. (30) sorghum should be harvested when the grain in the upper one-third of the head begins to turn to the mature grain color as cellulose and protein are more digestible at the earlier stages of growth. Other studies have shown that although early harvest increases the quality and digestibility of the silage, the amount of nutrients produced and the value of silage per acre is reduced by early harvest (11,13,15,18,23,24, 39). The higher quality of sorghum silage from the younger stages is more than offset by increased yield of silage if harvested at later stages of maturity. The decrease in digestibility of the mature stages is attributed to the hardness of the seed (24,30).

Delayed harvest also saves the cost of handling the additional water which is present in immature silages, reduces fermentation losses, seepage losses, and acid formation, and increases the dry matter per pound of silage (23,24). Gore and McCullough (12) reported that 48% of the variation in dry matter intake from silages was accounted for by differences in crude fiber and silage dry matter content. These factors are nearly equal in magnitude, but opposite in effect.

The daily variation in dry matter content of the plant tends to follow the pattern of variation for total sugars. Dry matter percentage increases during the morning, reaches a maximum between 2 and 6 p.m. and decreases until daylight (20,21).

Drought has an interesting effect on the carbohydrate balance in the plant. Carbohydrates are often considered important as defense substances to protect the protoplasm from increasing osmotic pressure (43). Vassiliev and Vassiliev (43) have found that during initial periods of water loss, total sugars increased due to an increase in both reducing and non-reducing sugars. As stress continued, sucrose decreased in concentration and monosaccharides and hemicelluloses continued to increase, with a net loss in total carbohydrates.

When the plants were irrigated after stress, a decided reduction in monosaccharides occurred while a slower decrease in sucrose continued. The reduction in monosaccharides was a fixed effect while the concentration of sucrose and hemicellulose tended to recover upon irrigation after stress.

EXPERIMENTAL PROCEDURE

1962 Experiment

Atlas forage sorghum was planted June 10, 1962, at the Kansas State University Agronomy Farm (Manhattan). The soil was an unnamed, alluvial silt loam. The field was fall plowed and 240 pounds of ammonium nitrate (80 pounds of N) per acre were broadcast and worked in before planting.

The seed was thickly planted with a hand planter in 20- and 40-inch rows. Four rows spaced 40 inches apart or 8 rows spaced 20 inches apart, 22 feet in length constituted a plot. When the plants were from 3 to 5 inches tall, the plots were thinned to the desired stands of 60, 240, and 480 square inches per plant within each row width. These spacings correspond to 104,500; 26,100; and 13,100 plants per acre respectively, and were designated as high, medium, and low populations. The 6 treatments were grown in a randomized block design with 4 replications. All cultivation for weed control was done by hand.

In general, the season was favorable for plant growth as 24.66 inches of precipitation fell during the growing season (May 1 to October 31). Only 16.53 inches of this total fell after the sorghum was planted, but this was fairly well distributed throughout the growing season.

Sampling was begun when the plants reached full bloom on August 15, 66 days after planting, and was continued at 10 to 16 day intervals until frost. The harvest dates represented advancing stages of maturity of the grain from bloom to a very mature stage. The sorghum grain reached physiological maturity between the fourth and fifth harvest dates. The last harvest date on October 26 was taken after the first killing frost on October 25.

On each harvest date a sample was obtained by harvesting 4 feet of 1 row in the 40-inch row width plots or 4 feet of each of 2 rows in the 20-inch row width plots. Samples were taken from rows which did not border an adjacent plot. Several plants were always left in the row between successive harvest dates to provide normal competition among the remaining plants. The samples were weighed and the culms were counted. The samples were chopped using an experimental forage chopper.

A sub-sample was taken from each samples after chopping and mixing. Sub-samples were taken to the laboratory, weighed, and autoclaved for 10 minutes at 10 pounds pressure to stop enzymatic activity. The sub-samples were dried for 1 week at 70°C and weighed to obtain dry weight. The samples were then ground in a Christy-Norris mill. In order to reduce the number of samples for chemical analysis, equal amounts of ground plant material from replications I and III and from II and IV were composited. A sample was taken from each plot after frost and divided into leaves (both blade and sheath), culms, and heads to determine percentage composition.

Reducing sugars, total sugars, and acid hydrolyzable carbohydrates were determined by the method outlined by Kersting et al. (16) with some modifications (4,8). Non-reducing sugars were determined by differences between total and reducing sugars. Total carbohydrates were obtained by taking the sum of total sugars and acid hydrolyzable carbohydrates. Protein content was determined by the boric acid modification of the Gunning-Kjeldahl method (2,3,32). Crude fiber was determined by the Kansas State University Chemical Service

Laboratory. All determinations were based on the oven dry weight of the plant material. All statistical analyses were made using procedures outlined by Snedecor (35). Data were expressed on the basis of pounds per acre, percent of dry weight, milligrams per gram dry weight, and grams per plant.

1963 Experiment

In 1963, Atlas forage sorghum was grown under 2 different management systems, a standard 40-inch row width and a drilled system using 10-inch rows. The test was planted on June 4, 1963, at the Kansas State University Agronomy Farm (Manhattan) on an unnamed, alluvial, silt loam soil. The field was fall plowed and 80 pounds of nitrogen (240 pounds of ammonium nitrate) per acre were broadcast and worked in before planting.

The 40-inch rows were thickly planted with a hand planter and later thinned to 4 inches between plants. This represented a population of about 39,000 plants per acre. The 10-inch rows were thickly planted with about 10 plants per linear foot of row. This spacing represented approximately 523,000 plants per acre. Four, 40-inch rows and ten, 10-inch rows, 22 feet in length constituted a plot.

The season was relatively dry with only 11.88 inches of precipitation falling during the growing season (May 1 to October 31). However, the sorghum made good growth and yields were fairly high presumably because of favorable subsoil moisture reserves. Weed control was obtained with a pre-emergence application mixture of 2 parts of Propazine and 1 part of Atrazine applied at the rate of about 3 pounds per acre.

The experimental design was a split-plot replicated 4 times. Management systems constituted main plots and harvest dates were sub-plots.

Sampling was begun August 16, at about 3/4 to full bloom. This was 73 days after planting. Sampling was continued at 2-week intervals until frost. The last sample was taken 5 days before the first killing frost of the year. The grain in the 2 systems matured at about the same rate and reached physiological maturity between the third and fourth harvest dates. On each harvest date, the 2 center rows of the 40-inch plots and the 4 center rows from the 10-inch plots were cut about 1 inch above the ground. Fresh weight of the forage was obtained in the field. A sub-sample was taken from each plot and was chopped and weighed. The samples were then dried for 1 week at 65°C and re-weighed to obtain dry weight. Samples were mixed and then ground in a Christy-Norris mill. A smaller sample was taken from the ground plant material for chemical analysis. Data were expressed on the basis of pounds per acre, percent of dry weight, and milligrams per gram dry weight. A sample was taken after frost from each system and divided into leaves, culms, and heads to determine percentage composition.

Further procedures of analysis were identical to those used in the 1962 experiment.

RESULTS AND DISCUSSION

Dry Matter

1962 Experiment. Accumulation of dry matter per plant following anthesis is shown in Fig. 1 and appendix Table 1. During the sampling period, there was a consistent increase in dry matter per plant in all populations. Lowest plant weight was found at the high population. The medium population had more dry matter per plant than the high population. The greatest increase in

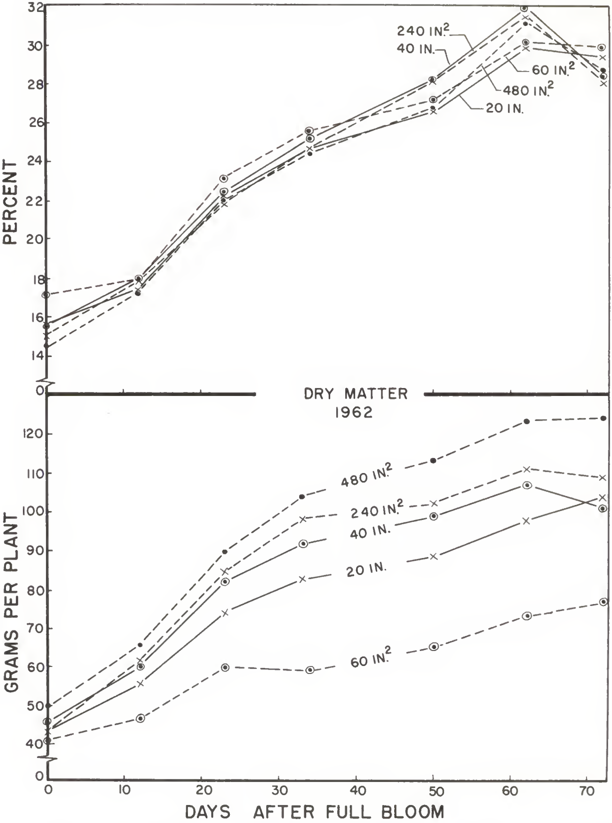

Fig. 1. Dry matter percentage and yield per plant in 1962.

dry matter per plant during the sampling period was observed in the low population. This accounts for the highly significant[1] differences among populations.

The relative rate of increase in dry matter per plant was much greater at the medium and low populations than at the high population. The greatest rate of increase was observed at the low population. This resulted in a highly significant population x date interaction.

The 40-inch row width accumulated significantly more dry matter per plant than the 20-inch row width. A significant (10% level) row width x population interaction was observed and was due primarily to the relatively greater increase in dry matter accumulation by the low population in the 20-inch rows than in the 40-inch rows. Highly significant differences were found in dry matter accumulation among dates presumably because of continued photosynthesis until frost.

Figure 1 and appendix Table 2 present information on dry matter percentage. Dry matter percentage increase was highly significant among harvest dates with a significant decrease occurring at the last harvest date, which was taken after frost. A significant difference was observed among populations, due primarily to the higher dry matter percentage in the high population. The medium population was intermediate and the low population was lowest in dry matter percentage. The 40-inch rows were significantly higher in percent dry matter than the 20-inch rows. A sharp decrease in dry matter percentage was observed at the last harvest date. The cause of this decrease was not determined. The significant (10% level) date x row width interaction was attributed

[1]In reporting the results "significant" and "highly significant" refer to statistical significance at the 5% and 1% levels, respectively.

to a slightly faster rate of increase in dry matter percentage in the 40-inch than in the 20-inch rows during the later stages of growth and to a greater decrease in dry matter in the 40-inch rows after frost.

The increase in dry matter yield per acre was highly significant during the sampling period. Data are shown in Fig. 2 and appendix Table 3. Highly significant differences were found among populations, due primarily to a greater yield of dry matter at the high population than at the medium and low populations.

A significant difference was observed between row widths. The 20-inch rows produced significantly more dry matter per acre during the early part of the growing season, but decreased the seventh week after bloom. At this harvest date, the 40-inch rows had more dry matter per acre, but the 20-inch rows again had more than the 40-inch rows at the final harvest date.

From these data it would appear that forage sorghum will continue to increase in dry matter until frost stops growth. It was found that although the low population produced the greatest relative increase in dry matter per culm, the high population produced the greatest yield of dry matter per acre. Thus, the greater relative increase in stalk size could not offset the effect of low population. Based on these data, maximum dry weight yields are obtained by planting forage sorghum at high populations and by delaying harvest until the grain is mature.

1963 Experiment. Information on dry matter percentage is found in Fig. 3 and appendix Table 4. In this experiment, 2 management systems were used: one was a conventional row system (40-inch rows), and the other was a drilled system (10-inch row width). Dry matter percentage increase was highly significant over the sampling period with a highly significant decrease occurring at the

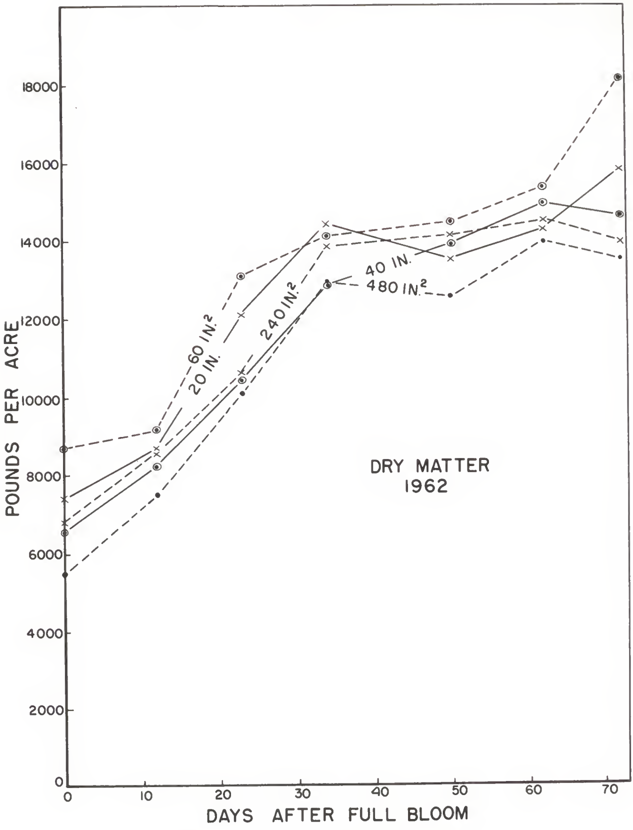

Fig. 2. Dry matter yield per acre in 1962.

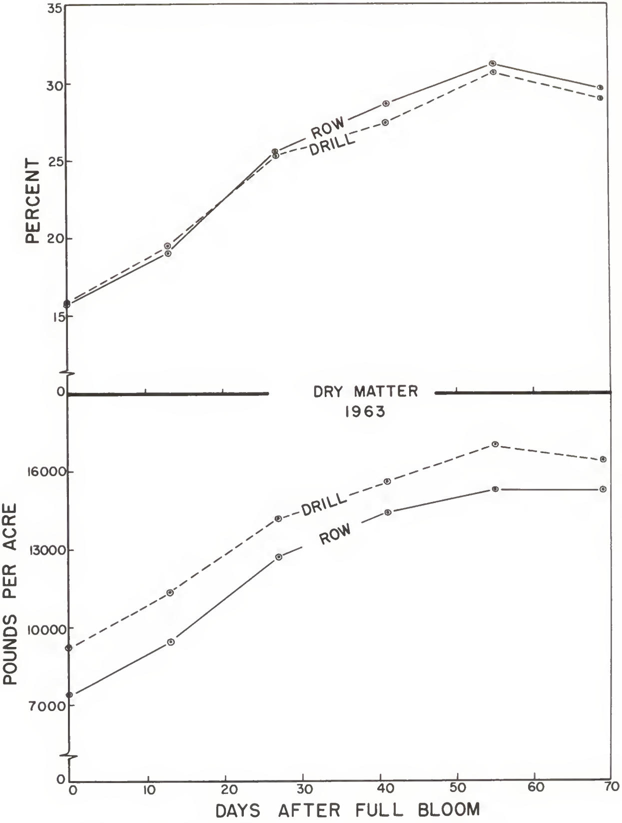

Fig. 3. Dry matter percentage and yield per acre in 1963.

last harvest date. Most of the difference was explained by a linear function, however, the quadratic, cubic, and quintic functions also contributed a significant amount of the date mean square. No significant differences were found between the two systems (drill versus row).

Figure 3 and appendix Table 5 contain data on dry matter accumulation in pounds per acre for 1963. Dry matter per acre increased significantly (1% level) over the sampling period. A slight decrease was observed at the last harvest date. The drill system produced significantly more dry matter per acre than the 40-inch row system. Most of the increase in dry matter yield among harvest dates was linear. However, the quadratic function was also significant, due to a decrease in dry matter at the last harvest date.

Protein

<u>1962 Experiment</u>. The protein percentages per plant are presented in Fig. 4 and appendix Table 6. Protein percentage decreased sharply after bloom, with the relative rate of decrease becoming less as the season progressed. After the sixth week following bloom, little change occurred in protein percentage. Thus most of the highly significant difference among populations was due to the rapid decrease in protein percentage in the first 6 weeks after bloom.

The low population was highest in protein percentage, although not significantly higher than the medium population. The high population was significantly lower (1% level) than the medium and high populations. All populations decreased in protein at approximately the same rate throughout the sampling period. No observable difference occurred between row widths.

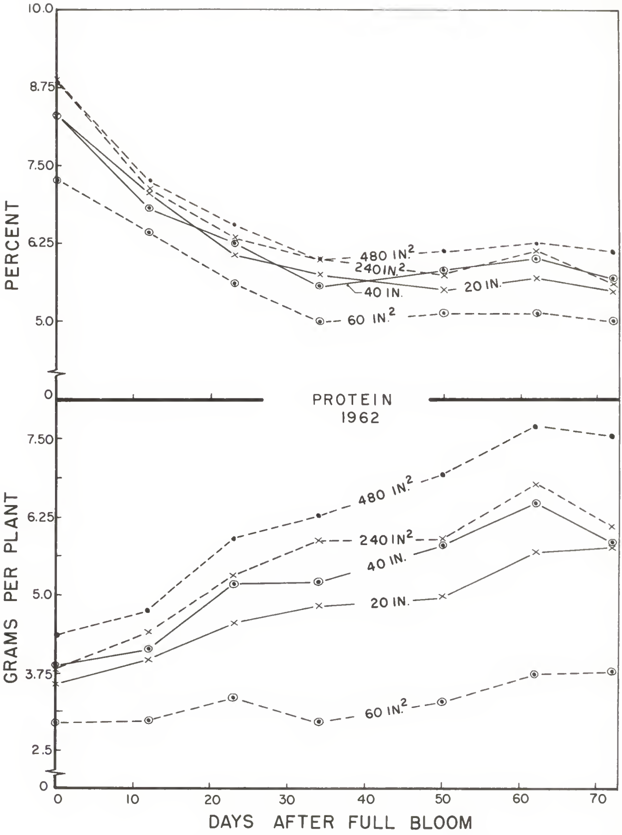

Fig. 4. Protein percentage and yield per plant in 1962.

Data for the accumulation of protein in grams per plant are presented in Fig. 4 and appendix Table 7. A highly significant difference was observed among harvest dates. Protein per plant increased consistently over the sampling period until the last harvest date when a slight decrease was observed. This decrease may have been due to the action of frost which occurred before the last harvest date.

The low population accumulated the most protein per plant. As expected, the medium population was intermediate and the high population lowest in protein content per plant. These differences accounted for the highly significant differences among populations. The relative rate of increase in protein per plant was much slower at the high population than at the medium and low populations. This resulted in a highly significant population x date interaction.

A highly significant difference was observed between row widths and was due to a greater accumulation of protein in the 40-inch rows than in the 20-inch rows.

These data indicate that although protein percentage decreases as the plant matures, the plant continues to take up nitrogen until frost. Thus, protein yield per acre tends to increase as harvest date is delayed.

1963 Experiment. The data for protein percentage in 1963 are presented in Fig. 5 and appendix Table 8. A sharp decrease was noted during the first 4 weeks after bloom. Protein percentage increased slightly the sixth week, decreased the eighth week, and increased again the tenth week after bloom. The highly significant differences among dates were accounted for primarily by the sharp decrease in protein percentage during the first 4 weeks following bloom. This decrease was primarily explained by the linear component of the

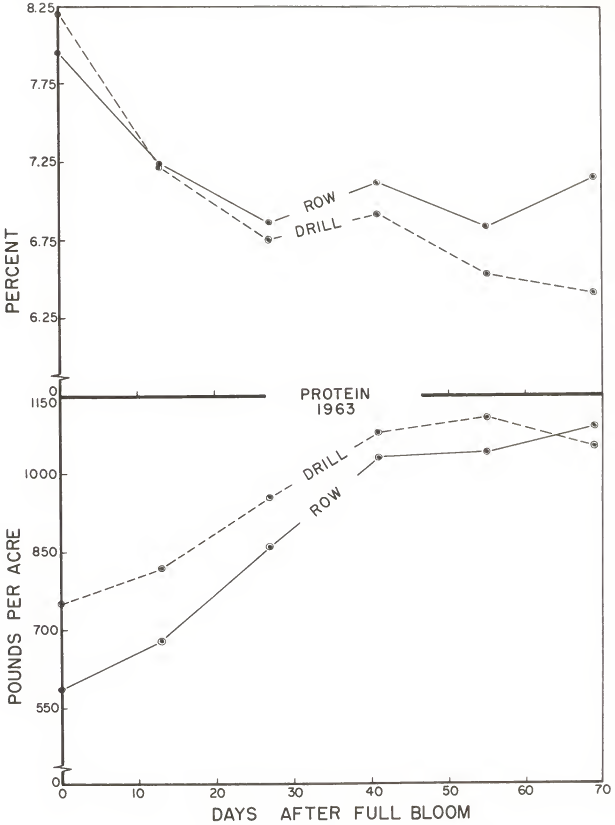

Fig. 5. Protein percentage and yield per acre in 1963.

date sum of squares. The quadratic component also explained a large percentage of the change due to the tendency of protein percentage to level out and increase slightly during the latter part of the sampling period. The cubic component explained a lesser, but significant, part of the effect of harvest dates.

A significant difference was observed between planting systems. The two systems were nearly equal in protein percentage at and immediately after bloom, with the row system remaining significantly higher during the latter part of the sampling period. Both systems decreased rapidly in protein percentage during the first 4 weeks after bloom, increased the sixth week, and decreased again the eighth week. However, at the final harvest date, the drill system continued to decrease while the row system increased in protein percentage.

Figure 5 and appendix Table 9 present data for protein yield per acre, which increased rapidly following anthesis with only minor changes occurring after the sixth week. This increase accounted for the highly significant differences among harvest dates. The effect of harvest dates was explained almost entirely by a linear trend. The quadratic component contributed a smaller percentage of the dates mean squares and was significant at the 10% level.

The drilled system produced a significantly higher (10% level) yield of protein per acre than the row system.

These data indicate that although protein percentage decreases after bloom, protein accumulation per acre continues to increase until frost. Thus, in order to obtain maximum protein yields, harvest should be delayed until the grain is mature.

Crude Fiber

<u>1962 Experiment</u>. Crude fiber percentages as affected by row width, harvest date, and plant population are shown in Fig. 6 and appendix Table 10. The percentage decreased consistently from anthesis until frost. Highly significant differences were found among dates. A sharp decrease in fiber percentage was observed during the first 4 weeks after bloom, followed by a slower decrease during the rest of the sampling period and a slight increase after frost. A highly significant difference was found among populations. The mean fiber content of the high population was significantly higher than that of either the medium or low populations. Crude fiber percentage of plants in the 20-inch rows was significantly higher than in the 40-inch rows. The rate of decrease in fiber percentage with advancing maturity was less in the high population than in the medium or low population; thus, a highly significant population x date interaction was noted.

Data for crude fiber yield per plant are found in Fig. 6 and appendix Table 11. The crude fiber increase per plant was highly significant during the sampling period, indicating that fiber continued to be synthesized by the plant even though fiber percentage decreased. A highly significant difference was found among populations, with the high population accumulating the least fiber per plant. As expected, the medium population was intermediate and the low population highest in fiber per plant. Plants grown in 40-inch rows accumulated significantly more fiber per plant than did plants in 20-inch rows.

<u>1963 Experiment</u>. Data on fiber percentage as affected by management system and harvest date are found in Fig. 7 and appendix Table 12. Crude fiber percentage decreased rapidly following anthesis until 6 weeks after bloom when it began to increase slowly. This resulted in highly significant differences

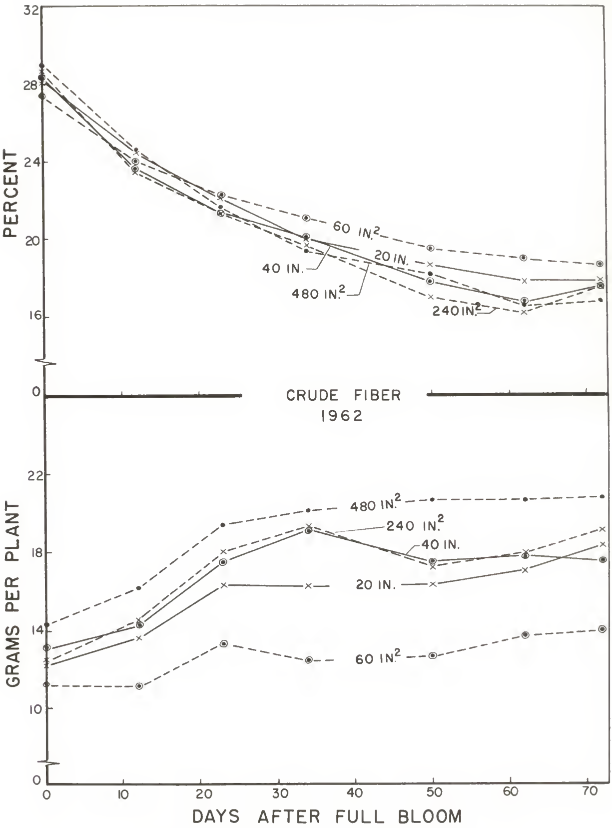

Fig. 6. Crude fiber percentage and yield per plant in 1962.

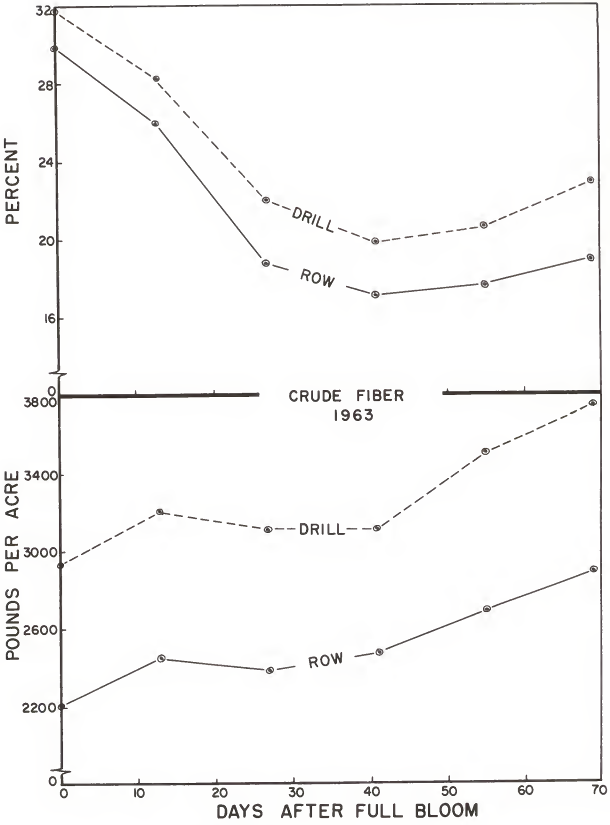

Fig. 7. Crude fiber percentage and yield per acre in 1963.

among harvest dates. The difference was primarily a linear function, but a large percentage of the date sum of squares was also explained by the quadratic component due to the increase in percentage near the end of the sampling period. A highly significant difference between management systems was due to a higher crude fiber percentage in the drill system. Evidently, small culm diameter and lack of parenchyma tissue reduced the accumulation of the more soluble carbohydrates in relation to the amount of fiber.

Data for crude fiber yield per acre are found in Fig. 7 and appendix Table 13. A highly significant increase in fiber yield occurred during the sampling period. The increase was not consistent as a decrease was noted the fourth week after bloom (grain in the soft dough stage). Fiber increased sharply after physiological maturity of the grain and continued to increase through the remainder of the sampling period. The increase in fiber yield was primarily a linear function. However, the quartic and quadratic components were significant at the 10% level. A significantly higher (1% level) yield of crude fiber was produced by the drill system.

These data indicate that although fiber percentage decreases after bloom, fiber yield increases with maturity (as dry matter increases), especially after the grain is mature. This would suggest that an early harvest date would be desirable to obtain maximum digestibility of dry matter.

Carbohydrate Fractions

<u>1962 Experiment</u>. Information on reducing, non-reducing, and total sugars, and acid hydrolyzable carbohydrates is found in Figs. 8 and 9 and appendix Tables 14, 15, 16, and 17. Non-reducing sugars were nearly absent at bloom. They increased rapdily after anthesis and continued to increase until frost,

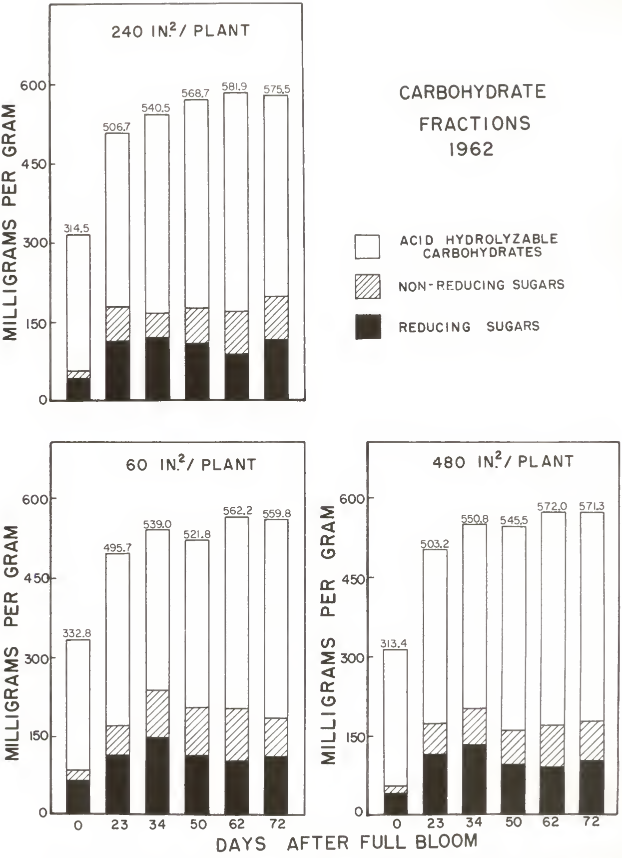

Fig. 8. Contribution of carbohydrate fractions to total carbohydrates as affected by plant population in 1962.

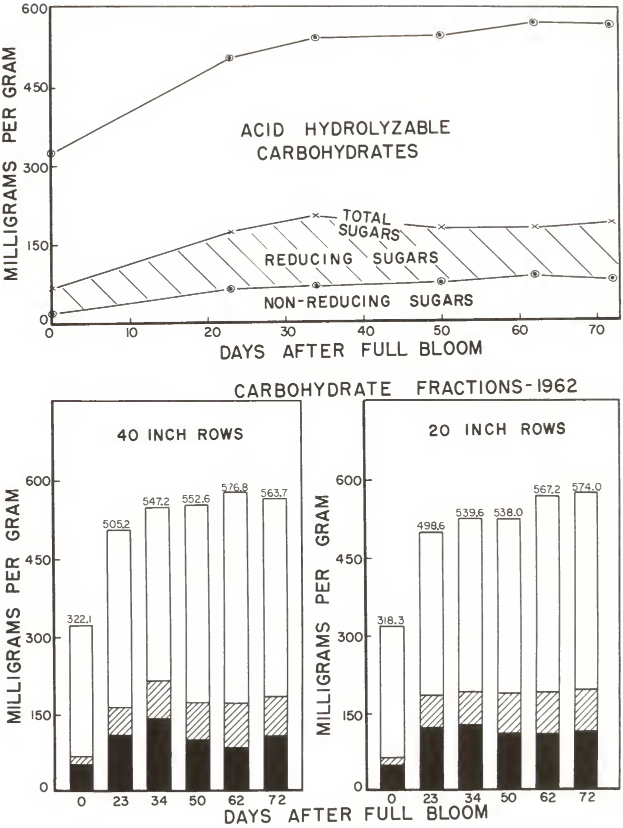

Fig. 9. Contribution of carbohydrate fractions to total carbohydrates as affected by stage of maturity (top) and row width in 1962.

resulting in a highly significant increase during the sampling period. A noticeable, but non-significant, decrease in non-reducing sugars was observed after frost.

Significantly more (1% level) non-reducing sugar was found at the high population than at the medium and low populations. A highly significant population x date interaction was detected. This was due primarily to a decrease in non-reducing sugar at the medium population the fifth week after bloom and a decrease the seventh week after bloom at the low population in contrast to the high population which continued to increase during the entire period.

The increase in reducing sugars was highly significant during the sampling period, with most of the increase occurring during the first 5 weeks after bloom. Reducing sugars decreased after physiological maturity of the grain until frost when a significant increase occurred, corresponding to a similar decrease in non-reducing sugars after frost. A highly significant difference was found among populations, due to a greater amount of reducing sugars at the high population.

Increase in total sugars was highly significant from bloom to physiological maturity of the grain (about 7 weeks after bloom). A significant decrease occurred after physiological maturity with little change during the latter part of the sampling period. Highly significant differences among populations were attributed to a greater amount of the total carbohydrates accumulating as sugars in the high than in the medium and low populations.

A consistent and highly significant increase in acid hydrolyzable carbohydrates was observed during the sampling period. This was due primarily to an increase in the contribution of grain to total dry matter since acid hydrolyzable carbohydrates are the primary form of carbohydrates in the grain. Plants in the high population accumulated significantly less (1% level) acid hydrolyzable carbohydrates than plants in the medium and low populations, because less grain was produced at the high population. The 40-inch rows produced significantly more acid hydrolyzable carbohydrates than the 20-inch rows. The highly significant population x date interaction was explained by a faster rate of increase in acid hydrolyzable carbohydrates in the medium and low populations than in the high population.

1963 Experiment. Information on carbohydrate fractions obtained in 1963 is found in Figs. 10, 11, and 12; and in appendix Tables 18, 19, 20, and 21. Non-reducing sugars contributed only a small part of total carbohydrates at bloom. They increased significantly (1% level) until physiological maturity of the grain (7 weeks after bloom), after which they decreased until the end of the sampling period. The quadratic component accounted for the greatest amount (69.5%) of the date sum of squares, while the linear fraction explained 27.9% of the date effect. The systems did not differ significantly in levels of non-reducing sugars in the plants.

Reducing sugars followed a similar pattern; increasing from bloom to physiological maturity of the grain and then decreasing until the end of the sampling period. Highly significant differences among harvest dates were detected. The differences were explained almost entirely by the quadratic component of date sum of squares. The row system accumulated a significantly greater amount (10% level) of reducing sugars than the drill system.

Total sugars increased from bloom to physiological maturity of the grain and decreased afterwards until the end of the sampling period. The quadratic component explained most of the highly significant differences among dates.

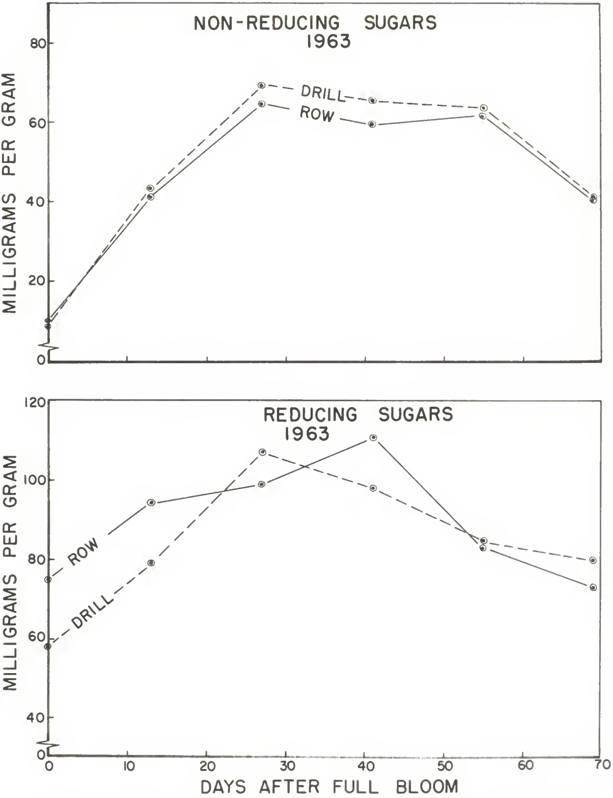

Fig. 10. Concentration of non-reducing and reducing sugars in 1963.

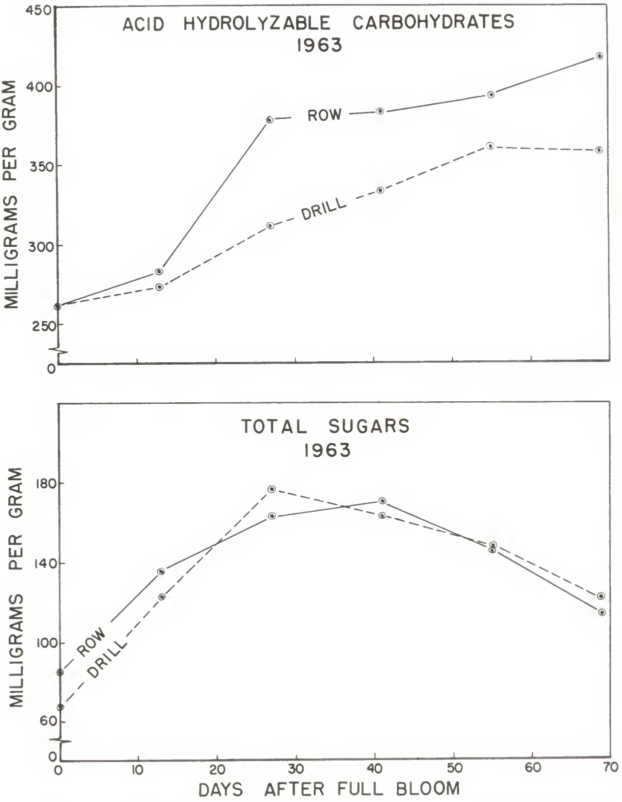

Fig. 11. Concentration of total sugars and acid hydrolyzable carbohydrates in 1963.

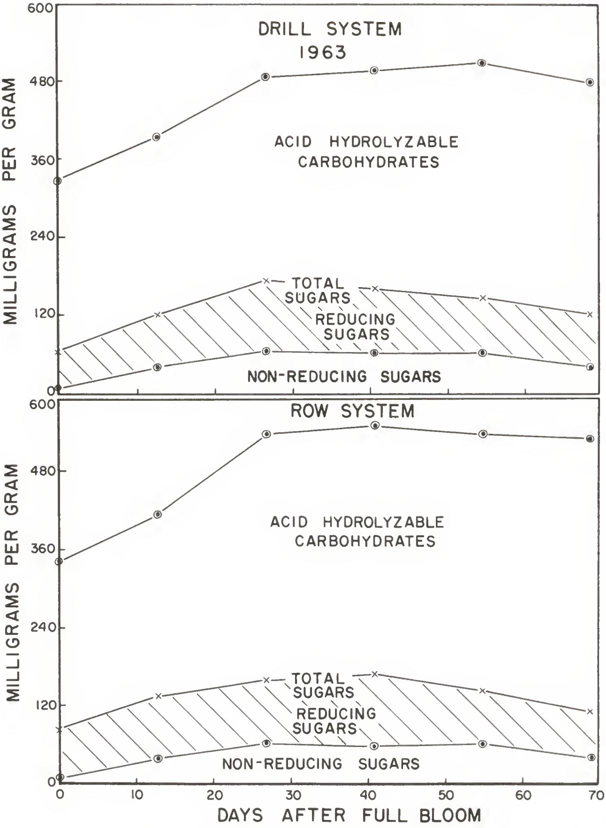

Fig. 12. Contribution of carbohydrate fractions to total carbohydrates in 1963.

The increase in acid hydrolyzable carbohydrates was highly significant following anthesis. The greatest increase occurred in the first 4 weeks following bloom, with less accumulation in the latter part of the sampling period. Most of the increase was explained by the linear component of date sum of squares, although the quadratic, quartic, and quintic components were also significant. Plants in the row system accumulated significantly more (1% level) acid hydrolyzable carbohydrates than plants in the drill system. The highly significant dates x systems interaction was attributed to a greater rate of increase in acid hydrolyzable carbohydrates in the row system than in the drill system. Plants in the row system produced more grain (which is about 70% acid hydrolyzable carbohydrates) than did plants in the drill system.

Total Carbohydrates

<u>1962 Experiment</u>. The sum of acid hydrolyzable carbohydrates and total sugars is referred to as total carbohydrates. Data for total carbohydrates concentration is found in Fig. 13 and appendix Table 22. The increase in total carbohydrate concentration was highly significant over the sampling period. Accumulation of carbohydrates continued until frost. Significant differences among populations or between row width means were not found.

The amount of carbohydrates per plant (Fig. 13 and appendix Table 23) varied significantly (1% level) among harvest dates. A highly significant difference was found among populations. As expected, the high population had the lowest yield and the low population the highest yield of carbohydrates per plant. Plants in 40-inch rows accumulated significantly more (1% level) carbohydrates than those in 20-inch rows. The highly significant population x date interaction was explained by a gre[illegible]lative rate of increase in carbohydrates by plants at the medium and low population than at the high population.

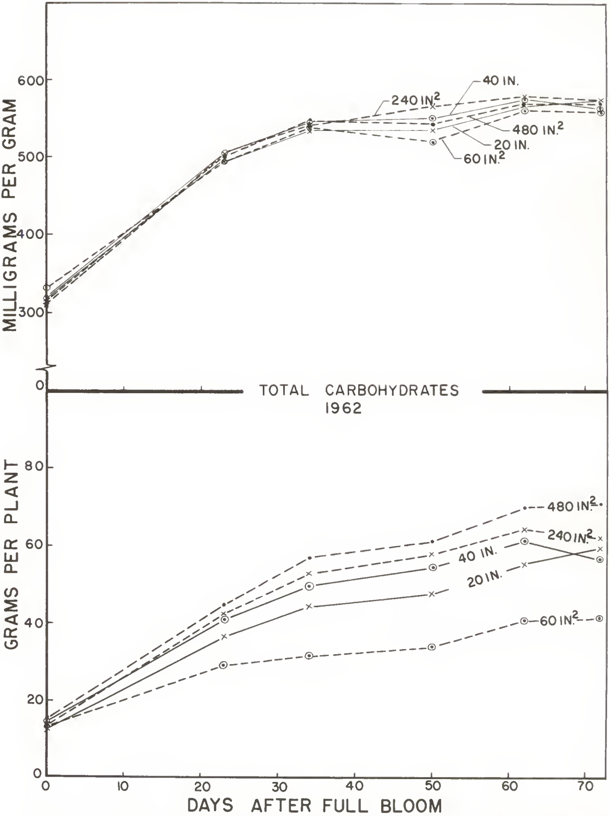

Fig. 13. Total carbohydrate concentration and yield per plant in 1962.

1963 Experiment. Data for carbohydrate accumulation (milligrams per gram dry weight) are presented in Fig. 14 and appendix Table 24. Carbohydrate concentration increase was highly significant over the sampling period. The greatest increase occurred during the first 4 weeks following anthesis. The concentration of soluble carbohydrates in the plant tended to decrease during the latter part of the sampling period. The linear component accounted for 67% of the date sum of squares, while the quadratic component accounted for 30%. However, the quartic and quintic functions were also highly significant. The row system was significantly higher than the drill system in total soluble carbohydrate concentration.

The increase in yield of soluble carbohydrates per acre (Fig. 14 and appendix Table 25) was highly significant during the sampling period. The increase was rapid following bloom, but tended to level off and decreased slightly (but not significantly) at the last harvest date. Most of the date sum of squares was explained by the linear component, however, the quadratic, cubic, and quartic components were also significant. Management systems did not significantly affect yield of soluble carbohydrates.

Final Stover, Grain, and Total Forage Yield

1962 Experiment. Yield data obtained from a final harvest date taken after frost are found in appendix Table 27. Final forage yield, stover yield, and grain yield per acre were determined. The high population produced significantly more (1% level) total forage per acre than the medium and low populations. Twenty-inch rows produced significantly more forage per acre than did 40-inch rows.

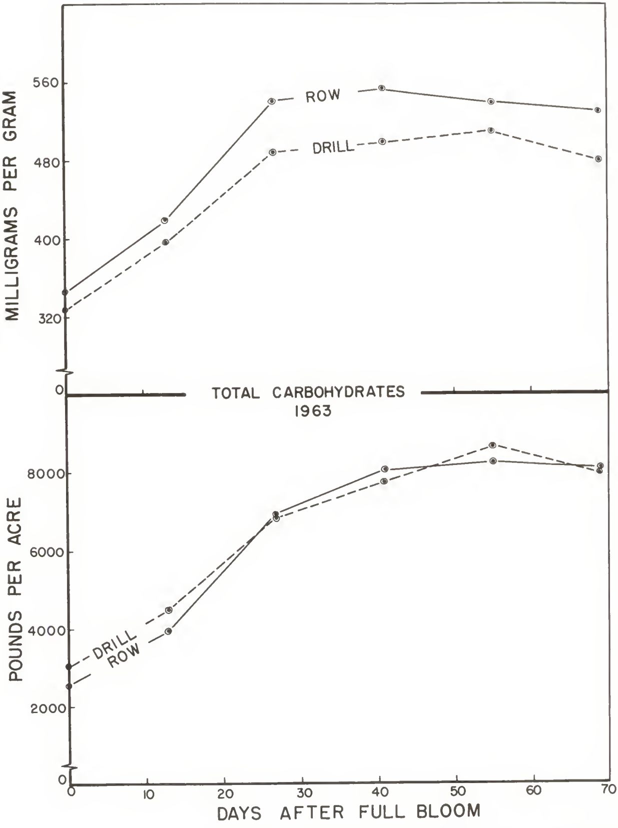

Fig. 14. Total carbohydrate concentration and yield per acre in 1963.

The high population produced a significantly greater (1% level) amount of stover per acre than the medium and high populations. A highly significant difference was also observed between row widths due to a higher stover yield in the 20-inch rows.

The high population also produced significantly more (10% level) grain per acre than the medium and high populations. No difference in grain yield due to row widths was found.

1963 Experiment. At the final harvest, (appendix Table 26) the drill system produced significantly more (1% level) stover and total forage per acre than the row system. However, the row system produced significantly more (1% level) grain per acre. Some lodging was noted in the drill system at this harvest.

Percentage Contribution of Leaves, Culms, and Heads

A sub-sample from each plot was divided into leaves, culms, and heads at the final harvest date after frost. As shown in appendix Tables 28 and 29, about 50% of the total dry matter was contributed by the culms, while the heads and leaves each contributed about 25%. Contribution by the culm remained fairly constant over the various treatments. Percent contribution by the leaves increased and contribution by the heads decreased at higher population densities and narrow row spacings.

As shown in appendix Tables 30, 31, 32, and 33, the culms contained more reducing and non-reducing sugars than the heads and leaves and contributed the greatest percentage of these 2 carbohydrate fractions in the plant at maturity. The heads contained very little sugar at this stage. At the high populations a greater percentage of the sugars was contributed by the leaves than at lower populations.

Acid hydrolyzable carbohydrate percentage (appendix Tables 34 and 35) was highest in the heads; followed by the leaves and culms respectively. The heads contributed about 50%, the culms about 30%, and the leaves 20% of the total acid hydrolyzable carbohydrates found in the plant. Percent of acid hydrolyzable carbohydrates contributed by the heads increased at low population densities and wide row spacings with a corresponding decrease in percent contributed by the leaves.

Heads were highest in total carbohydrate yield (appendix Tables 36 and 37), followed by the culms and leaves respectively. However, the culms contributed about 50% of the carbohydrate yield per plant since they contributed more dry weight than heads. The leaves contained only about 15% of the total soluble carbohydrates in the plant.

The levels of carbohydrates at maturity were lower in 1963 than in 1962. This may have been due to the drought conditions which prevailed in 1963. Yaadia _et al_. (42) have shown that increased water stress in the leaves decreases the rate of photosynthesis, with the rate approaching zero at wilting. Wilting accelerated the conversion of starch to sugars which were used in respiration.

As shown in appendix Tables 38 and 39, the leaves were highest in fiber percentage, while the culms were intermediate and the heads relatively low in fiber. Fiber percentage increased at high population densities in all plant parts. Due to their greater dry weight, the culms contained about 55% of the total fiber in the plant while the leaves contributed about 35% of the total. Percent contribution by the leaves increased at high population densities and narrow row spacings.

Data in appendix Tables 40 and 41 show that protein percentage was highest in the heads; with the leaves intermediate and the culms relatively low in protein.

The percentages were higher in 1963 than in 1962 due to more adverse growing conditions. Protein was highest in all plant parts at low population densities. The heads contributed from 45 to 50% of the total protein in the plant; the lower percentage contribution occurring in 1963. The leaves contributed about 30% of the protein and the culms about 20%. Percentage contribution to total protein by the leaves increased at high population densities and narrow row spacings, while that of both culms and heads tended to decrease under these conditions.

SUMMARY AND CONCLUSIONS

A study was conducted in 1962 and 1963 to determine the trends in carbohydrate, fiber, protein, and dry matter accumulation in Atlas forage sorghum as affected by stage of maturity and differences in planting systems. In 1962, 40-inch and 20-inch row widths were used at populations of 104,500 plants per acre (high); 26,100 plants per acre (medium); and 13,100 plants per acre (low). In 1963 the study was revised to determine the effect of stage of maturity and 2 management systems on yield and chemical composition. The management systems were forage sorghum thickly drilled in 10-inch rows with about 523,000 plants per acre versus 40-inch rows with 39,000 plants per acre.

In both years dry matter percentage and yield increased consistently during the sampling period until frost. Plants grown at low populations and in 40-inch rows made the greatest relative increase in dry matter per plant. However, the highest yields per acre were obtained with high stand densities and narrow rows. At maturity, about 50% of the dry matter in the plant was contributed by the culm, 25% by the leaves, and 25% by the head.

Protein percentages decreased sharply following anthesis with little change after the grain was mature. However, protein yield per plant and per acre increased throughout the sampling period. Plants grown at low populations were higher in protein percentage and protein per plant than those grown at high populations. Protein yield per acre tended to increase with an increase in population. Plants grown in 40-inch rows contained more protein per plant than those in narrow rows, but protein yield per acre was highest in the narrow rows. About 50% of the protein in Atlas plants at maturity is found in the heads, with the leaves containing about 30% and the culms 20% of the total protein.

Crude fiber percentage decreased sharply after anthesis, but remained nearly constant or increased slightly following maturity of the grain. Crude fiber yield per plant and per acre increased throughout the sampling period. Plants grown at high populations and in narrow rows were higher in both crude fiber percentage and yield per acre than plants in 40-inch rows and at low population densities. Leaves were highest in crude fiber percentage. However, due to their greater contribution to dry matter, the culms contributed about 55% of the fiber in Atlas at maturity, while the leaves contributed about 35%.

Total carbohydrate percentage and yield increased throughout the sampling period until frost. Non-reducing sugars were nearly absent at bloom, but increased sharply thereafter. Reducing sugars continued to increase until the grain reached physiological maturity (about 7 weeks after bloom) after which they decreased until frost. Acid hydrolyzable carbohydrates increased consistently after bloom in both percentage and yield, and were highest in plants grown at low populations and in 40-inch rows since these plants produced a greater yield of grain.

Plants at low populations and in 40-inch rows accumulated more carbohydrates per plant than those in high populations and narrow rows. Carbohydrate percentage was not significantly affected by plant population or row width in 1962; however, in 1963, plants in the row system were higher in carbohydrate percentage than in the drill system. Carbohydrate yield per acre did not differ between systems because the drill system produced the highest yield of dry matter. Culms contributed about 50% of the carbohydrates in the plant at maturity and only 15% was in the leaves.

The grain yield of Atlas sorgo increased with increased stand density in 1962, but in 1963 with an extremely high population, grain yield was depressed. In contrast, highest total forage yield was obtained from the highest stand density. Highest forage yield was obtained at the last harvest date before frost.

Based on these results, it was concluded that:

1) high populations are superior in total yield per acre of dry matter, protein, and carbohydrates, but they also produce a greater percentage and yield of fiber,
2) narrow rows are superior to 40-inch rows in forage yield per acre,
3) accumulation of dry matter, carbohydrates, protein, and fiber continues until frost,

   and

4) although dry matter yield is increased by delayed harvest, digestibility of the silage may be decreased because of increased hardness of the seed and increased fiber content of the plant.

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APPENDIX

Table 1. Dry matter (grams per plant) in Atlas forage sorghum as affected by stage of maturity, plant population, and row width in 1962.

Harvest date Days after bloom	Population High	Population Med.	Population Low	Row width 40	Row width 20	Date mean
0	40.6	43.2	49.5	45.7	43.2	44.4
12	46.2	61.6	65.6	59.9	55.8	57.8
23	59.8	84.3	89.8	82.0	73.9	78.0
34	58.8	98.2	104.0	91.7	82.3	87.0
50	65.0	102.0	113.4	98.7	88.3	93.5
62	73.0	111.0	123.2	106.9	97.9	102.4
72	74.4	108.6	124.0	100.8	103.9	102.3
Ave.	59.7	87.0	95.6	83.7	77.9	

Dates L.S.D. .05 level = 8.4
Population L.S.D. .05 level = 5.5
Row width L.S.D. .05 level = 4.5
Population x date L.S.D. .05 level = 14.6

Table 2. Dry matter percentage in Atlas forage sorghum as affected by stage of maturity, plant population, and row width in 1962.

Harvest date Days after bloom	Population High	Population Med.	Population Low	Row width 40	Row width 20	Date mean
0	17.2	15.1	14.5	15.5	15.6	15.6
12	18.0	17.9	17.3	18.0	17.4	17.7
23	23.2	21.8	21.9	22.5	22.2	22.3
34	25.6	24.7	24.5	25.2	24.7	24.9
50	27.2	28.1	26.8	28.2	26.6	27.4
62	30.2	31.5	31.2	32.0	29.9	31.0
72	29.9	28.0	28.7	28.4	29.4	28.9
Ave.	24.5	23.9	23.6	24.3	23.7	

Dates L.S.D. .05 level = 1.0
Population L.S.D. .05 level = 0.7
Row width L.S.D. .05 level = 0.5
Date x row width L.S.D. .05 level = 1.4

Table 3. Dry matter (pounds per acre) in Atlas forage sorghum as affected by stage of maturity, plant population, and row width in 1962.

Harvest date Days after bloom	Population			Row width		Date mean
	High	Med.	Low	40	20	
0	8,735	6,824	5,484	6,586	7,443	7,014
12	9,193	8,600	7,522	8,238	8,638	8,438
23	13,113	10,618	10,091	10,430	12,118	11,274
34	14,130	13,872	12,970	12,894	14,421	13,657
50	14,465	14,162	12,582	13,934	13,539	13,736
62	15,351	14,506	13,950	14,949	14,255	14,602
72	18,169	13,958	13,497	14,609	15,807	15,208
Ave.	13,308	11,791	10,870	11,663	12,317	

Dates L.S.D. .05 = 1,083
Population L.S.D. .05 = 709
Row width L.S.D. .05 = 547

Table 4. Dry matter percentage in Atlas forage sorghum as affected by stage of maturity and management system in 1963.

Harvest date Weeks after bloom	System		Date mean
	Drill	Row	
0	15.96	15.85	15.91
2	19.47	19.02	19.24
4	25.22	25.42	25.32
6	27.40	28.56	27.98
8	30.54	31.09	30.82
10	28.95	29.52	29.23
Ave.	24.59	24.91	

Dates L.S.D. .05 level = 1.15

Table 5. Dry matter (pounds per acre) in Atlas forage sorghum as affected by stage of maturity and management system in 1963.

Harvest date Weeks after bloom	System		Date mean
	Drill	Row	
0	9,222	7,375	8,299
2	11,359	9,426	10,392
4	14,204	12,714	13,459
6	15,592	14,489	15,040
8	16,979	15,275	16,127
10	16,404	15,256	15,830
Ave.	13,959	12,422	

Systems L.S.D. .05 level = 1,177
Dates L.S.D. .05 level = 918

Table 6. Protein percentage in Atlas forage sorghum as affected by stage of maturity, plant population, and row width in 1962.

Harvest date Days after bloom	Population			Row width		Date mean
	High	Med.	Low	40	20	
0	7.28	8.89	8.81	8.32	8.34	8.33
12	6.42	7.12	7.26	6.83	7.04	6.94
23	5.59	6.31	6.58	6.24	6.08	6.16
34	4.98	6.00	5.98	5.57	5.74	5.66
50	5.16	5.75	6.11	5.81	5.53	5.67
62	5.12	6.11	6.26	5.99	5.68	5.83
72	5.03	5.63	6.11	5.71	5.47	5.59
Ave.	5.66	6.55	6.73	6.35	6.27	

Dates L.S.D. .05 level = .42
Population L.S.D. .05 level = .28

Table 7. Protein (grams per plant) in Atlas forage sorghum as affected by stage of maturity, plant population, and row width in 1962.

Harvest date Days after bloom	Population			Row width		Date mean
	High	Med.	Low	40	20	
0	2.95	3.81	4.36	3.84	3.57	3.71
12	2.97	4.41	4.76	4.13	3.97	4.05
23	3.35	5.33	5.91	5.18	4.54	4.86
34	2.94	5.88	6.26	5.21	4.85	5.03
50	3.33	5.89	6.95	5.81	4.98	5.39
62	3.74	6.79	7.73	6.50	5.68	6.09
72	3.77	6.12	7.58	5.86	5.78	5.82
Ave.	3.29	5.46	6.22	5.22	4.77	

Dates L.S.D. .05 level = .55
Population L.S.D. .05 level = .36
Row width L.S.D. .05 level = .29
Population x date L.S.D. .05 level = .95

Table 8. Protein percentage in Atlas forage sorghum as affected by stage of maturity and management system in 1963.

Harvest date Weeks after bloom	System		Date mean
	Drill	Row	
0	8.20	7.95	8.08
2	7.22	7.23	7.23
4	6.75	6.86	6.81
6	6.92	7.12	7.02
8	6.53	6.83	6.68
10	6.41	7.15	6.78
Ave.	7.01	7.19	

Systems L.S.D. .05 level = 0.14
Dates L.S.D. .05 level = 0.35

Table 9. Protein (pounds per acre) in Atlas forage sorghum as affected by stage of maturity and management system in 1963.

Harvest date Weeks after bloom	System		Date mean
	Drill	Row	
0	752.6	586.4	669.5
2	819.7	680.6	750.1
4	954.5	861.7	912.8
6	1078.5	1031.7	1055.1
8	1108.2	1042.1	1075.1
10	1052.0	1091.2	1071.6
Ave.	960.9	883.9	

Dates L.S.D. .05 level = 97.8
Systems L.S.D. .05 level = 65.2

Table 10. Crude fiber percentage in Atlas forage sorghum as affected by stage of maturity, plant population, and row width in 1962.

Harvest date Days after bloom	Population			Row width		Date mean
	High	Med.	Low	40	20	
0	27.42	28.63	29.00	28.41	28.28	28.35
12	24.00	23.53	24.63	23.66	24.45	24.05
23	22.24	21.32	21.59	21.34	22.09	21.72
34	21.08	19.68	19.40	20.09	20.02	20.05
50	19.51	16.99	18.19	17.81	18.65	18.23
62	18.96	16.19	16.76	16.81	17.80	17.31
72	18.72	17.57	16.80	17.59	17.80	17.69
Ave.	21.70	20.56	20.91	20.82	21.30	

Dates L.S.D. .05 level = 0.84
Population L.S.D. .05 level = 0.55
Row width L.S.D. .05 level = 0.45
Population x date L.S.D. .05 level = 1.45

Table 11. Crude fiber (grams per plant) in Atlas forage sorghum as affected by stage of maturity, plant population, and row width in 1962.

Harvest date Days after bloom	Population			Row width		Date mean
	High	Med.	Low	40	20	
0	11.16	12.38	14.30	13.05	12.18	12.61
12	11.08	14.50	16.14	14.20	13.61	13.91
23	13.29	17.97	19.37	17.49	16.27	16.88
34	12.37	19.31	20.09	18.59	16.22	17.26
50	12.59	17.23	20.64	17.38	16.26	16.82
62	13.66	17.94	20.65	17.83	17.00	17.42
72	13.89	19.06	20.78	17.50	18.32	17.91
Ave.	12.58	16.91	18.85	16.53	15.69	

Dates L.S.D. .05 level = 1.49
Populations L.S.D. .05 level = 0.97
Row width L.S.D. .05 level = 0.80

Table 12. Crude fiber percentage in Atlas forage sorghum as affected by stage of maturity and management system in 1963.

Harvest date Weeks after bloom	System		Date mean
	Drill	Row	
0	31.74	29.89	30.82
2	28.26	25.99	27.12
4	21.98	18.77	20.38
6	19.84	17.09	18.47
8	20.64	17.64	19.14
10	22.88	18.92	20.90
Ave.	24.22	21.38	

Systems L.S.D. .05 level = 0.64
Dates L.S.D. .05 level = 0.92

Table 13. Crude fiber (pounds per acre) in Atlas forage sorghum as affected by stage of maturity and management system in 1963.

Harvest date Weeks after bloom	Systems Drill	Row	Date mean
0	2,926	2,203	2,565
2	3,209	2,450	2,829
4	3,110	2,384	2,747
6	3,105	2,476	2,791
8	3,505	2,691	3,098
10	3,752	2,886	3,319
Ave.	3,094	2,515	

Systems L.S.D. .05 level = 244
Dates L.S.D. .05 level = 237

Table 14. Non-reducing sugars (milligrams per gram dry weight) in Atlas forage sorghum as affected by stage of maturity, plant population, and row width in 1962.

Harvest date	Population			Row width		Date mean
Days after bloom	High	Med.	Low	40	20	
0	19.79	13.70	13.77	16.02	15.49	15.75
23	56.06	66.14	58.47	56.28	64.17	60.22
34	88.67	45.97	91.12	72.12	65.05	68.59
50	93.41	67.81	65.46	73.54	77.67	75.60
62	100.44	80.20	79.23	86.45	86.80	86.62
72	79.42	80.45	76.56	75.99	81.64	78.81
Ave.	72.97	59.05	60.79	63.40	65.14	64.27

Dates L.S.D. .05 level = 9.85
Population L.S.D. .05 level = 6.96
Population x date L.S.D. .05 level = 17.06

Table 15. Reducing sugars (milligrams per gram dry weight) in Atlas forage sorghum as affected by stage of maturity, plant population, and row width in 1962.

Harvest date Days after bloom	Population			Row width		Date mean
	High	Med.	Low	40	20	
0	62.26	42.72	40.45	50.64	46.32	48.48
23	111.33	112.12	114.41	106.25	118.99	112.62
34	147.83	119.09	132.59	140.90	125.45	133.17
50	110.70	107.53	93.98	98.81	109.32	104.07
62	102.25	88.05	89.39	83.84	102.61	93.23
72	109.61	114.73	101.75	105.54	112.19	108.70
Ave.	107.33	97.38	95.53	97.66	102.42	100.04

Dates L.S.D. .05 level = 10.11
Populations L.S.D. .05 level = 7.15
Row width x date L.S.D. .05 level = 14.30

Table 16. Total sugars (milligrams per gram dry weight) in Atlas forage sorghum as affected by stage of maturity, plant population, and row width in 1962.

Harvest date Days after bloom	Population			Row width		Date mean
	High	Med.	Low	40	20	
0	82.06	56.42	54.22	66.65	61.81	64.23
23	165.81	174.64	172.87	162.33	179.88	171.11
34	236.50	164.47	203.41	212.46	190.46	201.46
50	204.11	175.34	159.70	172.35	187.09	179.72
62	202.69	167.64	168.38	169.97	189.17	179.57
72	189.11	195.19	178.31	181.55	193.52	187.36
Ave.	180.05	155.67	156.15	160.89	166.99	

Dates L.S.D. .05 level = 14.94
Population L.S.D. .05 level = 10.56
Population x date L.S.D. .05 level = 25.88

Table 17. Acid hydrolyzable carbohydrates (milligrams per gram dry weight) in Atlas forage sorghum as affected by stage of maturity, plant population, and row width in 1962.

Harvest date	Population			Row width		Date mean
Days after bloom	High	Med.	Low	40	20	
0	250.76	258.02	259.15	255.45	256.50	255.98
23	327.99	328.45	330.31	342.42	315.41	329.03
34	302.52	375.50	347.13	334.26	349.18	341.72
50	317.65	393.39	385.99	380.32	351.03	365.67
62	359.70	413.60	403.35	406.69	377.74	392.21
72	370.79	380.31	393.00	382.14	380.59	381.36
Ave.	321.62	358.21	353.15	350.25	338.41	

Dates L.S.D. .05 level = 18.88
Population L.S.D. .05 level = 13.35
Row width L.S.D. .05 level = 10.90
Population x date L.S.D. .05 level = 32.71

Table 18. Non-reducing sugars (milligrams per gram dry weight) in Atlas forage sorghum as affected by stage of maturity and management system in 1963.

Harvest date	System		Date mean
Weeks after bloom	Drill	Row	
0	8.75	9.63	9.19
2	43.73	41.31	42.52
4	69.72	64.58	67.15
6	65.55	59.59	62.57
8	63.81	61.90	62.86
10	41.46	40.66	41.06
Ave.	48.84	46.28	

Dates L.S.D. .05 level = 10.26

Table 19. Reducing sugars (milligrams per dry weight) in Atlas forage sorghum as affected by stage of maturity and management system in 1963.

Harvest date Weeks after bloom	System Drill	System Row	Date mean
0	58.04	74.77	66.40
2	78.98	94.28	86.63
4	106.78	98.74	102.76
6	97.90	110.83	104.36
8	84.46	83.35	83.91
10	79.98	73.08	76.58
Ave.	84.36	89.18	

Dates L.S.D. .05 level = 13.14

Table 20. Total sugars (milligrams per gram dry weight) in Atlas forage sorghum as affected by stage of maturity and management system in 1963.

Harvest date Weeks after bloom	System Drill	System Row	Date mean
0	66.79	84.40	75.59
2	122.72	135.59	129.16
4	176.50	163.33	169.91
6	163.45	170.42	166.94
8	148.28	145.26	146.77
10	121.46	113.74	117.60
Ave.	133.20	135.46	

Dates L.S.D. .05 level = 19.08

Table 21. Acid hydrolyzable carbohydrates (milligrams per gram dry weight) in Atlas forage sorghum as affected by stage of maturity and management system in 1963.

Harvest date Weeks after bloom	System		Date mean
	Drill	Row	
0	261.52	261.46	261.49
2	273.46	283.15	278.30
4	311.52	378.27	344.89
6	334.98	383.39	359.19
8	360.90	394.07	377.42
10	358.72	417.53	388.13
Ave.	316.83	352.98	

Systems L.S.D. .05 level = 11.80
Dates L.S.D. .05 level = 15.59
Dates x system L.S.D. .05 level = 22.05

Table 22. Total carbohydrates (milligrams per gram dry weight) in Atlas forage sorghum as affected by stage of maturity, plant population, and row width in 1962.

Harvest date Days after bloom	Population			Row width		Date mean
	High	Med.	Low	40	20	
0	332.81	314.46	313.37	322.11	318.32	320.21
23	495.72	506.72	503.18	505.18	498.57	501.87
34	539.02	540.46	550.85	547.28	539.61	543.44
50	521.75	568.73	545.46	552.62	538.01	545.32
62	562.22	581.85	571.96	576.87	567.15	572.01
72	559.82	575.49	571.31	563.67	574.08	568.88
Ave.	501.89	514.62	509.36	511.29	505.96	

Dates L.S.D. .05 level = 18.09

Table 23. Total carbohydrates (grams per plant) in Atlas forage sorghum as affected by stage of maturity, plant population, and row width in 1962.

Harvest date	Population			Row width		Date mean
Days after bloom	High	Med.	Low	40	20	
0	13.54	13.56	15.51	14.64	13.76	14.20
23	29.68	42.71	45.22	41.42	37.00	39.21
34	31.86	53.16	57.31	50.07	44.82	47.44
50	34.26	58.08	61.72	54.76	47.95	51.36
62	41.10	64.62	70.39	61.74	55.66	58.70
72	41.62	62.56	70.90	56.88	59.87	58.36
Ave.	32.01	49.12	53.51	46.58	43.17	

Dates L.S.D. .05 level = 4.40
Population L.S.D. .05 level = 2.20
Row width L.S.D. .05 level = 1.80
Population x date L.S.D. .05 level = 7.63

Table 24. Total carbohydrates (milligrams per gram dry weight) in Atlas forage sorghum as affected by stage of maturity and management system in 1963.

Harvest date	Systems		Date mean
Weeks after bloom	Drill	Row	
0	328.31	345.86	337.08
2	396.18	418.74	407.46
4	488.02	541.60	514.81
6	498.43	553.81	526.12
8	509.05	539.33	524.19
10	480.18	531.27	505.72
Ave.	450.03	488.43	

Systems L.S.D. .05 level = 8.71
Dates L.S.D. .05 level = 15.61
Dates x system L.S.D. .05 level = 22.07

Table 25. Total carbohydrates (pounds per acre) in Atlas forage sorghum as affected by stage of maturity and management system in 1963.

Harvest date Weeks after bloom	System		Date mean
	Drill	Row	
0	3,041	2,552	2,796
2	4,501	3,950	4,226
4	6,837	6,889	6,863
6	7,764	8,020	7,892
8	8,647	8,245	8,446
10	7,953	8,104	8,029
Ave.	6,457	6,293	

Dates L.S.D. .05 level = 563

Table 26. Grain, stover, and total forage yield (pounds per acre) in Atlas forage sorghum as affected by management system in 1963 when harvested 11 weeks after bloom.

System	Stover	Grain	Total forage
Drill	13,549	2,854	16,403
Row	11,874	3,382	15,256

System L.S.D. for stover yield .05 level = 415
System L.S.D. for grain yield .05 level = 142
System L.S.D. for total forage yield .05 level = 550

Table 27. Grain, stover, and total forage yield (pounds per acre) in Atlas forage sorghum as affected by plant population and row width when harvested 11 weeks after bloom in 1962.

Population	Row width 40	Row width 20	Ave.
STOVER YIELD (lbs/A); OVEN DRY			
High	11,628	14,659	13,144
Medium	9,776	12,028	10,902
Low	9,700	10,572	10,136
Ave.	10,368	12,420	

Row width L.S.D. .05 level = 1,388
Population L.S.D. .05 level = 1,700

Population	Row width 40	Row width 20	Ave.
GRAIN YIELD (lbs/A); OVEN DRY			
High	3,980	4,784	4,382
Medium	3,817	3,701	3,759
Low	3,552	3,450	3,501
Ave.	3,783	3,978	

Population L.S.D. .05 level = 798

Population	Row width 40	Row width 20	Ave.
TOTAL FORAGE YIELD (lbs/A); OVEN DRY			
High	15,608	19,442	17,526
Medium	13,593	15,728	14,661
Low	13,252	14,022	13,637
Ave.	14,151	16,398	

Row width L.S.D. .05 level = 1,945
Population L.S.D. .05 level = 2,382

Table 28. Percent contribution of leaves, culms, and heads to total dry matter in Atlas forage sorghum in 1962.

Plant part	Population			Row width		Average
	High	Med.	Low	40	20	
Leaves	23.8	20.9	22.2	20.8	23.8	22.3
Culms	53.1	48.1	48.7	48.7	51.3	50.0
Heads	23.1	30.9	29.1	30.5	24.9	27.7

Table 29. Percent contribution of leaves, culms, and heads to total dry matter in Atlas forage sorghum in 1963.

Plant part	System		Average
	Drill	Row	
Leaves	29.4	21.7	25.6
Culms	49.6	52.4	51.0
Heads	20.9	25.9	23.4

Table 30. Non-reducing sugars (milligrams per gram) in leaves, culms, and heads, and percent contribution of each plant part to total non-reducing sugars in the plant at 11 weeks after bloom, 1962.

Plant part	Population			Row width		Average
	High	Med.	Low	40	20	
			CONCENTRATION (mg/g)			
Leaves	25.1	19.5	14.8	18.2	21.4	19.8
Culms	75.6	101.7	81.5	92.8	79.7	86.2
Heads	11.3	10.5	11.7	10.1	12.2	11.2
			PERCENT CONTRIBUTION			
Leaves	12.3	7.3	6.9	7.3	10.4	8.8
Culms	82.5	86.9	86.0	86.8	83.5	85.1
Heads	5.2	5.8	7.1	5.9	6.1	6.0

Table 31. Non-reducing sugars (milligrams per gram) in leaves, culms, and heads, and percent contribution of each plant part to total non-reducing sugars in the plant at 11 weeks after bloom, 1963.

Plant part	System		Average
	Drill	Row	
	CONCENTRATION (mg/g)		
Leaves	19.8	23.6	21.7
Culms	150.4	130.4	140.4
Heads	9.3	9.1	9.2
	PERCENT CONTRIBUTION		
Leaves	7.1	6.8	7.0
Culms	90.6	90.1	90.4
Heads	2.4	3.1	2.6

Table 32. Reducing sugars (milligrams per gram) in leaves, culms, and heads, and percent contribution of each plant part to total reducing sugars in the plant at 11 weeks after bloom, 1962.

Plant part	Population			Row width		Average
	High	Med.	Low	40	20	
			CONCENTRATION (mg/g)			
Leaves	64.5	57.2	48.7	56.4	57.2	56.8
Culms	258.5	253.5	247.5	252.9	253.4	253.2
Heads	6.4	4.5	4.6	4.2	6.0	5.1
			PERCENT CONTRIBUTION			
Leaves	9.8	8.8	8.1	8.6	9.3	8.9
Culms	89.3	90.1	90.9	90.4	89.7	90.1
Heads	.9	1.0	.9	.9	1.0	.9

Table 33. Reducing sugars (milligrams per gram) in leaves, culms, and heads, and percent contribution of each plant part to total reducing sugars in the plant at 11 weeks after bloom, 1963.

Plant part	System		Average
	Drill	Row	
	CONCENTRATION (mg/g)		
Leaves	40.8	48.0	44.4
Culms	223.2	230.5	226.9
Heads	1.9	1.8	1.8
	PERCENT CONTRIBUTION		
Leaves	9.7	7.9	8.8
Culms	89.9	91.7	90.8
Heads	.3	.3	.3

Table 34. Acid hydrolyzable carbohydrates (milligrams per gram) in leaves, culms, and heads, and percent contribution of each plant part to total acid hydrolyzable carbohydrates at 11 weeks after bloom, 1962.

Plant part	Population			Row width		Average
	High	Med.	Low	40	20	
CONCENTRATION (mg/g)						
Leaves	299.6	288.0	296.3	298.4	290.8	294.6
Culms	235.1	215.9	214.3	223.6	219.9	221.8
Heads	721.9	690.8	702.1	713.6	696.3	704.9
PERCENT CONTRIBUTION						
Leaves	22.2	16.2	17.5	16.0	21.4	18.6
Culms	33.6	27.9	27.9	28.1	31.6	29.8
Heads	44.2	56.0	54.5	55.8	47.0	51.5

Table 35. Acid hydrolyzable carbohydrates (milligrams per gram) in leaves, culms, and heads, and percent contribution of each plant part to total acid hydrolyzable carbohydrates at 11 weeks after bloom, 1963.

Plant part	System		Average
	Drill	Row	
CONCENTRATION (mg/g)			
Leaves	219.5	252.1	235.8
Culms	223.1	230.6	226.8
Heads	706.0	731.4	718.7
PERCENT CONTRIBUTION			
Leaves	20.0	15.0	17.5
Culms	34.3	33.1	33.7
Heads	45.7	51.9	48.8

Table 36. Total carbohydrates (milligrams per gram) in leaves, culms, and heads, and percent contribution of each plant part to total carbohydrates in the plant at 11 weeks after bloom, 1962.

Plant part	Population			Row width		Average
	High	Med.	Low	40	20	
			CONCENTRATION (mg/g)			
Leaves	389.2	364.7	359.8	373.0	369.4	371.2
Culms	569.2	571.1	543.3	569.3	553.0	561.2
Heads	739.6	705.8	718.4	727.9	714.5	721.2
			PERCENT CONTRIBUTION			
Leaves	16.4	13.4	14.4	13.5	16.0	14.7
Culms	53.4	48.3	47.8	48.1	51.6	49.8
Heads	30.2	38.3	37.8	38.5	32.4	35.4

Table 37. Total carbohydrates (milligrams per gram) in leaves, culms, and heads, and percent contribution of each plant part to total carbohydrates in the plant at 11 weeks after bloom, 1963.

Plant part	System		Average
	Drill	Row	
	CONCENTRATION (mg/g)		
Leaves	334.9	323.7	329.3
Culms	596.7	591.4	594.1
Heads	717.2	742.2	729.7
	PERCENT CONTRIBUTION		
Leaves	18.1	12.3	15.2
Culms	54.4	54.1	54.2
Heads	27.5	33.6	30.6

Table 38. Crude fiber (percent of dry weight) in leaves, culms, and heads, and percent contribution of each plant part to total crude fiber in the plant at 11 weeks after bloom, 1962.

Plant part	Population			Row width		Average
	High	Med.	Low	40	20	
			CONCENTRATION (percent)			
Leaves	27.5	26.7	26.3	26.6	27.1	26.8
Culms	20.2	19.6	19.5	19.5	20.0	19.8
Heads	6.3	5.9	6.7	6.0	6.6	6.3
			PERCENT CONTRIBUTION			
Leaves	34.9	33.2	33.8	32.8	35.1	34.0
Culms	57.3	56.0	55.0	56.3	56.0	56.1
Heads	7.8	10.8	11.2	10.9	8.9	9.9

Table 39. Crude fiber (percent of dry weight) in leaves, culms, and heads, and percent contribution of each plant part to total crude fiber in the plant at 11 weeks after bloom, 1963.

Plant part	System		Average
	Drill	Row	
	CONCENTRATION (percent)		
Leaves	29.7	26.2	27.9
Culms	22.4	20.9	21.6
Heads	6.2	5.5	5.9
	PERCENT CONTRIBUTION		
Leaves	41.3	31.5	36.4
Culms	52.5	60.6	56.6
Heads	6.2	7.9	7.0

Table 40. Protein (percent of dry weight) in leaves, culms, and heads, and percent contribution of each plant part to total protein in the plant at 11 weeks after bloom, 1962.

Plant part	Population			Row width		Average
	High	Med.	Low	40	20	
	CONCENTRATION (percent)					
Leaves	6.38	7.25	7.75	7.06	7.19	7.12
Culms	1.75	2.00	2.75	2.19	2.12	2.14
Heads	9.44	9.94	10.12	10.00	9.62	9.81
	PERCENT CONTRIBUTION					
Leaves	33.5	27.5	28.8	26.7	33.0	29.9
Culms	19.6	17.1	22.1	18.7	20.6	19.6
Heads	46.9	55.4	49.1	54.6	46.4	50.4

Table 41. Protein (percent of dry weight) in leaves, culms, and heads, and percent contribution of each plant part to total protein in the plant at 11 weeks after bloom, 1963.

Plant part	System		Average
	Drill	Row	
	CONCENTRATION (percent)		
Leaves	6.88	8.12	7.50
Culms	2,38	3.06	2.72
Heads	12.20	11.69	11.94
	PERCENT CONTRIBUTION		
Leaves	35.1	27.5	31.3
Culms	20.5	25.0	22.8
Heads	44.3	47.4	45.8

PLANTING SYSTEM AND STAGE OF MATURITY AS FACTORS AFFECTING YIELD AND CHEMICAL COMPOSITION OF ATLAS FORAGE SORGHUM

by

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Forage sorghum is a popular silage crop in the Great Plains. Yield, digestibility, and palatability of sorghum silage may be affected by stage of maturity at harvest, plant population, and row width. This investigation was conducted to determine trends in accumulation of dry matter, protein, crude fiber, and carbohydrates as affected by stage of maturity and management system.

Atlas sorgo was grown in 1962 in a randomized block design with 3 plant populations (high 104,500 plants per acre; medium 26,100; and low 13,100) in 20- and 40-inch rows. In 1963 Atlas sorgo was planted in a split plot with systems as main plots and harvest dates as sub-plots. The systems compared were drilled 10-inch and standard 40-inch rows with about 523,000 and 39,000 plants per acre, respectively.

Plant samples were taken in both years at 10 to 16 day intervals from bloom until frost. After frost, forage and grain yields were determined and plants were divided into leaves (blade and sheath), culms, and heads to determine percentage contribution. Nitrogen, fiber, and carbohydrate determinations were made.

Total dry matter increased throughout the sampling period until frost. The high populations and narrow rows produced the highest yield per acre while the low populations and 40-inch rows accumulated the most dry matter per plant. The culms contributed 50 percent of the total dry matter of the plant at maturity.

Protein yield increased and protein percentage decreased throughout the sampling period with most of the change occurring the first 6 weeks after bloom. Plants grown in 40-inch rows and at low populations were highest in protein percentage and protein yield per plant. However, highest protein yield per acre was obtained from narrow rows and high plant populations. Most of the protein was contributed by the heads.

Total yield of crude fiber per plant and per acre increased while crude fiber percentage decreased during the sampling period. Plants grown at high populations and in narrow rows were higher in both crude fiber percentage and yield per acre than those in 40-inch rows and at low populations. Leaves were highest in crude fiber percentage, but the culms contributed about 50 percent of the total crude fiber of the plant.

Non-reducing sugars were nearly absent at bloom, but increased sharply thereafter. Reducing sugars were highest near the time of physiological maturity of the grain (7 weeks after bloom). Acid hydrolyzable carbohydrates increased consistently following anthesis and were highest in both percentage and yield per acre in 40-inch rows and at low populations since plants in these systems produced a greater yield of grain. The heads contained about 70 percent acid hydrolyzable carbohydrates. The culms were highest in sugar content.

Total carbohydrate (total sugars plus acid hydrolyzable carbohydrates) percentage and yield per acre increased during the sampling period. Carbohydrate yield did not differ among management systems, but percentage was highest in the drill system in 1963. Culms contributed about 50 percent of the total carbohydrates in the plant at maturity.

High populations and narrow rows produced the highest stover and total forage yields. Grain yield also increased with increasing population, but reached a maximum and then decreased at extremely high populations.