

EVALUATION
AND SIMULATION OF A HARVESTING
AND JUICE EXPRESSION SYSTEM FOR SWEET SORGHUM

by

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INTRODUCTION

Sorghum syrup or "molasses" is a product of the juice of certain varieties of sweet sorghum. Its distinct flavor is an old favorite for many people and in times past sorghum was considered a staple in many rural areas.

Swope (1975) points out that the domestic production of sweet sorghum has peaked twice in the past 100 years. Before the Civil War annual production was about 7 million gallons. Around 1880, production peaked at 28 million gallons as a result of sweetener shortages during the Civil War. Annual production then declined to 15 million gallons by 1915. In 1920, record production of molasses from sorghum reached 50 million gallons as a result of World War I. Production has continually declined since the 1920's, with World War II having little effect upon demand for the product. In 1975 the estimated annual production was under one million gallons.

Conventional methods which require considerable amounts of hand labor are still used in certain rural areas to harvest and "boil" sweet sorghum juice into molasses. Clark and Wright (1975) describe the traditional method of producing molasses as one which "requires a tremendous amount of hand labor per unit of product output." The conventional method requires stripping the leaves from mature plants and removing the "tops" or seed heads in the field. The bare canes are then taken to small, two- or three-roller mills for expressing of juice. Animals are sometimes used as a power source for the mills (Figure 1).

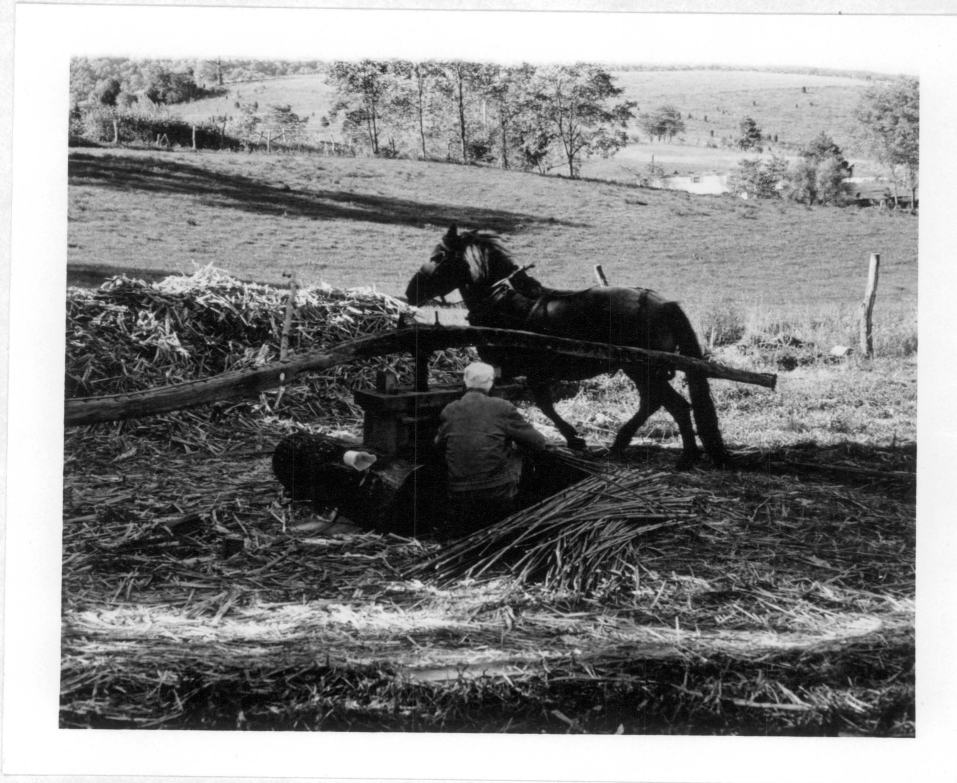


Figure 1. Traditional method of expressing juice from sweet sorghum for syrup production.

The juice from the mill is then boiled to desired consistency in large open "kettles" or pans. This process is very time-consuming and requires someone to continuously "skim" the boiling liquid to remove undesirable coagulates and other particulate matter.

Interest in sweet sorghum as a source of sweeteners should not be confined to the production of syrup. Likums (1976) reports that it should also be considered as a source of crystalline sugar. Likums reported that Lime and Smith of the Foods Corps Utilization Laboratory in Weslaco, Texas have successfully produced raw sugar from sorghum juice in factory production tests.

Research on the development of a "community-sized sorghum syrup plant" has been underway for four years at Virginia Polytechnic Institute and State University. A completely mechanized system for harvesting, expressing juice, and the rapid evaporation of juice into syrup has been designed, constructed and tested. The entire system is described in detail by Clark and Wright (1975) and by Wright et al. (1976). Chintawonganovich, Clark and Wright (1977) present a thorough description of the evaporation process. This report is concerned with evaluations and improvements of the harvesting and juice expression systems.

Data on capacities, efficiencies and time requirements of the various operations were taken. A computer program which simulates the operation of the system was compiled from data taken and experience gained with the system. The program is a dynamic model which uses several distinct input variables. The model simulates harvesting, transportation of bulk material, separation of stalk sections from bulk material and the expression of juice from stalk sections. The model

computes necessary units of harvesting and transportation equipment which will allow the separation and milling functions to operate continuously.

Throughout this study, the following principal objectives were used as guidelines:

1. To improve the performance of the harvesting and juice expression systems described by Wright et al. (1976).
2. To evaluate the system after improvements were made prior to and during the 1976 processing season.
3. To develop a computer program to simulate harvesting, hauling, and juice expression operations.

REVIEW OF LITERATURE

Culture of Sweet Sorghum

Sweet sorghum is grown similarly to corn. Two major exceptions are planting dates and the planting depth of seed. Wright *et al.* (1976) recommend planting sorghum no earlier than ten days after corn. Sorghum seed should be placed in the soil no deeper than one inch. A measure of soil temperature at one-inch depth is a more precise method of determining proper planting dates. The soil temperature should be above 65°F when measured between 7:00 a.m. and 8:00 a.m. for best planting results when sufficient moisture is available. Morning soil temperatures usually reach 65°F during the last two weeks of May in Virginia.

Clean cultivation and no-till planting procedures are the two principal methods used for planting sorghum. Freeman, Broadhead and Zummo (1973) describe clean or conventional planting methods in detail. Clark and Wright (1975) outline procedures for both conventional and no-till practices in the Virginia Highlands.

Harvest of sweet sorghum may begin as early as August 15 if the growing season has been warm. However, according to Clark and Wright (1975), the best time to harvest is when the seeds are in the "hard dough" stage because the juice contains maximum dissolved sugars at this time. Harvesting may continue until the first killing frost. Normally, a 30 to 35 day harvest season can be expected.

Harvesting and Processing of Sweet Sorghum

Sweet sorghum may be harvested and processed using any of three different methods. Conventional hand methods which require considerable

amounts of labor are often used by small operators. Most of this production is in depressed rural areas, often used by church and civic organizations for fund raising. Likums (1976) reports that expensive equipment used for handling sugar cane can easily be adapted to harvest and process sweet sorghum. Perhaps a more practical method of obtaining juice from sorghum for the small scale producer would be the method developed at Virginia Polytechnic Institute and State University (Wright, et al. 1976).

Both the VPI & SU process and the system described by Likums utilize machines which cut standing sorghum into stalk sections or billets. Gentry and Gadesho (1972) found that the quality of juice from sugar cane, which is very similar to that from sweet sorghum (as measured by refractory properties, pH, or brix) was not affected by relatively clean uniform short lengths of cut. However, deterioration of quality was found to exist when delays in milling exceeded 24 hours. It was observed at VPI & SU that milling of sorghum could be delayed as long as 48 hours without marked degradation of juice during cool weather. A brief description of the VPI & SU system follows.

The operation developed at VPI & SU was similar to that used by the Waconia Sorghum Company of Cedar Rapids, Iowa. A modified forage harvester cut standing sorghum into 5 to 6 inch lengths (Figure 2). It was necessary to operate the harvester at a relatively low forward speed (1.5 mph) and to keep cutter knives sharp in order to obtain clean cuts and avoid shattered stalks. The harvester blew the cut material into a false-end gate wagon. When full, the wagon was taken to a stationary separation system. The cut sorghum was unloaded onto a conveyor which



Figure 2. Chopping sorghum with modified forage harvester.

fed material into the system (Figure 3). Stalks were separated from other sorghum parts pneumatically. The stalks were then carried by belt to a small three-roller mill for expressing juice. A schematic of the separating system is shown in Figure 4. The system is described more fully by Wright et al. (1976). Aerodynamic properties of the leaves seed heads, individual sorghum seed and other material in the cut sorghum played an important role in the development of the separator.

Aerodynamic Characteristics of Components of Chopped Sorghum

Mohsenin (1970) developed the following general relationship for computing vertical displacement of a particle falling from rest in a fluid, such as air, in which buoyancy effects could be ignored.

$$S_v = V_t^2 \ln \cosh \frac{gt}{V_t} \quad (1)$$

where

S_v = vertical displacement

V_t = terminal velocity

g = gravitational constant

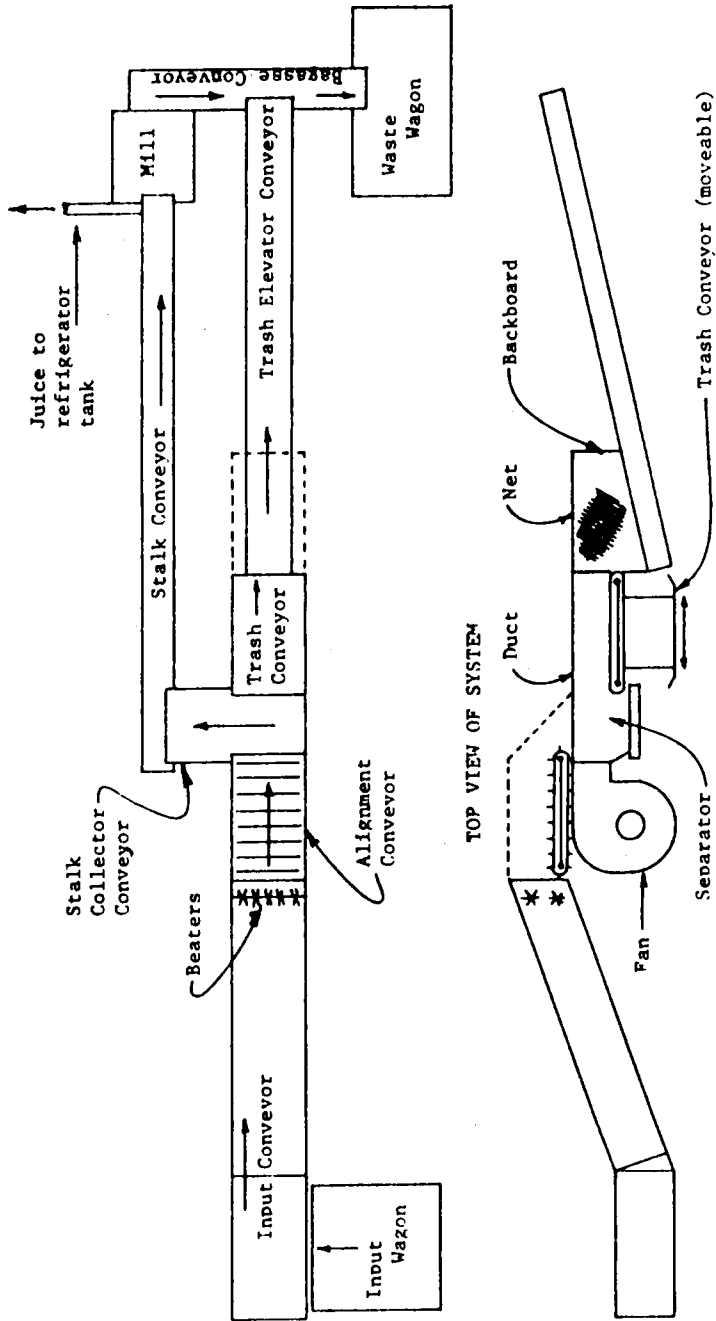
t = elapsed time of fall

Once the particle attains terminal velocity the relationship becomes:

$$S_v = V_t t \quad (2)$$



Figure 3. Wagon with "false-end gate" unloading at separation plant.



PLAN VIEW

FIGURE 4. SCHEMATIC OF SORGHUM STALK SEPARATOR

Mohsenin (1970) also computed the drag coefficient for particles falling in low density media using the following equation:

$$C_d = \frac{2 mg}{v_t^2 A_p P_f} \quad (3)$$

where

C_d = drag coefficient

m = mass of particle

A_p = frontal area of particle

P_f = mass density of fluid

Chopped sorghum can be divided into four categories:

1. Stalk sections or billets
2. Leaves and other fragments
3. Individual seeds
4. Seed heads

A knowledge of the aerodynamic properties of the various parts of chopped sorghum was essential for the development of a pneumatic system for separating billets from the other parts. Initial experience with pneumatic separation revealed that there would be few problems involved with separation of leaves and leaf fragments.

Massey (1974) conducted an investigation to determine aerodynamic characteristics for billets, individual seed, and seed heads. A drop tower designed and constructed by Bowling (1973) was used to obtain data for the study. The tower, a modification of those described by Bilanski, Collins and Chu (1962) and Keck and Goss (1965), was twenty

feet tall with provisions for inserting a catch plate at each two-foot interval.

The apparatus was constructed so that a light beam focused across an opening onto a photodiode. When the light beam was interrupted by a falling particle, the photodiode activated a relay which started an electronic counter. After the particle fell through a certain distance, it struck a catch plate. The sound of the particle striking the catch plate was sensed by a ceramic microphone, which in turn, activated another relay to stop the counter. Aerodynamic properties such as terminal velocities and drag coefficients could be calculated using time-displacement data obtained for the particles along with their measured physical properties of mass, frontal area and volume.

Massey obtained time-displacement data for individual sorghum seed, billets and seed heads. Frontal area, density and mass were determined for each of the respective sorghum parts. Drag coefficients and terminal velocities were computed using the data obtained from iterative solutions to equations 1, 2 and 3.

Pneumatic Separation of Stalk Sections from Chopped Sorghum

Aerodynamic properties determined by Massey were used to design equipment to separate stalk sections from other plant material. The basic separation concept was to drop a thin layer of plant parts into an air stream and utilize horizontal dispersion to accomplish separation.

The basic expression for drag force on a particle moving through a fluid is:

$$F = 1/2 C_d A_p P_f V^2 \quad (4)$$

where

F = resisting drag force

V = relative velocity between particle and viscous medium

Using equation (4), Massey developed the following equation to predict the horizontal displacement of a particle dropped into a horizontally flowing fluid stream:

$$F = 1/2 C_d A_p P_f (V_a - V_h)^2 = m a_h = m \frac{dV_h}{dt} \quad (5)$$

where

F = horizontal force on the particle

V_a = horizontal air velocity

V_h = horizontal particle velocity at any time, t

m = particle mass

a_h = horizontal particle acceleration

Using initial conditions, $V_h = 0$ and $S_h = 0$ at $t = 0$ equation (5) becomes:

$$S_h = V_a t - \frac{\ln(1 + V_a k t)}{k} \quad (6)$$

where

S_h = horizontal particle displacement

$$k = \frac{C_d A_p P_f}{2m}$$

Fan selection was one of the major considerations in developing the separation system. Economic and energy considerations restricted the selection of a fan for the separation system. A centrifugal blower with a 3 ft. by 4 ft. outlet producing an air stream velocity of 2600 ft./min. was selected. Using equation (6) Massey computed and plotted horizontal and vertical displacement for sorghum parts in the air stream. Dispersion of sorghum material dropped two feet before entering the air stream is shown in Figure 5. Figure 6 shows dispersion of material released directly into the stream, indicating that the best separation would take place for material dropped directly into the air stream.

Computer Simulation of Agricultural Systems

Brown (1968) points out that farmers have difficulty in finding the right machine combination for their farm operations. Suppliers of farm credit accuse farm machinery of being a major culprit in farm business failures. Management studies have shown that some farms are under-mechanized and others are over-mechanized. Optimum returns cannot be expected under either of these situations. Brown summarizes, "An efficient farm machinery system is one that provides the machine services which a farm requires in a satisfactory manner with regard to timeliness, work quality and cost."

In recent years investigators have used computer simulation techniques to solve machinery management problems. Waund and Mundell (1968) report that the Green Giant Company uses computer models for decision making in three basic areas:

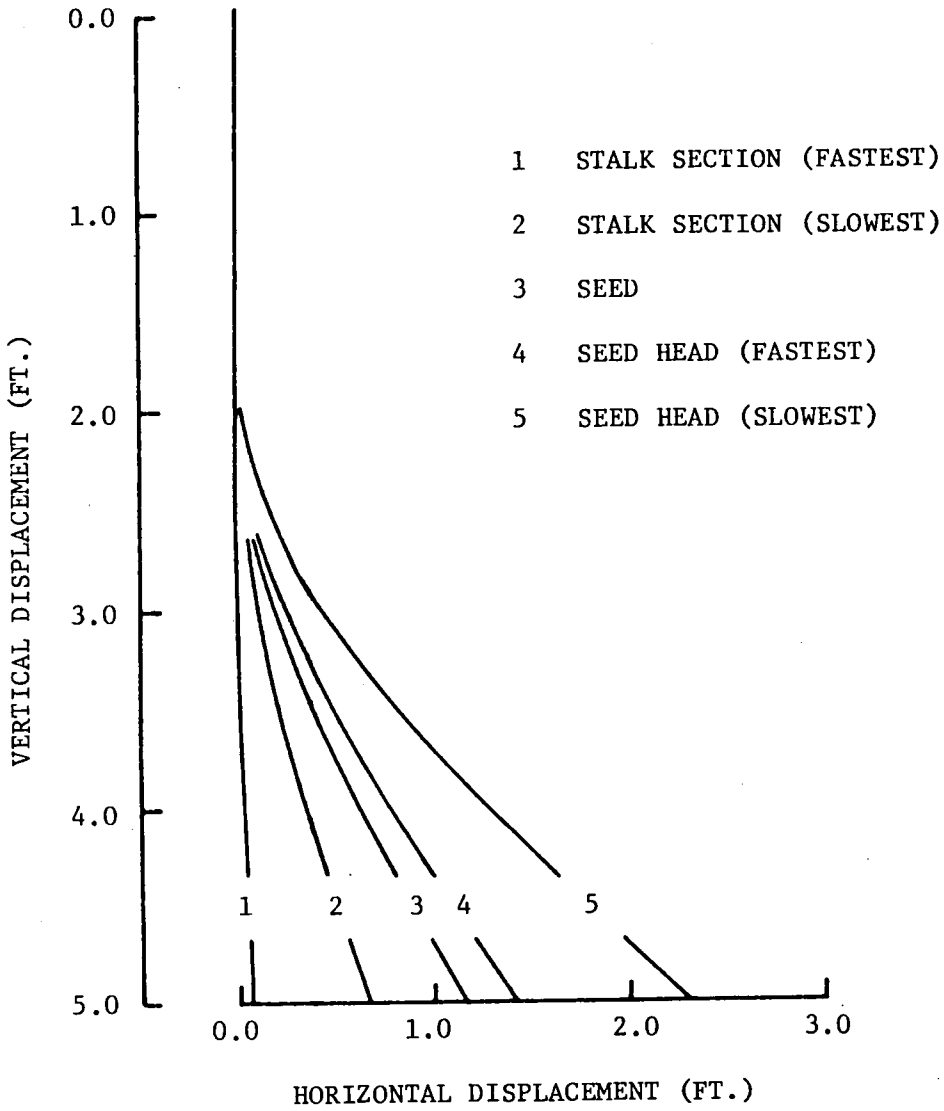


FIGURE 5. HORIZONTAL VS. VERTICAL DISPLACEMENT FOR PLANT PARTS DROPPED FROM A DISTANCE OF 2 FT. BEFORE ENTERING THE HORIZONTAL AIR STREAM OF 2600 FT/MIN.

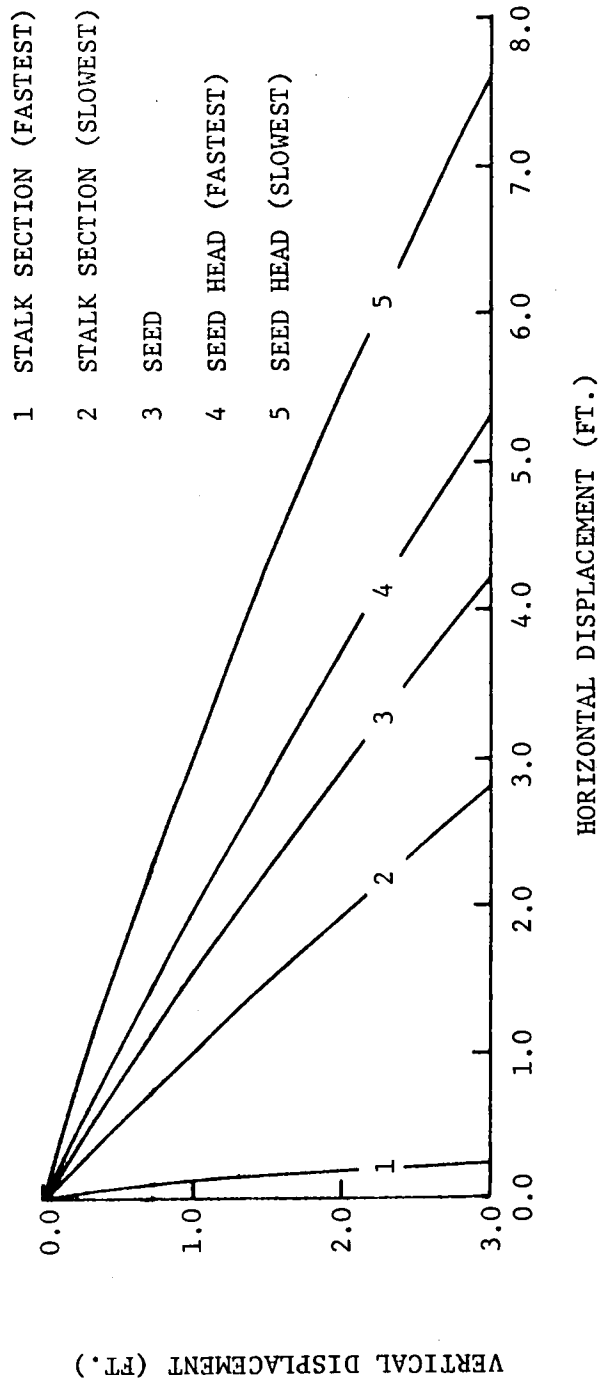


FIGURE 6. HORIZONTAL VS. VERTICAL DISPLACEMENT FOR PLANT PARTS RELEASED DIRECTLY INTO THE HORIZONTAL AIR STREAM OF 2600 FT/MIN.

1. Product mix by plant
2. Harvesting plans by area
3. Equipment and facilities plans

Plans for these activities are now developed in a day's time rather than weeks or months.

Van Bargaen and Peart (1973) constructed a computer model which simulated planter performance and supporting activities. Field efficiency was used as a measure of machine performance. Such factors as undesirable interruptions, travel time and service activities were included in the model. Idle time, or time that the planter was capable of operating but not functioning because of supporting activities, was evaluated using the model. The Van Bargaen and Peart model compared favorably with the performance of 14 corn planting systems in Indiana. The researchers concluded that savings could be made in materials handling of bagged seed, insecticide and herbicide.

Shukla, Chisholm and Phillips (1973) used a computer program for evaluating sugar cane harvesting, loading and transportation systems which supply the daily grinding capacities of a sugar mill. The program was designed to allow for wide variation of applications throughout the sugar cane growing areas. Economic differences resulting from the use of various sugar cane harvesters were demonstrated using this model.

Hughes (1975) developed a static and deterministic model which simulated silage transporting. The model used energy and labor as measures of system effectiveness. Storage locations and transportation systems had a profound effect upon the length of the harvest

season until harvesting capacity became a limiting factor. Storage locations near fields were found to reduce labor and energy requirements for harvesting and feeding systems. However, Hughes points out that the model was inadequate and that several feeding locations, definite feeding schedules, multiple crops, multiple storage locations and decision processes should be included.

Mears, Shiano and Singley (1976) developed a model of a proposed asparagus packing line. The purpose of the simulation was to determine the feasibility of developing a commercial packing line to handle non-selectively mechanically-harvested asparagus. The investigators were able to predict that by cost analysis and maximum utilization of the packing line, the proposed system should be profitable to the farmer, processor and retailer assuming further increases in hand harvesting cost occur in relation to selling price.

The preceding examples show that computer simulation is a valuable tool for evaluating agriculture systems. However, models should be constructed with care and be made as general as possible to allow wide application. Another advantage is that proposed physical systems can be evaluated before they are actually constructed. Thus, a computer model would be a very useful tool in evaluating a system to process sweet sorghum.

MATERIALS AND METHODS

A Description of the VPI and SU Sorghum Separation System

The forage harvester modified by Wright et al. (1976) was used to cut standing sorghum in the field. The harvester was a single row machine drawn by a tractor. A wagon with a false end-gate was hitched to the rear of the harvester for collecting material. The loads of sorghum were pulled to the separation plant by tractor.

Utilizing the aerodynamic characteristics of sorghum plant parts, a separation system was designed and constructed at VPI & SU. Figure 4 is a schematic of the system as operated in the fall season of 1975. Cut material was unloaded from wagons into the horizontal portion of the input conveyor. From the input conveyor it was metered with rotating beaters, and by controlling input conveyor speed, onto an alignment conveyor which served to orient the central axes of the stalk sections and seed heads into a position perpendicular to the direction of material flow. The alignment conveyor then delivered the material in a thin layer into the air stream produced by the centrifugal fan, where it was dispersed horizontally. The stalk sections, which were least affected by the air stream, tended to fall onto the collector conveyor which delivered them to the stalk conveyor. This conveyor, in turn, carried the stalk sections to a mill where the juice was expressed from them. The trash conveyor, which formed a portion of the bottom of the air duct beyond the stalk conveyor, intercepted the seed heads, loose seed and leaves and transferred this material to a trash elevator.

The position of this conveyor over the collector conveyor was adjustable so that separation of plant parts could be maximized.

Bagasse from the mill and material from the trash elevator were deposited on another elevator which carried the waste material to a wagon for later disposal. A 1/8 inch mesh nylon netting extended beyond the end of the air duct over the trash elevator and separated leaves and other waste material from the air stream (Figure 7). Clark and Wright (1975) describe this system in greater detail.

Equipment Alterations

Several equipment additions were made to the separation system in preparation for the 1976 processing season to reduce labor, improve performance, and make it easier to operate. A set of leveling beaters was installed to maintain a constant depth of material on the input conveyor. Previously leveling was accomplished by hand. Additional measures for speed control of the input conveyor were designed. A hydraulically controlled unit was installed to make possible the instant adjustment of the trash conveyor position as needed during processing. Changes were made in the alignment conveyor to allow cut material to fall directly into the air stream without any initial drop. Additional netting was installed to improve leaf-air separation.

The two leveling beaters (Figure 8) were each 24 inches in diameter and constructed with a 1-inch diameter axle centered inside a 4-inch pipe from which 1/2-inch rods, 10 inches long extended radially. The rods were spaced 1 inch apart longitudinally in a spiral pattern of 8-inch pitch. The beaters were supported on each end with pillow



Figure 7. Netting which served to separate leaves and other waste material from air stream.

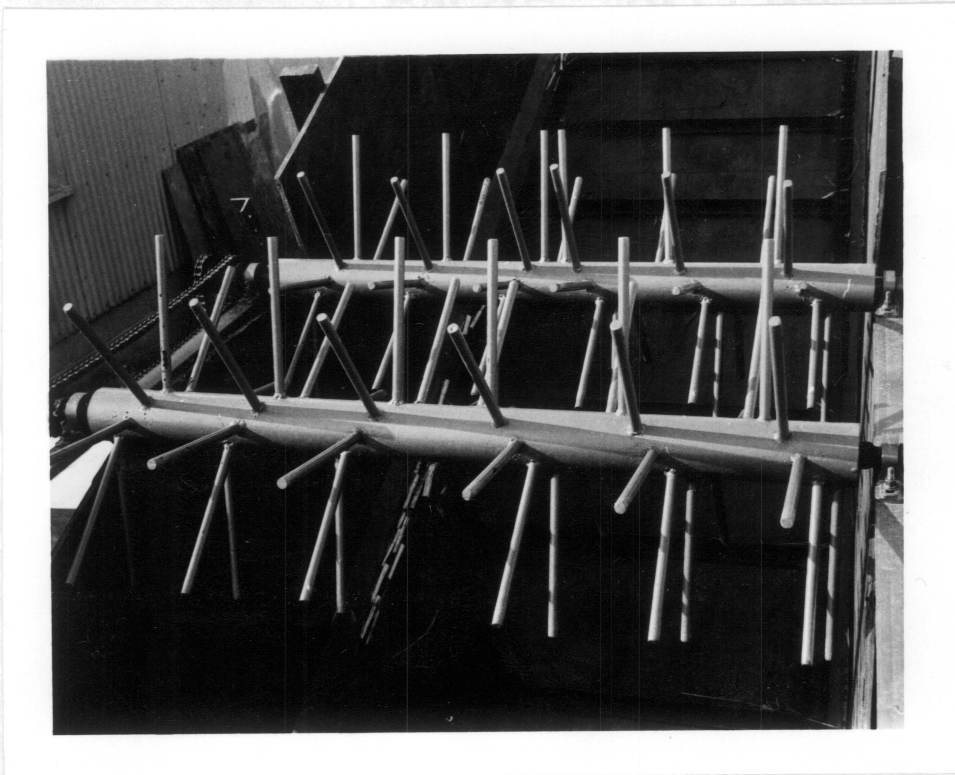


Figure 8. Leveling beaters for cut material mounted above input conveyor.

block ball bearings. Power was supplied by a 1/2 hp. 30 r.p.m. gear head electric motor through a roller chain drive system. Provisions were included for adjusting the leveling depth.

Problems had previously been encountered in attaining input conveyor speeds slow enough to match capacities of the other components in the separation system. These were solved by placing a 4-speed truck transmission in series with the existing 3-speed transmission which, in turn, was powered by a hydraulic motor (Figure 9). This combination provided 13 different gear combinations for speed control plus the additional control available by varying oil flow to the hydraulic motor. Thus, input conveyor speed could be varied to meet operating requirements during processing and also provide higher speeds for initial filling.

A unit consisting of an inclined conveyor belt and stalk collection conveyor mounted in a frame was installed below the air duct to aid in separation (Figure 10). The stalk collection conveyor was mounted in a horizontal plane at the bottom of the frame. The forward roller of the inclined conveyor was mounted with pillow block bearings at the top of the frame and served as a pivot for the conveyor. A hydraulic cylinder mounted to a cross-member underneath and at the bottom end of the inclined conveyor was used to vary its angle of inclination. The entire unit hung from tracks mounted on either side of the air duct. Another hydraulic cylinder was attached between the frame of the unit and the base of the fan, allowing for adjustments necessary to collect stalks displaced by the air stream. This controlled

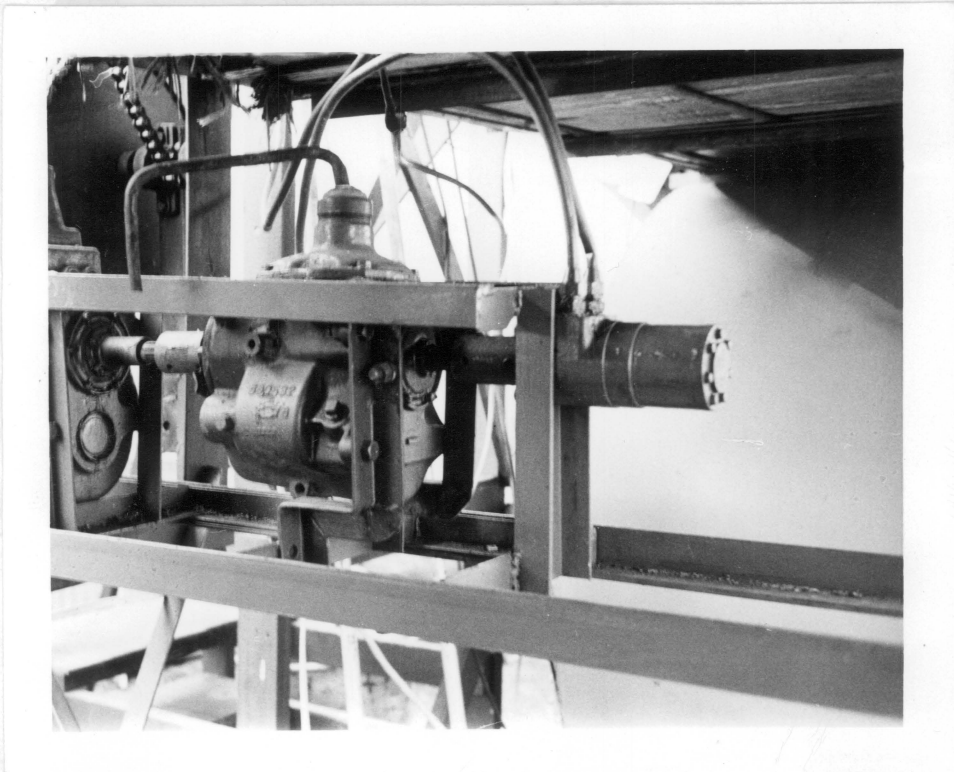


Figure 9. Three-speed and four-speed transmissions coupled in series for speed control of input conveyor.

Standardized
ARTESIAN BOND
FOR COTTON FIBER

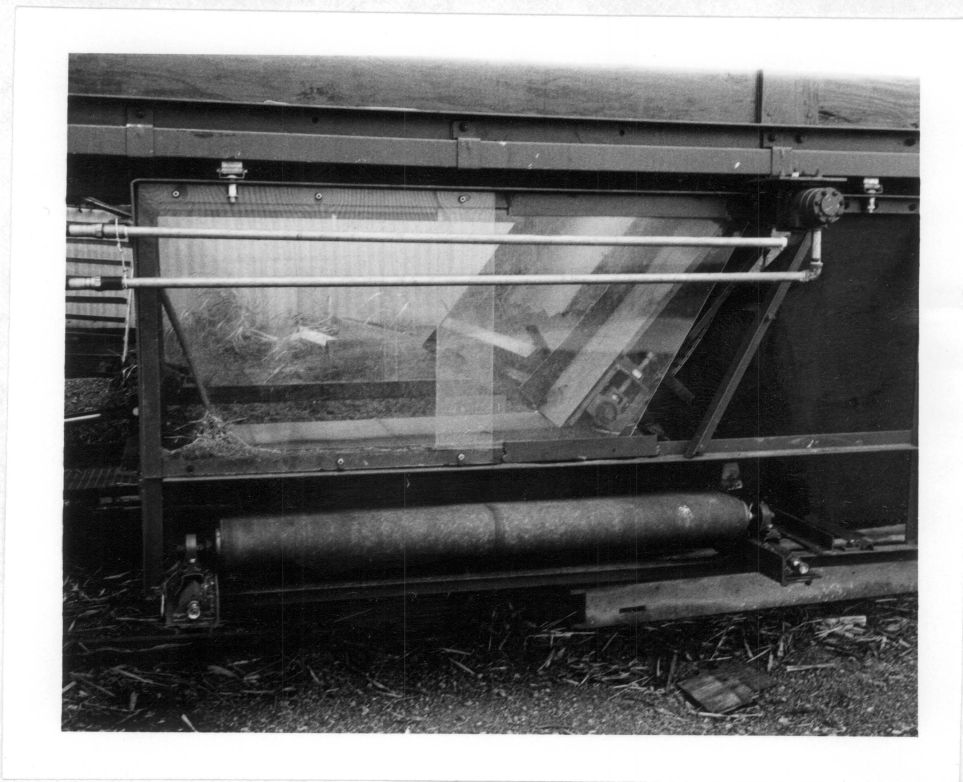


Figure 10. Unit containing stalk collection conveyor and inclined separation belt.

the amount of material falling on the collector conveyor and optimal separation could easily be obtained. The inclined conveyor was powered with a hydraulic motor and its speed was adjustable by varying the oil flow to the motor. The stalk collector conveyor was powered by a 1/4 hp. 15 r.p.m. gear reduction electric motor. Sufficient hydraulic power to operate the two cylinders and the motor for the inclined belt was available from the existing hydraulic system.

The alignment conveyor used in the 1975 season dropped chopped material from the top of the conveyor for a distance of approximately 6 inches before it entered the air stream. According to Massey (1974), however, the material should drop directly into the air stream (Figures 5 and 6). To correct this, the direction of the alignment conveyor was reversed and material was carried to the air stream on the bottom side in an "under shot" configuration, thus allowing the material to fall directly into the air stream.

Other steps taken to improve the system included making various components of the system such as electric motor mountings more rigid and reliable. It was also necessary to reorganize various conveyors and elevators to install the inclined separator belt unit. The nylon net which served as a leaf-air separator was extended to obtain better separation.

Sorghum Culture for Test Material

Approximately 8 acres of sweet sorghum were grown for testing and evaluating the experimental system. Varieties were Sugar Drip (4.20 acres), Red Amber (1.78 acres), Dale (1.78 acres), and Mer (0.24 acres).

The plots were sprayed for weed and grass control on the sixth and seventh of May with a per acre tank mix of Aatrex at a rate of 4.53 pounds and Paraquat at 0.3 gallons applied with 54 gallons of water. A non-ionic surfactant was also added to the mix. The soil was damp at the time of application.

The sorghum was planted on May 24 and 25 using no-till methods. The planter was a two-row Allis Chalmers model modified for no-tillage planting and equipped with sorghum plates. Furadan at 14 lbs/acre was applied with the seed. The seed was treated with Isotox at a rate of 4 ounces per 100 lb. of seed. Table 1 shows the seed rates used for the different varieties of sorghum planted.

Fertilizer (10-10-10 analysis) was broadcast on June 1 at a rate of 519 lbs/acre.

The growing season was dry during late summer and early fall. The effects of the drought were quite pronounced in those portions of the field which were high and of light soil texture. However, in the heavier soils, in the lower parts of the field, stands were good and the crop appeared to be unaffected by the dry weather.

Harvesting and processing operations were started September 19 and discontinued October 14 when the first killing frost occurred. The seeds were in the "milk stage" when operations began. A total of 14 loads or approximately 29 tons of sorghum were harvested and processed. The remaining crop was given to local farmers for hand harvesting and data was taken for comparison with the processing techniques of the VPI & SU system. Sections of the field most affected

TABLE 1. SEED RATES AND PLANTING DATES FOR SWEET SORGHUM.

VARIETY	PLANTING DATE	SEED RATE (LBS/AC)	SEED RATE (KG/HA)
DALE	5-24-76	4.56	5.11
MER	5-24-76	3.64	4.08
RED AMBER	5-24-76	4.28	4.80
SUGAR DRIP	5-24-76	3.94	4.42

by the drought were left standing. Table 2 contains chopped sorghum yield data for the portions of the crop harvested.

Time Studies

Aggregated time study data were taken to evaluate the performance of the VPI & SU system. These data were useful in evaluating results of the 1976 season and in compiling a computer program to simulate the system. The entire system was divided into three areas for taking the time study data. These were:

1. Harvesting
2. Transportation
3. Separation and Juice Expression

A wagon was brought from the plant to an exchange point near the field where it was hitched to the harvester. The machinery train consisting of tractor, harvester, and wagon would then move to an area in the field for harvesting. When the wagon was full, the train would return to the exchange point to unhitch the wagon. Times required to complete the following activities were recorded:

1. Hitching at exchange point
2. Total time the machinery was in the field
3. The time the harvester was actually cutting sorghum
4. The time required for unhitching the wagon at the exchange point and hitching it to tractor for transport

The time required for the tractor to pull a loaded wagon to the plant and the time elapsed for the tractor to return to the field were

TABLE 2. YIELD DATA FOR SWEET SORGHUM HARVESTED.

VARIETY	MASS HARVESTED (LBS)	AREA HARVESTED (AC)	AREA HARVESTED (HA)	BULK YIELD (LBS/AC)	BULK YIELD (KG/HA)
DALE	8820.0	0.40	0.16	22050.0	24715.0
MER *	-----	-----	-----	-----	-----
RED AMBER	22932.0	1.29	0.52	17777.0	19925.0
SUGAR DRIP	69604.0	2.58	1.04	26979.0	30239.0

* MER DID NOT MATURE.

both recorded for each round trip. The average distance to the field was 1785 feet.

Once the loaded wagon reached the plant it was weighed using portable highway-type truck scales. When weighing was completed, the system and wagon were prepared for unloading into the input conveyor. The time required to complete this process was termed set-up time. After set-up, the wagon unloading commenced and continued until the wagon was empty or the input conveyor was full. Processing was then started. Interruptions were made during processing to make adjustments, conduct tests, make observations and maintain the system. The following were recorded:

1. Weigh time
2. Set-up time
3. Unloading time
4. Total processing time for each load
5. Actual processing time for each load, exclusive of interruptions.

Procedures Used for Obtaining Product Data

The net weights of each load of chopped sorghum and the juice expressed from the separated stalks were recorded. The sugar content in degrees brix for the juice from each load was also determined and corrected to 20°C.

The juice from each load of sorghum was collected in a tank which rested on platform scales. When processing was completed for a

load, a reading was taken from the scales and the net weight of juice was computed.

Procedures Used for Determining the Performance of the Separator

The effectiveness of the pneumatic separator and the inclined belt was tested by separating 25 to 50 pounds of material in each of six different runs. The separated material was collected from the stalk conveyor and trash elevator in separate containers (Figure 4). The material from each was then divided into three categories:

1. stalk sections
2. seed heads
3. leaves and debris

The material from each group was weighed and the weights recorded. Individual seeds were not separated from the other material because the ones on the belt carrying material to the mill for juice expression fell through the flat wire mesh of the stalk conveyor belt and did not enter the mill.

The stalk sections from each belt were further analyzed by dividing them according to diameter into four groups, 0 - 1/4, 1/4 - 1/2, 1/2 - 3/4, 3/4 - 1 inches. Juice was expressed from each group using a Carver Laboratory Press. Juice weights and brix readings were taken and recorded.

RESULTS AND DISCUSSION

Evaluation of Performance of the Separation System

The performance of the separation system was evaluated by collecting 6 samples of the separated material. Samples 1-3 were of Sugar Drip variety and samples 4-6 were Dale. The material on the stalk conveyor and the material on the trash conveyor (refer to Figure 4) were collected in separate containers. The material in each container was divided into groups consisting of distinct sorghum parts and each group was weighed. The stalks from samples 4-6 were divided into categories according to diameter and further analyzed.

Tables 3 and 4 show the mass of sorghum parts on the trash and stalk belts, respectively. The masses from the two tables were combined in Table 5 to obtain the mass distribution of the material before separation.

The distribution of sorghum parts in percent of the mass of material before separation is given in Table 6. The percent of seed heads for Dale was much less than that for Sugar Drip. This was expected because the seed heads for Dale appeared to be smaller than those of the Sugar Drip variety. The percent of stalks was high and the percent of leaves and debris was low for Dale. This was caused, in part, by desiccation of the leaves following two light frosts that occurred before harvesting of this variety began.

Table 7 presents the distribution of plant parts on the trash conveyor. The percent of stalks for Dale samples was much higher than that for Sugar Drip. Two factors affected this. First, the total

TABLE 3. MASS DISTRIBUTION OF SORGHUM PARTS ON TRASH CONVEYOR AFTER SEPARATION.

SAMPLE NUMBER	SEED HEADS		STALKS		LEAVES AND DEBRIS		TOTAL PARTS	
	(LBS)	(KG)	(LBS)	(KG)	(LBS)	(KG)	(LBS)	(KG)
1	2.563	1.163	3.688	1.673	10.750	4.876	17.001	7.71
2	3.625	1.644	10.875	4.933	16.000	7.257	30.500	13.834
3	2.751	1.247	6.250	2.835	16.250	7.371	25.250	11.453
4	0.500	0.227	3.750	1.701	3.313	1.503	7.563	3.431
5	0.813	0.369	3.313	1.503	2.563	1.162	6.689	3.034
6	0.500	0.227	3.500	1.588	2.875	1.304	6.875	3.118
AVERAGE FOR SUGAR DRIP (SAMPLES 1-3)								
	2.979	1.351	6.938	3.147	14.333	6.501	24.250	10.000
AVERAGE FOR DALE (SAMPLES 3-6)								
	0.664	0.274	3.521	1.597	2.917	1.323	7.042	3.190
OVERALL AVERAGE								
	1.792	0.813	5.229	2.372	8.625	3.912	15.646	7.100

TABLE 4. MASS DISTRIBUTION OF SORGHUM PARTS ON STALK CONVEYOR AFTER SEPARATION.

SAMPLE NUMBER	SEED HEADS		STALKS		LEAVES AND DEBRIS		TOTAL PARTS	
	(LBS)	(KG)	(LBS)	(KG)	(LBS)	(KG)	(LBS)	(KG)
1	0.266	0.121	16.438	7.456	0.135	0.061	16.839	7.68
2	0.398	0.181	18.625	8.448	0.234	0.106	19.257	8.735
3	0.683	0.310	20.438	9.270	0.416	0.189	21.537	9.769
4	0.188	0.085	19.250	8.732	0.125	0.057	19.563	8.874
5	0.250	0.113	20.438	9.271	0.125	0.057	20.813	9.441
6	0.375	0.170	21.313	9.667	0.250	0.113	21.938	9.951
AVERAGE FOR SUGAR DRIP (SAMPLES 1-3)								
	0.449	0.204	18.500	8.390	0.262	0.119	19.211	8.710
AVERAGE FOR DALE (SAMPLES 3-6)								
	0.271	0.113	20.334	9.220	0.167	0.076	20.771	9.420
OVERALL AVERAGE								
	0.361	0.164	19.417	8.810	0.214	0.097	19.991	9.060

TABLE 5. MASS DISTRIBUTION OF SORGHUM PARTS BEFORE SEPARATION.

SAMPLE NUMBER	SEED HEADS (LBS)	(KG)	STALKS (LBS)	(KG)	LEAVES AND DEBRIS (LBS)	(KG)	TOTAL PARTS (LBS)	(KG)
1	2.829	1.283	20.126	9.129	10.885	4.937	33.840	15.350
2	4.023	1.824	29.500	13.381	16.234	7.364	49.757	22.569
3	3.433	1.557	26.688	12.105	16.666	7.560	46.787	21.222
4	0.688	0.312	23.000	10.433	3.438	1.559	27.125	12.304
5	1.063	0.482	23.751	10.773	2.688	1.219	27.502	12.475
6	0.875	0.397	24.813	11.255	3.125	1.417	28.813	13.069
AVERAGE FOR SUGAR DRIP (SAMPLES 1-3)								
	3.428	1.555	25.438	11.538	14.596	6.621	43.461	19.714
AVERAGE FOR DALE (SAMPLES 3-6)								
	0.875	0.397	23.855	10.820	3.084	1.399	27.813	12.616
OVERALL AVERAGE								
	2.152	0.976	24.646	11.179	8.839	4.009	35.637	16.165

TABLE 6. DISTRIBUTION OF SORGHUM PARTS IN PERCENT OF THE MASS OF MATERIAL BEFORE SEPARATION.

SAMPLE NUMBER	SEED HEADS	STALKS	LEAVES AND DEBRIS
1	8.36	59.47	32.17
2	8.09	59.29	32.63
3	7.34	57.04	35.62
4	2.54	84.79	12.67
5	3.87	86.36	9.77
6	3.04	86.12	10.84
AVERAGE FOR SUGAR DRIP (SAMPLES 1-3) 7.93			
AVERAGE FOR DALE (SAMPLES 3-6) 3.15			
OVERALL AVERAGE 5.54			

TABLE 7. DISTRIBUTION OF SORGHUM PARTS ON TRASH CONVEYOR IN PERCENT OF THE MASS OF MATERIAL ON THE CONVEYOR.

SAMPLE NUMBER	SEED HEADS	STALKS	LEAVES AND DEBRIS
1	15.08	21.69	63.23
2	11.89	35.66	52.46
3	10.89	24.75	64.36
4	6.61	49.58	43.81
5	12.15	49.53	38.32
6	7.27	50.91	41.82
AVERAGE FOR SUGAR DRIP (SAMPLES 1-3)			
	12.62	27.37	60.02
AVERAGE FOR DALE (SAMPLES 3-6)			
	8.68	50.01	41.31
OVERALL AVERAGE			
	10.65	38.69	50.66

material before separation had a higher percentage of stalks. Second, the Dale was grown in an area of the field most affected by drought and the chopped sorghum had a higher percentage of small stalks which were more susceptible to being blown into the trash. However, not all of the stalks were small. One section of the plot in a low area grew high standing stalks of large diameter.

The distribution of material on the stalk belt is shown in Table 8. The distribution indicates that the material to be expressed was relatively free from seed heads, leaves and debris. Very little difference was observed here for the two varieties except in the case of seed heads. The higher percentage for Sugar Drip was most likely attributable to the relative size of the seed heads.

Other indicators of separator performance are shown in Table 9. The percent of total stalks on the stalk belt was higher for Dale than for Sugar Drip. The reason for this is not clearly understood. However, the high percentage of stalks in the Dale before separation was probably a contributing factor. The high percentage of total seed heads on the stalk belt may also be misleading because the material before separation contained very few seed heads (Table 6).

Not all of the stalks separated with the trash were desirable for syrup production. Coleman (1970) reported that the top 4 internodes of sweet sorghum represent about 18% of the stalk weight and are higher in titratable acids, starch and sucrose than the remainder of the stalk. When the top 3 or 4 internodes were removed the finished syrup had less starch, contaminant jelling, "less bite" and the syrup yield was

TABLE 8. DISTRIBUTION OF SORGHUM PARTS ON STALK CONVEYOR IN PERCENT OF THE MASS OF MATERIAL ON THE CONVEYOR.

SAMPLE NUMBER	SEED HEADS	STALKS	LEAVES AND DEBRIS
1	1.58	97.62	0.80
2	2.07	96.72	1.22
3	3.17	94.90	1.93
4	0.96	98.40	0.64
5	1.20	98.20	0.60
6	1.71	97.15	1.14
AVERAGE FOR SUGAR DRIP (SAMPLES 1-3) 2.27			
AVERAGE FOR DALE (SAMPLES 3-6) 1.29			
OVERALL AVERAGE 1.78			

1.32

0.79

1.06

96.41

97.92

97.16

TABLE 9. OTHER INDICATORS OF THE PERFORMANCE OF SEPARATOR.

SAMPLE NUMBER	PERCENT OF TOTAL STALKS ON STALK BELT	PERCENT OF TOTAL SEED HEADS ON STALK BELT	PERCENT OF TOTAL LEAVES ON STALK BELT
1	81.68	9.40	1.24
2	63.14	9.89	1.44
3	76.58	19.90	2.50
4	83.70	27.33	3.64
5	86.05	23.52	4.65
6	85.89	42.86	8.00

AVERAGE FOR SUGAR DRIP (SAMPLES 1-3)	73.80	13.07	1.73
AVERAGE FOR DALE (SAMPLES 3-6)	85.22	31.23	5.43
OVERALL AVERAGE	79.51	22.15	3.58

decreased only slightly. Because the smaller stalk pieces usually come from the upper sections of the plant, they are the least desirable for the production of quality syrup.

The stalks of the Dale samples taken from the trash and stalk conveyors were divided into categories according to size. They were counted, weighed and then the juice expressed and weighed. Brix readings for the juice were taken and adjusted for temperature. These results are tabulated in Tables 10 and 11. Most of the stalks on the trash conveyor were small, the majority falling below 0.5 inches in diameter. The total number of stalks less than 0.25 inches in diameter were divided almost equally between the two conveyors. Approximately 12 percent of those larger than 0.25 inches were on the stalk conveyor and 88 percent on the trash conveyor.

The juice yield per stalk increased with the stalk diameter. This is not surprising since one would expect the juice yield to be a function of the diameter squared. The brix of the juice increased only slightly with stalk diameter. The relative location of the stalk sections could not be determined from the chopped sorghum. It is reasonable to assume, however, that the majority of the small stalk sections on the trash belt were from the upper nodes of standing sorghum and were undesirable for quality syrup production.

Evaluation of Time and Motion Data

Time and Motion data were collected for each of the 14 loads of sorghum harvested and processed. Times required to complete various activities in the harvesting operation are listed in Table 12.

TABLE 10. WEIGHT OF STALKS AND JUICE PRODUCED FROM STALKS ON TRASH CONVEYOR DIVIDED INTO CATEGORIES ACCORDING TO STALK SIZE (DALE VARIETY).

SAMPLE NUMBER	STALK (IN)	STALK DIAMETER (CM)	NUMBER OF STALKS	WEIGHT OF STALKS (OZ)	STALKS (GM)	JUICE (OZ)	JUICE YIELD (GM)	BRIX AT 20 C
4	0.00-0.25	0.000-0.635	122	16	454	2.82	79.9	13.2
	0.25-0.50	0.635-1.270	85	35	992	16.00	453.7	13.7
	0.50-0.75	1.270-1.905	5	4	113	2.21	62.7	14.1
	0.75-1.00	1.905-2.540						
	TOTALS FOR SAMPLE			<u>212</u>	<u>55</u>	<u>1559</u>	<u>21.03</u>	<u>596.1</u>
5	0.00-0.25	0.000-0.635	122	15	425	4.97	140.8	13.4
	0.25-0.50	0.635-1.270	99	30	850	11.75	333.1	13.6
	0.50-0.75	1.270-1.905	6	5	141	3.28	93.1	14.3
	0.75-1.00	1.905-2.540						
	TOTALS FOR SAMPLE			<u>227</u>	<u>50</u>	<u>1416</u>	<u>20.00</u>	<u>567.0</u>
6	0.00-0.25	0.000-0.635	151	23	652	8.08	229.1	12.7
	0.25-0.50	0.635-1.270	80	17	482	11.23	318.3	13.8
	0.50-0.75	1.270-1.905	9	7	198	2.76	78.4	13.9
	0.75-1.00	1.905-2.540						
	TOTALS FOR SAMPLE			<u>240</u>	<u>47</u>	<u>1332</u>	<u>22.07</u>	<u>625.8</u>

TABLE 11. WEIGHT OF STALKS AND JUICE PRODUCED FROM STALKS ON STALK CONVEYOR DIVIDED INTO CATEGORIES ACCORDING TO STALK SIZE (DALE VARIETY).

SAMPLE NUMBER	STALK DIAMETER (IN)	STALK DIAMETER (CM)	NUMBER OF STALKS	WEIGHT OF STALKS (OZ)	STALKS (GM)	JUICE YIELD (OZ)	JUICE YIELD (GM)	BRIX AT 20 C
4	0.00-0.25	0.000-0.635	150	22	624	8.81	249.7	13.3
	0.25-0.50	0.635-1.270	332	128	3628	58.47	1657.7	13.8
	0.50-0.75	1.270-1.905	145	125	3544	65.84	1866.4	14.3
	0.75-1.00	1.905-2.540	22	27	765	15.18	430.4	13.4
	TOTALS FOR SAMPLE		649	302	8562	148.30	4204.2	14.0
5	0.00-0.25	0.000-0.635	158	23	652	8.72	247.2	13.6
	0.25-0.50	0.635-1.270	406	134	3799	58.37	1654.7	14.2
	0.50-0.75	1.270-1.905	145	125	3543	61.45	1742.2	14.2
	0.75-1.00	1.905-2.540	28	39	1106	22.53	638.6	13.7
	TOTALS FOR SAMPLE		737	321	9100	151.07	4282.7	14.1
6	0.00-0.25	0.000-0.635	140	22	624	8.02	227.3	13.4
	0.25-0.50	0.635-1.270	389	155	4394	66.02	1871.7	14.0
	0.50-0.75	1.270-1.905	149	129	3657	63.23	1792.5	14.0
	0.75-1.00	1.905-2.540	18	24	680	12.96	367.3	12.9
	TOTALS FOR SAMPLE		696	330	9355	150.23	4258.8	13.9

TABLE 12. TIME STUDY DATA FOR HARVESTING OPERATION.

LOAD NO.	MASS OF SORGHUM IN EACH LOAD (LBS)	MASS OF SORGHUM (KG)	HITCH TIME (MIN)	UNHITCH TIME (MIN)	FIELD OPERATION TIME (MIN)	ACTUAL HARVEST TIME (MIN)	TOTAL HARVEST TIME (MIN)
1	3710.0	1683.0	4.52	2.10	43.00	19.65	49.62
2	3550.0	1610.0	5.65	2.21	38.00	27.60	45.68
3	4060.0	1842.0	4.15	2.36	39.00	22.35	45.51
4	5690.0	2581.0	5.20	2.35	52.00	35.65	59.55
5	3890.0	1764.0	3.87	2.19	32.00	21.67	38.06
6	4110.0	1864.0	2.15	4.61	40.00	22.66	46.76
7	4230.0	1919.0	4.65	2.52	60.00	40.67	67.17
8	4120.0	1869.0	2.84	2.80	60.00	32.40	65.64
9	3760.0	1706.0	4.40	3.55	50.00	29.47	57.95
10	4320.0	1960.0	3.69	2.95	60.00	35.16	66.64
11	3140.0	1424.0	5.28	2.55	109.00	22.47	116.83
12	4270.0	1937.0	6.69	5.58	67.00	32.39	79.27
13	4030.0	1828.0	4.75	2.29	38.00	20.40	45.04
14	4790.0	2173.0	3.30	3.05	39.00	24.81	45.35
OVERALL AVERAGE	4119.0	1868.0	4.37	2.94	51.93	21.67	59.23

NOTE: LOADS 1-6,9,10 WERE SUGAR DRIP VARIETY.
LOADS 7,8,11,12 WERE RED AMBER VARIETY.
LOADS 13,14 WERE DALE VARIETY.

Theoretical material capacity was calculated by dividing the mass of material in each load by the actual harvest time, i.e., the time that the harvester was actually cutting sorghum. Effective material capacity for the harvesting operation was obtained by dividing the total harvest time into the material harvested for each load. Field efficiency for the operation is the ratio in percent of actual harvest time and the total harvest time. These parameters are presented in Table 13. The average efficiency was low because the field was very irregular in shape and particularly because of muddy conditions during the harvesting of load number 11.

Travel times and speeds of tractors and wagons en route to the separation system are shown in Table 14. It was necessary to cross a highway in the transport route and the travel times reported include waiting times at the highway. Speeds were computed using an average distance to the field of 1785 feet (544m).

Table 15 shows the time study data for separation and juice expression. Down time to conduct tests and make various changes in the system is included in the total process time. Actual process time is also recorded. Times required for weighing, making set-ups and unloading are listed in the table and summed to obtain the preparation time recorded for each load.

Parameters for the separation and juice expression system are presented in Table 16. Theoretical material capacity for each load was obtained by dividing the actual processing time into the net weight of each load. Effective material capacity is the net weight divided by

TABLE 13. PARAMETERS FOR HARVESTING OPERATION. *

LOAD	THEORETICAL MATERIAL CAPACITY (TONS/HR)	EFFECTIVE MATERIAL CAPACITY (KG/HR)	EFFECTIVE MATERIAL CAPACITY (TONS/HR)	MATERIAL CAPACITY (KG/HR)	FIELD EFFICIENCY (PERCENT)
1	5.664	5138.0	2.243	2035.0	39.60
2	3.859	3501.0	2.322	2106.0	60.18
3	5.450	4944.0	2.676	2427.0	49.11
4	4.788	4344.0	2.866	2600.0	59.87
5	5.385	4885.0	3.066	2781.0	56.94
6	5.441	4936.0	2.637	2392.0	48.46
7	3.120	2830.0	1.889	1714.0	60.55
8	3.815	3461.0	1.883	1708.0	49.36
9	3.828	3473.0	1.947	1766.0	50.85
10	3.686	3344.0	1.945	1764.0	52.76
11	4.192	3803.0	0.806	731.0	19.23 **
12	3.955	3588.0	1.616	1466.0	40.86
13	5.926	5376.0	2.684	2435.0	45.29
14	5.792	5254.0	3.169	2875.0	54.71
OVERALL AVERAGE	4.636	4206.0	2.268	2057.0	49.13

* TERRAIN WAS HILLY AND FIELD WAS VERY IRREGULAR IN SHAPE.

** A RAIN OCCURED THE NIGHT BEFORE AND DIFFCULTY WAS ENCOUNTERED IN HARVESTING.

TABLE 14. TIME STUDY DATA AND PARAMETERS FOR TRANSPORT SYSTEM. *

LOAD	TIME TO FIELD (MIN)	TIME FROM FIELD (MIN)	SPEED TO FIELD (MPH)	SPEED TO FIELD (M/S)	SPEED FROM FIELD (MPH)	SPEED FROM FIELD (M/S)
1	3.56	5.45	5.70	2.55	3.72	1.66
2	3.63	5.91	5.59	2.50	3.43	1.53
3	3.65	5.35	5.56	2.49	3.79	1.69
4	3.90	5.56	5.20	2.32	3.65	1.63
5	3.15	4.02	6.44	2.88	5.05	2.26
6	3.17	5.05	6.40	2.86	3.69	1.65
7	4.34	4.82	4.67	2.09	4.21	1.88
8	4.93	4.38	4.11	1.84	4.63	2.07
9	2.52	4.61	8.05	3.60	4.40	1.97
10	2.98	4.32	6.81	3.04	4.70	2.10
11	3.56	3.60	5.70	2.55	5.63	2.52
12	2.57	5.05	7.89	3.53	4.02	1.80
13	4.00	4.31	5.07	2.27	4.17	1.86
14	2.00	3.10	10.14	4.53	6.54	2.92
OVERALL AVERAGE	3.43	4.71	6.24	2.78	4.44	1.98

* THE DISTANCE TO FIELD WAS 1785 FEET OR 544 METERS.

TABLE 15. TIME STUDY DATA FOR SEPARATION AND JUICE EXPRESSION SYSTEM.

LOAD NO.	WEIGH TIME (MIN)	SET UP TIME (MIN)	UNLOAD TIME (MIN)	PREPARATION TIME (MIN)	ACTUAL PROCESS TIME (MIN)	TOTAL PROCESS TIME (MIN)
1	11.32	12.00	10.62	33.94	78.0	137.0
2	10.89	17.40	10.16	38.45	79.0	175.0
3	4.65	9.68	8.65	22.98	119.0	186.0
4	5.15	10.28	5.58	21.01	95.0	157.0
5	6.53	10.33	7.93	24.79	80.0	139.0
6	7.80	10.78	10.50	29.08	80.0	151.0
7	3.12	6.12	9.80	19.04	67.0	73.0
8	3.50	12.90	10.20	26.60	80.0	124.0
9	4.20	7.10	7.55	18.85	80.0	142.0
10	4.57	8.64	7.23	20.44	90.0	128.0
11	5.28	10.30	7.03	22.61	59.0	149.0
12	2.35	10.39	6.10	18.84	113.0	159.0
13	4.32	9.47	6.63	20.42	98.0	131.0
14	6.45	8.90	6.00	21.35	113.0	282.0
OVERALL AVERAGE	5.72	10.31	8.14	24.17	88.0	152.0

TABLE 16. PARAMETERS FOR SEPARATION AND JUICE EXPRESSION SYSTEM.

LOAD NO.	THEORETICAL MATERIAL CAPACITY (TONS/HR)	THEORETICAL MATERIAL CAPACITY (KG/HR)	EFFECTIVE MATERIAL CAPACITY (TONS/HR)	EFFECTIVE MATERIAL CAPACITY (KG/HR)	PLANT EFFICIENCY (PERCENT)
1	1.43	1297.0	0.81	735.0	56.93
2	1.35	1225.0	0.61	553.0	45.14
3	1.02	925.0	0.65	590.0	63.98
4	1.80	1633.0	1.09	989.0	60.51
5	1.46	1324.0	0.84	762.0	57.55
6	1.54	1397.0	0.82	744.0	52.98
7	1.89	1715.0	1.75	1579.0	91.78
8	1.54	1397.0	1.00	900.0	64.52
9	1.41	1279.0	0.79	717.0	56.34
10	1.44	1306.0	1.01	916.0	70.35
11	1.60	1451.0	0.63	572.0	39.60
12	1.13	1025.0	0.81	735.0	71.07
13	1.23	1116.0	0.92	835.0	74.81
14	1.27	1152.0	0.51	463.0	40.07
AVERAGE FOR SUGAR DRIP (LOADS 1-6,9,10)					
	1.49	1352.0	0.94	853.0	62.01
AVERAGE FOR RED AMBER (LOADS 7,8,11,12)					
	1.37	1243.0	0.72	653.0	55.33
AVERAGE FOR DALE (LOADS 13,14)					
	1.25	1134.0	0.72	652.0	57.44
OVERALL AVERAGE					
	1.44	1306.0	0.87	789.0	60.40

the total processing time. The plant efficiency shown in the table is a ratio of the actual process time divided by the total process time and is expressed as a percent.

During processing, the mill ran at or near stall, i.e., maximum capacity. All of the loads of Sugar Drip were harvested before any frost occurred and the theoretical capacity of bulk or unseparated material per unit time was highest for that variety. The theoretical capacity of bulk material was lowest while processing the Dale variety, probably the result of the high percentage of stalks in the unseparated material (Table 6). Load number 12 of the Red Amber variety was affected by frost, which in turn contributed to the average theoretical capacity being lower than for Sugar Drip. Plant efficiencies for both Red Amber and Dale were less than that of Sugar Drip. These lower efficiencies are not related to variety but are the result of mechanical problems which occurred in the later part of the season.

Ratios of the amount of juice produced to the amount of material processed from each load are tabulated in Table 17. The ratio was lowest for Red Amber and the juice produced from that variety appeared to be of low quality. The ratio for Dale was highest as a result of the high concentration of stalks in the unseparated material.

Information given in Table 18 supports the fact that Red Amber was a poor juice producer. Theoretical juice flows were obtained by dividing the mass of juice produced from each load by the actual process time for each load. This figure is lowest for Red Amber. Effective juice flows for the loads and varieties were also computed by dividing mass of juice by total process time.

TABLE 17. JUICE AND BULK MATERIAL RELATIONSHIPS.

LOAD NO.	MASS OF BULK MATERIAL PROCESSED (LBS)	MASS OF BULK PROCESSED (KG)	MASS OF JUICE EXPRESSED FROM STALKS (LBS)	MASS OF JUICE EXPRESSED FROM STALKS (KG)	JUICE TO BULK RATIO
1	3710.0	1683.0	681.0	309.0	0.1836
2	3550.0	1610.0	487.0	221.0	0.1372
3	4060.0	1842.0	621.0	282.0	0.1530
4	5690.0	2581.0	747.0	389.0	0.1313
5	3890.0	1764.0	645.0	293.0	0.1658
6	4110.0	1864.0	619.0	281.0	0.1506
7	4230.0	1919.0	618.0	280.0	0.1461
8	4120.0	1869.0	622.0	282.0	0.1510
9	3760.0	1706.0	649.0	294.0	0.1726
10	4320.0	1960.0	737.0	334.0	0.1706
11	3140.0	1424.0	402.0	182.0	0.1280
12	4270.0	1937.0	565.0	256.0	0.1323
13	4030.0	1828.0	823.0	373.0	0.2042
14	4790.0	2173.0	738.0	335.0	0.1541
AVERAGE FOR SUGAR DRIP (LOADS 1-6,9,10)					
	4144.0	1880.0	727.0	330.0	0.1562
AVERAGE FOR RED AMBER (LOADS 7,8,11,12)					
	3705.0	1681.0	569.0	258.0	0.1302
AVERAGE FOR DALE (LOADS 13,14)					
	4410.0	2000.0	886.0	402.0	0.1792
OVERALL AVERAGE					
	4119.0	1868.0	728.0	330.0	0.1557

TABLE 18. MASS FLOW OF JUICE FROM MILL.

LOAD NO.	THEORETICAL JUICE FLOW (LBS/HR)	THEORETICAL JUICE FLOW (KG/HR)	EFFECTIVE JUICE FLOW (LBS/HR)	EFFECTIVE JUICE FLOW (KG/HR)
1	523.85	273.61	298.25	135.28
2	369.87	167.77	166.97	75.74
3	313.11	142.02	200.32	90.86
4	471.79	214.00	285.48	129.49
5	483.75	219.43	278.42	126.29
6	464.25	210.58	245.96	111.57
7	553.43	251.03	507.95	230.40
8	466.50	211.60	300.97	136.52
9	486.75	220.79	274.23	124.39
10	491.33	222.86	345.47	156.70
11	408.81	185.43	168.88	73.43
12	300.00	136.07	213.21	96.71
13	503.88	228.56	376.95	107.98
14	391.86	177.74	157.02	71.22
AVERAGE FOR SUGAR DRIP (LOADS 1-6,9,10)				
	462.46	210.77	290.40	131.72
AVERAGE FOR RED AMBER (LOADS 7,8,11,12)				
	354.41	160.76	187.54	85.07
AVERAGE FOR DALE (LOADS 13,14)				
	447.87	203.15	266.98	121.10
OVERALL AVERAGE				
	444.94	201.82	272.36	123.54

NOTE: MILL EFFICIENCY IS THE SAME AS PLANT EFFICIENCY IN TABLE 16.

Brix or soluble solids are closely related to the amount of sugar in the juice (Table 19). Brix readings for the juice produced from each load were taken and corrected to 20°C. The mass per unit volume of juice and the Brix solids per unit volume were found for corresponding Brix values in standard tables (Spencer and Meade, 1945). The Brix solids were lowest for Dale. This was partially a result of harvesting Dale, which matures much later than Sugar Drip, in the early "milk stage." The Sugar Drip processed was in the "late milk" and "dough stages" of seed maturity. The difference in Brix solids between Sugar Drip and Red Amber was very slight even though juice produced from Red Amber appeared milky, indicating the presence of starch and other impurities.

Only part of the juice expressed during the 1976 season was used for syrup production. Approximate syrup yields per load were calculated using juice yields and Brix readings. Specific gravities corresponding to each Brix reading were also taken from standard tables (Spencer and Meade 1945), and expected volumes of juice and syrup were calculated for each load. Brix solids for each batch of juice produced were calculated using information from Table 19. Syrup yields were calculated by dividing the Brix solids for each batch of juice by the Brix solids per gallon for a 78 degree syrup weighing 9.096 lbs/gal. Approximate syrup yields and the other values used in calculations are listed in Table 20, including metric equivalents.

TABLE 19. BRIX SOLIDS FOR SORGHUM JUICE.

LOAD NO.	BRIX AT 20 C	MASS PER UNIT VOLUME OF JUICE (LBS/GAL)	KG/L	BRIX SOLIDS PER UNIT VOLUME OF JUICE (LBS/GAL)	KG/L
1	14.2	8.802	1.053	1.250	0.1498
2	16.4	8.881	1.064	1.456	0.1745
3	16.0	8.866	1.062	1.419	0.1700
4	16.1	8.873	1.063	1.428	0.1711
5	17.1	8.905	1.067	1.522	0.1824
6	14.8	8.823	1.057	1.400	0.1678
7	17.0	8.902	1.067	1.513	0.1813
8	16.5	8.886	1.065	1.466	0.1756
9	16.8	8.895	1.066	1.494	0.1790
10	17.2	8.909	1.068	1.532	0.1835
11	16.3	8.877	1.064	1.447	0.1734
12	15.3	8.841	1.059	1.353	0.1621
13	13.7	8.784	1.053	1.193	0.1430
14	13.7	8.784	1.053	1.193	0.1430
AVERAGE FOR SUGAR DRIP (LOADS 1-6,9,10)					
	16.2	8.874	1.063	1.448	0.1735
AVERAGE FOR RED AMBER (LOADS 7,8,11,12)					
	15.8	8.859	1.062	1.400	0.1678
AVERAGE FOR DALE (LOADS 13,14)					
	13.7	8.784	1.053	1.193	0.1429
OVERALL AVERAGE					
	15.8	8.859	1.062	1.405	0.1684

TABLE 20. RECORDED JUICE YIELDS AND CALCULATED SYRUP YIELDS.

LOAD NO.	JUICE YIELDS (LBS)	JUICE YIELDS (KG)	SPECIFIC GRAVITY	VOLUME OF JUICE (GAL)	VOLUME OF JUICE (L)	BRIX SOLIDS (LBS)	BRIX SOLIDS (KG)	APPROXIMATE SYRUP YIELDS (GAL)	APPROXIMATE SYRUP YIELDS (L)
1	681.0	308.9	1.05762	77.37	292.87	96.71	43.87	10.63	40.24
2	487.0	220.9	1.06707	54.84	207.58	79.84	36.21	8.73	33.05
3	621.0	281.7	1.06534	70.04	265.12	99.39	45.08	10.93	41.37
4	747.0	338.8	1.06577	84.19	318.68	120.22	54.53	13.22	50.04
5	645.0	292.6	1.07011	72.43	274.17	110.24	50.00	12.12	45.88
6	619.0	280.7	1.06018	70.16	265.58	98.22	44.55	10.80	40.88
7	618.0	280.3	1.06968	69.42	262.78	105.04	47.65	11.55	43.72
8	622.0	282.1	1.06751	70.00	264.97	102.62	46.54	11.28	42.70
9	649.0	294.4	1.06881	72.96	276.18	109.01	49.45	11.98	45.35
10	737.0	334.3	1.07055	82.73	313.16	126.74	57.49	13.93	52.73
11	402.0	182.3	1.06664	45.29	171.44	65.53	29.72	7.20	27.25
12	565.0	256.3	1.06233	63.91	241.92	86.47	39.22	9.51	36.00
13	823.0	373.3	1.05549	93.69	354.65	111.78	50.70	12.29	46.52
14	738.0	334.8	1.05549	84.02	318.04	100.23	45.46	11.02	41.71
AVERAGE FOR SUGAR DRIP (LOADS 1-6,9,10)									
	727.0	330.0	1.06568	72.41	274.10	104.80	47.54	11.52	43.61
AVERAGE FOR RED AMBER (LOADS 7,8,11,12)									
	569.0	258.0	1.06634	54.60	206.68	76.00	34.47	8.35	31.61
AVERAGE FOR DALE (LOADS 13,14)									
	886.0	402.0	1.05549	88.85	336.33	106.00	48.08	11.65	44.10
OVERALL AVERAGE									
	728.0	330.0	1.06447	72.22	273.38	100.86	45.75	11.09	41.98

NOTE: SYRUP YIELDS WERE COMPUTED BY DIVIDING BRIX SOLIDS FOR EACH LOAD BY THE BRIX SOLIDS PER UNIT VOLUME FOR A 78 DEGREE BRIX SOLUTION.

Simulation of Harvesting, Transportation, Separation and Juice
Expression Systems

Utilizing data collected and experience gained with the VPI & SU sorghum processing system, a computer program was compiled to simulate the system. The Fortran computer language was used in the program and it was run on an IBM/370 system. A copy of the program is included in Appendix I.

Figure 11 shows the flow of material through the simulated system. Sorghum is harvested using modified forage harvesters and then transported to the separation and milling location. Necessary preparations are there made for processing. Stalks are separated from the leaves and seed heads, and juice is expressed to be made into syrup. Solid by-products may be used for silage or other purposes.

The following assumptions were made when developing the program:

1. All harvesters used for harvesting sorghum are considered as one unit with lumped capacities and uniform efficiency.
2. Harvesting activities are spread over the entire day when harvesting capacity in excess of that needed to keep the separator and mill running continuously is available.
3. All loads of bulk material harvested are of equal weight except the last load harvested at the end of the day and the last load harvested from a field.
4. Sorghum may be harvested from several fields of known size and yield.

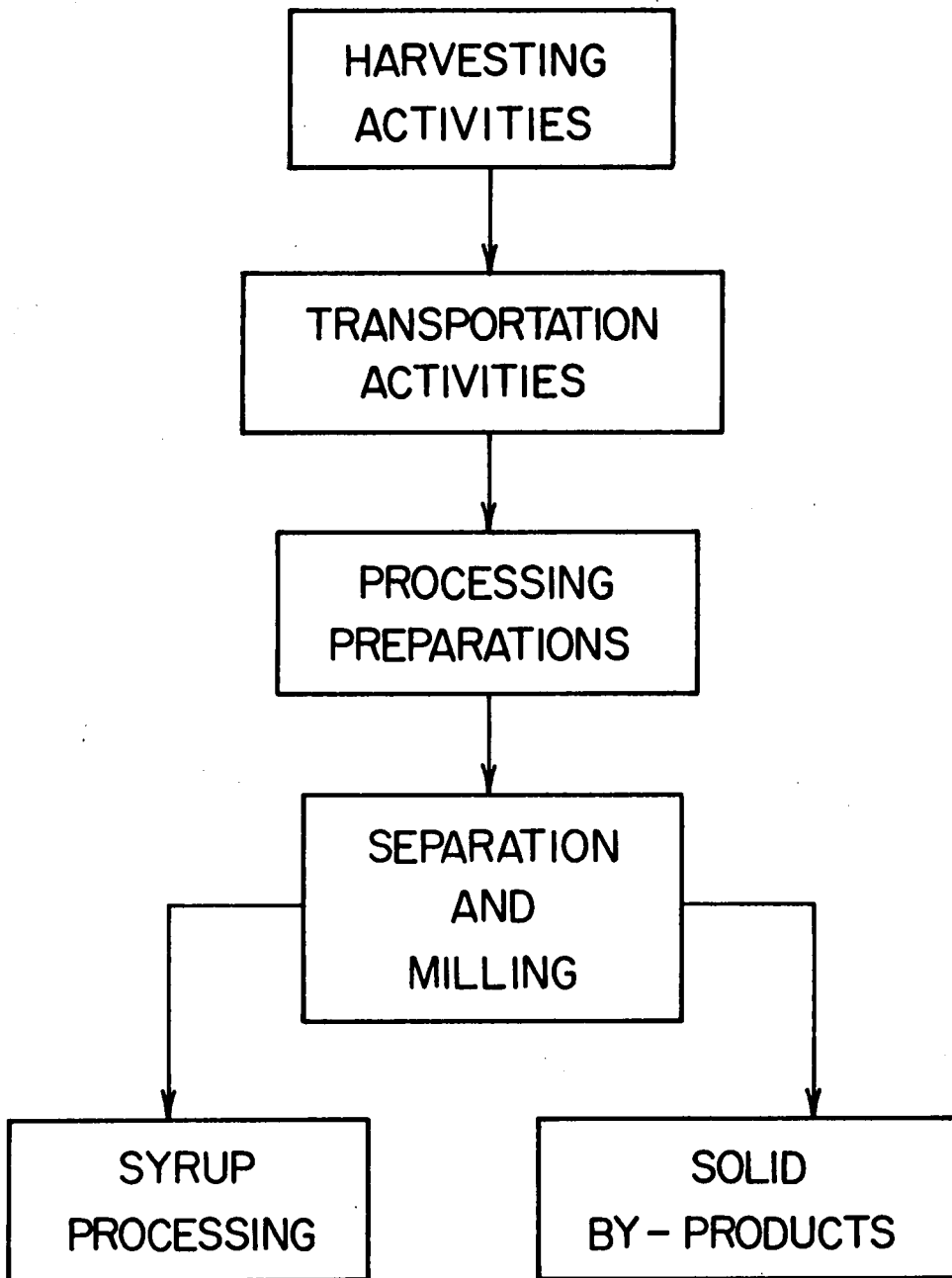


FIGURE II. FLOW DIAGRAM FOR SORGHUM PROCESSING SYSTEM.

5. The order of harvest for the fields is known and only one field can be harvested at a time.
6. The distance between each field and the distance from each field to the separation location is known.
7. There is only one processing location.
8. Speeds for moving equipment between all fields are the same.
9. The only lost harvesting time when moving between fields is travel time.
10. Field efficiency is constant for all fields.
11. Transportation of material to the separation location is accomplished using any of the following methods:
 - a) Tractors and wagons with a driver for each tractor.
 - b) Trucks with a driver for each truck.
 - c) Trucks with necessary drivers only. (It is assumed that these drivers always have transportation available for the return trip to the field.)
12. All hauling units have equal hauling capacity.
13. Wagons used for transporting material are hitched to the harvester during filling, i.e., not pulled by separate tractor.
14. Hauling units necessary to start harvesting operations each morning are available in the field.
15. Travel speeds of all loaded hauling units are the same.
16. Travel speeds of all empty hauling units are the same.
17. Only one hauling unit can be weighed at a time.

18. There is sufficient parking space at the processing location to accumulate loaded hauling units for night processing.
19. When material is available for processing, the system operates continuously and when one wagon is empty another is immediately ready for processing (i.e., there is enough space to prepare at least two hauling units for unloading).
20. The separation and juice expression system operates at constant capacity and efficiency.
21. Juice produced is a function of only the bulk material weight.
22. Specific gravity of sorghum juice is a linear function of the degree Brix of the juice between Brix values of 9 and 22.
23. Syrup yields are a function of Brix solids and the amount of juice.
24. The number of hauling units and/or tractors available are unlimited and the required number of hauling units and tractors to keep the separation system operating continuously are determined.

The simulation program was deterministic and dynamic in nature. Calculations involving the flow of material through the system were made inside a time loop (i.e., all activities of harvesting, transportation, and processing were checked after each time increment). Discrete input and calculated variables were used in the program. Input and output variables used in the program are defined in Sections 1 and 2, respectively, of Appendix II. A brief summary of the operation of the program follows.

All input variables unrelated to the individual characteristics of the fields to be harvested are read in on lines 56-58 of the program (Appendix I) followed by input variables related to each field. These latter include the distance between fields, the distance to the plant location (both in miles) and the area of each field in acres. Next the variables for the season are initialized followed by series of statements which compute the day of the season, labor requirements for the system, weight of material harvested during the season, and logic statements to determine if the season has ended or if all acres of sorghum have been harvested and processed. After these, operations variables are initialized for the beginning of each day.

A loop is then entered in which computations are made for moving sorghum through the system. With each pass through the loop, time elapsed during the working day is increased in increments of 0.01 hours. When the time elapsed becomes equal to or slightly greater than the total operation time (see definition of OPHOUR, Appendix II, Section 2) a new day of processing is started. At this time variables computed daily are re-initialized. When all fields are harvested or the specified number of processing days have been used, the program terminates.

The amount of material harvested during each pass through the time loop is computed in line 275. The equation is:

$$WTHAR = SPREAD * HARCAP * HAREFF * 0.01/100.0$$

where

WTHAR = weight harvested during each 0.01 hr. time increment
in lbs.

SPREAD = a "spread factor" described below

HARCAP = theoretical harvesting capacity of all harvesters,
lb/hr

HAREFF = overall field efficiency of harvesters when they are
run continuously, percent.

A group of harvesting units has a finite harvesting capacity and efficiency that when multiplied together equals their maximum harvesting rate. This rate applied over the length of the harvesting day must produce material for processing in excess of the plant requirements during the length of the processing day. This is necessary to assume continuous operation of the separating and milling facilities. Harvesting continuously at the maximum harvesting rate, however, would require a larger number of hauling units than is actually necessary, i.e., the number of hauling units would depend upon harvesting rate, rather than processing rate. To overcome this, the program harvests the first load of each day at the maximum harvest rate (SPREAD = 1.0). The program then computes a ratio of the remaining amount of material to be harvested for processing during the processing day to the amount of material which can be harvested at maximum harvesting capacity

during the remaining harvesting time. This ratio becomes the "spread factor" for harvesting during the remainder of the day. This approach in effect substitutes for idle time in the field and SPREAD becomes an indicator of the amount of available harvesting capacity used. Computation of SPREAD in the program also takes into account the lost time in any anticipated moves from one field to another and certain situations where harvesting time during a day may be shortened to assure that the last load harvested reaches the plant in time to be processed. The value of SPREAD is usually less than 1.00, and the value can never be greater than 1.00. The value of SPREAD should always be printed as part of the output when using the program. When a value equal to unity is obtained the total amount of material processed may be increased by increasing harvesting capacity (HARCAP).

The acres of sorghum harvested in the field in which harvesting is occurring (ACHAR) and the amount of material harvested any time during the season (TACHAR) is calculated using an input value for yield in lbs/ac. The weight on a hauling unit, (WEIGHT (LD)) along with the weight of material harvested at any time during the day (WTHARD) is also computed.

Provisions are made in the program for allowing the use of any of three types of transportation equipment. The type of hauling unit is indicated by the input variable ITRANS. A list of values for ITRANS and the denoted type of transportation follows:

- 0 = tractors and wagons, with a driver for each tractor.
- 1 = trucks, with a driver for each truck
- 2 = trucks with necessary drivers (it is assumed that these drivers always have available transportation for the return trip to the field).

When trucks are used for transportation it is assumed that a truck and driver is always in the field for each harvester during the harvest day. When tractors and wagons are used for transporting, it is assumed that wagons are hitched to the harvester for loading and the only labor required for the harvesting operation is for the operation of harvesters.

Transportation of hauling units to the separation plant is simulated from the time each hauling unit departs from the field until it reaches the plant by computing distances traveled during each time increment from input travel speed (SDFRFD). When the distance traveled becomes equal to the distance from the field to the plant, the hauling units are weighed.

When the specified time to complete weighing is reached, the hauling unit moves into a holding area and remains idle until it is needed for processing.

At the beginning of each day when the first hauling unit reaches the plant, start-up time is simulated by summing time increments until the input value of STARTM is reached. Start-up time is also simulated if the plant runs out of material and is restarted during the day.

Any hauling units which are prepared for processing after the plant is started and sufficient material is available for processing go through preparation simulation similar to that for starting the plant. The plant is operating while these preparations are being made and the time required is usually less than that for plant start-up.

After processing preparations are made processing activities begin. Processing is simulated only if material is available for processing. The accumulated amount of material separated, and the juice expressed (WTPRO (LDP)), is computed during each iteration from the product of plant capacity (PLTCAP) multiplied by the plant efficiency (PLTEFF), and the time increment (0.01 hour). When WTPROL (LDP) becomes equal to the weight of material harvested on each load WEIGHT (LDP), the value of LDP is increased by 1 and the new WTPROL (LDP) term is initialized at 0.00. Calculations are also made to determine the accumulated amount of material processed (TWIPRO), the weight of material to be processed during the remainder of the day (WTTPRO), the weight of material available for processing (WTALPR), and the amount of unprocessed material in the system (TWISYS).

After each load is processed, juice, syrup, and solid by-products are accumulated. The pounds of juice produced (LBSJUC) is obtained by multiplying the net weight of each load (WEIGHT (LDJ)) by the juice to bulk material ratio (LBSBUK). After this, the number of gallons of syrup (at 78° Brix) is obtained by multiplying LBSJUC by the Brix of the juice (Brix20) and dividing by 906.6 (the Brix solids for a 78° syrup is 9.096 lbs/gal and the degree Brix expressed in percent is

divided by 100 to convert it to a decimal; the product of these two divisors is 906.6). Solid by-products are accumulated from the product of the weight of material processed (WTPROS) and the percent of solid by-products (PCNTWA). The gallons of juice is calculated from the product of LBSJUC, the specific gravity of the juice (SPECGR) and the density of water at 20°C (8.322 lbs/gal).

The specific gravity of the juice is approximated from the following equation:

$$\text{SPECGR} = 1.03956 + 0.00432 * (\text{Brix20} - 10.0)$$

where

SPECGR = specific gravity of juice at 20°C.

BRX20 = degree Brix of juice at 20°C.

The above expression was developed from Brix vs. specific gravity tables given in Spencer and Meade (1945). This equation is intended for use only between the Brix values of 9 to 22.

After the amount of juice, syrup and solid by-products is calculated, empty hauling units are returned to the field for reloading. When tractors are used for pulling wagons, the tractors may return to the field without wagons to minimize total tractor requirements.

The total number of tractors and wagons, or trucks, is determined by adding hauling units and tractors in harvesting, transportation, and processing operations during each iteration. The maximum number of tractors (TRMAX) and the maximum number of hauling units (HUMAX) are determined each day. HUMAX is the number of wagons or trucks depending on the value of ITRANS. TRAMAX is the number of tractor

drivers when ITRANS = 0 and the number of truck drivers when ITRANS = 2. When ITRANS = 1 the number of truck drivers is TRMAX.

The program is general and any of the input or computed variables may be used as output values. The program can easily be adapted for simulating harvesting, transporting, and processing systems other than the VPI & SU sorghum processing system.

Simulation Using the Computer Program

The computer model may be used to determine the effect upon computed variables by changing any of 25 input variables. The effect of field location, number of fields, and individual field area upon the system can be determined. The acres of sorghum processed during a season can be found. The transportation equipment (trucks, or tractors and wagons) required to operate the separation and juice expression system at full capacity can be determined. Syrup and solid by-product yields can be predicted. The economics of simulated systems could be determined by applying cost to required machinery, labor and the cost of producing raw sorghum. Linear programming techniques could be applied to output data from the program to find theoretically optimum systems.

Output for 5 simulation runs using the computer program is shown in Appendix III. Input values and selected output data are tabulated for each run.

Input values obtained for analysis of data collected during the 1976 season was used in simulation Run No.1. Some simulated and actual output values are listed here:

	<u>Actual</u>	<u>Simulated</u>
Bulk Material Processed (lbs)	57666.00	57682.40
Juice Yield (gal)	1011.05	1015.70
Syrup Yield (gal)	156.30	155.19

The simulated output values agreed closely with those calculated from data taken during the processing season and the computer program appeared to operate correctly. There was no data available to make comparisons with the required amount of transportation equipment. The output value for labor in this simulation did not include labor required for transportation. Comparisons are made later between hand and mechanized methods. Transportation could not be included in these comparisons because processing occurred at several locations.

In simulation Run No. 2 input values of plant efficiency, harvesting efficiency, the juice to bulk ratio, the solid waste to bulk material ratio, the Brix of juice produced, and yield was increased to characterize the VPI & SU system operating in steady-state conditions more nearly like those expected under real-life conditions. The time required to complete harvesting in this simulation was much less than in the first. The amount of material processed and the amount of juice and syrup produced increased as expected. Again, labor requirements did not include transportation.

Simulation No. 3 tested the performance of the system over an entire season using the same input values as for No. 2, except that several fields were harvested and the total acres of sorghum were increased. During a 30-day season 43.29 acres of 45.00 acres were harvested. Labor requirements included transportation.

Simulation No. 4 and 5 used trucks to transport material. No. 4 used a driver for each truck and No. 5 used necessary drivers only. Labor requirements computed included drivers for trucks.

All five Simulation Runs used some of the data obtained during the 1976 season. The program should be tested with data reflecting uninterrupted operating conditions. Data from any agriculture system which harvests, transports and processes material could be used for the test. Once the program is tested, it could be used to evaluate production of syrup from sweet sorghum as well as vegetable canning, small grain harvesting and many other food production systems.

A Comparison of Labor Requirements for Conventional and the VPI and SU Processing Methods

Data was collected to determine the labor requirements for processing sorghum using conventional hand methods. The labor required to perform harvest and milling activities, total labor requirements and gallons of juice produced are presented in Table 21. The overall average juice yield per man-hour was 5.80 gallons.

Labor requirements for the VPI & SU system are presented in Table 22. They include labor for processing, set-up, harvest, total labor for each load processed, and gallons of juice produced per man-hour.

TABLE 21. LABOR REQUIREMENTS FOR CONVENTIONAL PROCESSING METHODS.

PROCESSOR	HARVEST MAN-HRS	MILLING MAN-HRS	TOTAL MAN-HRS	JUICE YIELD (GAL)	JUICE YIELD (L)	JUICE YIELD PER MAN-HR (GAL)	JUICE YIELD (L)
1	18.75	4.75	23.50	158	598.08	6.72	25.43
1	20.00	5.00	25.00	170	643.50	6.80	25.74
1	18.00	4.00	22.00	134	507.23	6.09	23.05
1	21.25	4.00	25.25	135	511.02	5.34	20.21
2	20.00	34.00	54.00	120	454.23	2.22	8.41
3	38.00	11.25	49.25	375	1419.49	7.61	28.81
				OVERALL AVERAGE		5.80	21.95

TABLE 22. LABOR REQUIREMENTS FOR THE VPI AND SU MECHANICAL SYSTEM.

LOAD NO.	PROCESSING MAN-HRS	SET-UP MAN-HRS	HARVEST MAN-HRS	TOTAL MAN-HRS	JUICE YIELD (GAL)	JUICE YIELD (L)	JUICE YIELD PER MAN-HR (GAL)	JUICE YIELD PER MAN-HR (L)
1	6.85	1.70	0.83	9.38	77.37	292.87	8.25	31.23
2	8.75	1.92	0.76	11.43	54.84	207.59	4.80	18.17
3	9.30	1.15	0.76	11.21	70.04	266.49	6.25	23.66
4	7.85	1.05	0.99	9.89	84.19	318.68	8.51	32.21
5	6.95	1.24	0.63	8.82	72.43	274.17	8.21	31.08
6	7.55	1.45	0.78	9.78	70.16	265.58	7.17	27.14
7	3.65	0.95	1.12	5.57	69.42	262.78	12.46	47.16
8	6.20	1.33	1.09	8.62	70.00	264.97	8.12	30.74
9	7.10	0.94	0.97	9.01	72.96	276.18	8.10	30.66
10	6.40	1.02	1.11	8.53	82.73	313.16	9.70	36.72
11	7.45	1.13	1.95	10.53	45.29	171.44	4.30	16.27
12	7.95	0.94	1.32	10.21	63.91	241.92	6.26	23.70
13	6.55	1.02	0.75	8.32	93.69	354.65	11.26	42.62
14	14.10	1.07	0.76	15.93	84.02	318.04	5.27	19.94
					OVERALL AVERAGE		7.76	29.37

The average number of gallons produced for each man-hour was 7.76. These calculations assumed that 3 men were needed for processing and set-up, and one man for harvesting.

In a continuous operation, time required for set-up should not be considered as part of the labor required to produce juice because the plant would be operating while set-up preparations are being made (i.e., this time would be counted twice if considered). Also, experience with the system indicates that three men should be able to operate the system and make set-ups when necessary. When labor for processing and harvesting only was considered, then the juice production was 8.40 gal/man-hr.

Simulation No. 1 in Appendix III used input values obtained during the processing season. The gal/man-hr from this simulation was 8.46, very close to the figure cited above.

A steady-state operation was simulated in Run No. 2. A value of 15.82 gallons of juice per man-hour was obtained. Similar values were obtained in Runs 3, 4 and 5. Thus, the juice production per man-hour is more than doubled using the mechanized system in steady-state production.

CONCLUSIONS

The VPI & SU pneumatic separation system separated 80% of the stalks from the chopped sorghum. This percentage could be increased as more knowledge of system operation and selection of varieties is obtained. The following conclusions were drawn from working with the VPI & SU sweet sorghum processing system:

1. Most of the unseparated stalks were small in diameter and were undesirable for quality syrup production.
2. Separation was best for sweet sorghum varieties which had small seed heads and large stalks.
3. Approximately 3 percent of the separated material on the stalk conveyor was seed heads, leaves and debris. Of the three operators, one person could easily remove this by hand.
4. Although the juice produced from the Dale variety had low Brix readings, probably due to immaturity at harvest, it was more amenable to pneumatic separation than the other varieties tested.
5. Sugar Drip produced juice with the highest Brix readings, however, the large seed heads produced by the variety made separation less than optimal.
6. The amount of juice produced from Red Amber was not as great as that from the other two varieties. The juice produced was milky, indicating the presence of starch and other impurities.
7. Three men can easily operate the separation and juice expression system. It appears that the throughput for the system can be increased by using a larger mill without increasing labor requirements.

8. A computer program was developed to simulate harvesting, transportation and separation and juice expression systems. Using input values obtained from data taken in the 1976 season, juice and syrup yields were within 1 percent of actual values. Labor requirements and the total amount of material processed were also within 1 percent of actual values.

9. The program is general and could be adapted to other harvesting, transporting and processing systems.

10. Simulation made using the model indicates that 40 to 45 acres of sorghum could be processed using the VPI & SU system under typical, local conditions (see Simulation Run No. 3, Appendix III). The number of acres could probably be increased by using a larger mill because the maximum capacity of the pneumatic separator was never reached.

11. In a continuous separation, the VPI & SU system reduces labor requirements for processing and harvesting by 50%.

12. Simulation of the VPI & SU system using typical inputs indicates that the amount of chopped sorghum processed in a 16-hour day would be approximately 40 tons, yielding about 145 gallons of syrup.

RECOMMENDATIONS

Equipment

The additional netting installed to separate leaves and debris from the air stream performed very well most of the season. However, when sorghum was processed which contained dried leaves, fragments tended to cling to the netting where it met the trash conveyor. Any future system should include as much netting for leaf-air separation as practical.

The leveling beaters installed for the 1976 season completely eliminated hand leveling in the input conveyor and should be included in the design of future systems.

The inclined belt installed under the air duct did not improve separation. Both stalks and leaves tended to roll or bounce from the inclined conveyor onto the stalk collection conveyor. However, the stalk collection conveyor and a horizontal trash collection conveyor (replacing the inclined conveyor) should be mounted in a frame similar to that in Figure 10 to make the adjustment for the amount of material falling on the stalk conveyor easy. The hydraulic cylinder connected between the frame and fan could be eliminated and adjustments made easily by hand.

The alignment conveyor should be constructed so that the initial drop of material before entering the air stream could be adjusted. The dispersion of material in the air was too great for optimum separation when material was dropped directly into the air stream.

The two automotive transmissions in Figure 9 allowed for a wide range of speed control of the input conveyor. This system of speed control should be considered in any future construction because used automotive transmissions are readily available and much less expensive than other specialized speed control equipment.

Caution should be taken when constructing air ducts for this type of pneumatic separator. The longitudinal center line of the duct should coincide exactly with the center line of the air stream in order to eliminate material contacting the sides of the duct. Also the dimensions of the air duct should increase gradually downstream from the fan.

Computer Simulation Program

The computer program developed to simulate the VPI & SU system was tested using data for only one season. It should also be tested against actual commercial systems. Because the program is general in design, it could be tested and applied using virtually any system which harvests, transports and processes agricultural material. An operation which freezes or cans vegetables would be ideal for such a test. Particular attention should be given to the required hauling units for the system because the VPI & SU sorghum processing system was never operated continuously, i.e., only one wagon was used for transporting material to the plant.

Sweet Sorghum Varieties

Research should be conducted to develop varieties of sorghum adapted to pneumatic separation. Varieties developed should have large stalks and small seed heads. The quality of juice produced and juice yield should be comparable to proven varieties such as Sugar Drip. It would also be desirable to have several varieties with different maturities to allow for an extended harvesting season.

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APPENDIX I
Computer Simulation Program

```

$JOB          WATFIV          SOR00010
C ***** SOR00020
C ***** SOR00030
C THIS PROGRAM IS A MODEL OF A SWEET SORGHUM PROCESSING OPERATION . SOR00040
C THE OPERATION HARVEST AND EXPRESSES JUICE FROM THE STALKS . SOR00050
C ***** SOR00060
C DIMENSION WEIGHT(50),WTPROL(50),WGTM(50),TMSTAR(50),TMPREP(50),PRPS SOR00070
C 1TTF(50),DISTR(50),ACRE(10),DS8FLD(50),DISTR(50), SOR00080
C 2DISPLT(10),EMDISF(50) SOR00090
C REAL MOVETM,MOVSPD,LBSBUK,LBSJUC SOR00100
C INTEGER PRODA,HUMAX,EMTRTF,TRMAX SOR00110
C 10 FORMAT(3I3,F8.2,F6.2,F8.2,F6.2,F7.1,3F6.3,F6.2,F6.3,F8.1,F5. SOR00120
C 11,4F6.3,2I2) SOR00130
C 15 FORMAT(3F6.3) SOR00140
C 200FORMAT('1PLANT CAPACITY (LBS/HR)',F9.3/' PLANT EFFICIENCY (PERCENT SOR00150
C 1)',F6.2/' HARVESTOR CAPACITY (LBS/HR)',F9.3/' FIELD EFFICIENCY (PESOR00160
C 2RCENT)',F6.2) SOR00170
C 210FORMAT(' TYPE OF HAULING UNITS',I4,3X,'(TRACTORS AND WAGONS)') SOR00180
C 220FORMAT(' TYPE OF HAULING UNITS',I4,3X,'(TRUCKS - A DRIVER FOR EACHSOR00190
C 1)') SOR00200
C 230FORMAT(' TYPE OF HAULING UNITS',I4,3X,'(TRUCKS - NECESSARY DRIVERSSOR00210
C 1)') SOR00220
C 240FORMAT(' HAULING UNIT CAPACITY (LBS) ',F8.1,' '/' ACRES OF SORGSOR00230
C 2HUM ',F7.3/' YIELD PER ACRE (LBS/ACRE) ',F9.1/' PRODUCTION DAYS ' SOR00240
C 3,13/' PROCESSING HOURS ',F5.2/' HARVESTING HOURS ',F5.2/' TRAVEL SOR00250
C 4PEED OF LOADED HAULING UNITS (MPH) ',F6.3,' '/' TRAVEL SPEED OSOR00260
C 5F EMPTY HAULING UNITS (MPH) ',F6.3/' MOVING SPEED OF FIELD EQUIPMSOR00270
C 6NT BETWEEN FIELDS (MPH) ',F6.3/' UNHITCH TIME FOR TRACTORS ENTERINSOR00280
C 7G HOLDING AREA (HR) ',F5.3/' HITCH TIME FOR RETURNING HAULING UNITSOR00290
C 8E (HR) ',F5.3/' WEIGH TIME (HR) ',F5.3/' PROCESSING PREPARATION TISOR00300
C 9ME FOR EACH LOAD (HR) ',F5.3) SOR00310
C 250FORMAT(' PROCESSING START UP TIME (HR) ',F5.3/' NUMBER OF HAULING SOR00320

```



```

1 UNITS WHICH CAN BE PROCESSED AT ONE TIME ',I3,' JUICE TO BULK MATESOR00330
2 RIAL RATIO ',F5.3/' SOLID WASTE TO BULK MATERIAL RATIO ',F5.3/ SOR00340
3 ' AVERAGE DEGREE BRX (20 C BASE) OF JUICE ',F4.1/' NUMBER OF FIELDSOR00350
4 DS ',I3/' NUMBER OF HARVESTORS ',I3////////' DATA FOR FIELDS LISTEDSOR00360
5 IN ORDER OF HARVEST'////' FIELD DISTANCE ACRES'/' NUMSOR00370
6 BER BETWEEN TO'/'T10,' FIELDS PLANT'/'T10,'(MILES) (MILES)'/'SOR00380
300FORMAT(I,X,I3,F11.3,2F10.3)
350FORMAT(////////'
1 '//' DAY OF ACRES BULK JUICE SYRUP LABOR SOR00410
2 NO. NO. SPREAD') SOR00420
360FORMAT(' SEASON HARVESTED MATERIAL YIELD YIELD (MAN-HRS) WASOR00430
IGONS TRACTORS FACTOR') SOR00440
370FORMAT(' SEASON HARVESTED MATERIAL YIELD YIELD (MAN-HRS) TRSOR00450
LUCKS DRIVERS FACTOR') SOR00460
380FORMAT(20X,'PROCESSED (GAL) (GAL)'/20X,'(LBS)')/'/' SOR00470
40 FORMAT(I,X,I5,F8.2,F13.1,F9.1,F7.1,F9.2,I8,I9,F11.3) SOR00480
500FORMAT(////////' THE SEASON EXPIRED WITH ',F6.2,' ACRES OF SORGHUM STANSOR00490
IDING,') SOR00500
600FORMAT(////////' PROCESSING WAS COMPLETED ON DAY NUMBER',I3,' OF SEASONSOR00510
1 WITH ',F5.2,' HOURS REMAINING IN DAY') SOR00520
C *****SOR00530
C READ IN INPUT VALUES HERE SOR00540
C *****SOR00550
O READ(5,10)NOFLD,PRODA,MAXPRO,PLTCAP,PLTEFF,HARCAP,HAREFF,HLCAP, SOR00560
1 STARTM,PREPTM,WEIGTM,SPTOFD,SPFRFD,OPHOUR,HARHR,PRPEMT,YIELD, SOR00570
2 BRIX20,MOVSPD,UHKTM,LBSBUK,PCNTWA,NOHAR,ITRANS SOR00580
ACRES=0.0 SOR00590
DO 100 I=1,NOFLD SOR00600
READ(5,15)DSBFLD(I),DISPLT(I),ACRE(I) SOR00610
100 ACRES=ACRES+ACRE(I) SOR00620
HOUROP=OPHOUR SOR00630
WRITE(8,20)PLTCAP,PLTEFF,HARCAP,HAREFF SOR00640

```

```

SOR00650
SOR00660
SOR00670
SOR00680
SOR00690
SOR00700
SOR00710
SOR00720
SOR00730
SOR00740
SOR00750
SOR00760
SOR00770
SOR00780
SOR00790
SOR00800
SOR00810
SOR00820
SOR00830
SOR00840
SOR00850
SOR00860
SOR00870
SOR00880
SOR00890
SOR00900
SOR00910
SOR00920
SOR00930
SOR00940
SOR00950
SOR00960

IF(ITRANS.EQ.0) WRITE(8,21)ITRANS
IF(ITRANS.EQ.1) WRITE(8,22)ITRANS
IF(ITRANS.EQ.2) WRITE(8,23)ITRANS
WRITE(8,24)HLCAP,ACRES,YIELD,PRODA,OPHOUR,HARHR,SPFRFD,SPTOFD,MOVSSOR00680
1PD,UHKTM,PRPEMT,WEIGTM,PREPTM
WRITE(8,25)STARTM,MAXPRO,LBSBUK,PCNTWA,BRIX20,NOFLD,NOHAR
DO 105 I=1,NOFLD
WRITE(8,30)I,DSBFLD(I),DISPLT(I),ACRE(I)
105 CONTINUE
WRITE(8,35)
IF(ITRANS.EQ.0) WRITE(8,36)
IF(ITRANS.NE.0) WRITE(8,37)
WRITE(8,38)
*****
C INITIALIZE VARIABLES FOR SEASON
*****
C
C NDA=0
KDA=0
WTHARS=0.0
LBSJUC=0.0
GALMOL=0.0
ACHAR=0.0
TACHAR=0.0
MOVETM=0.0
PRPTTF(1)=0.0
WGTM(1)=0.0
DISMOV=0.0
NFD=1
TACHR=0.0
HRMAN=0.0
NADHAR=NOHAR-1
*****
C

```

```

C COUNT DAY OF SEASON
C *****
110 IF(NDA.EQ.0) GO TO 112
    WTHARS=WTHARS+WTHARD
    IF(ITRANS.EQ.0.AND.TACHAR.LT.ACRES) HRMAN=(TRMAX+NOHAR)*HARHR+3*HOSOR01010
    1UROP+HRMAN
    IF(ITRANS.EQ.0.AND.NHUALP.EQ.0.AND.TACHAR.GE.ACRES) HRMAN=3.0*(TM-SOR01030
    1(OPHOUR-HOUROP))+STOPTM*(NOHAR+TRMAX)+HRMAN
    IF(ITRANS.EQ.1.AND.TACHAR.LT.ACRES) HRMAN=(HUMAX+NOHAR)*HARHR+3*HOSOR01050
    1UROP+HRMAN
    IF(ITRANS.EQ.1.AND.NHUALP.EQ.0.AND.TACHAR.GE.ACRES) HRMAN=3.0*(TM-SOR01070
    1(OPHOUR-HOUROP))+STOPTM*(NOHAR+HUMAX)+HRMAN
    IF(ITRANS.EQ.2.AND.TACHAR.LT.ACRES) HRMAN=(TRMAX+2*NOHAR)*HARHR+3*SOR01090
    1HOUROP+HRMAN
    IF(ITRANS.EQ.2.AND.NHUALP.EQ.0.AND.TACHAR.GE.ACRES) HRMAN=3.0*(TM-SOR01110
    1(OPHOUR-HOUROP))+STOPTM*(2*NOHAR+TRMAX)+HRMAN
    WRITE(8,40)NDA,TACHAR,WTHARS,GALJUC,GALMDL,HRMAN,HUMAX,TRMAX,SPREASOR01130
    1D
112 IF(TACHAR.GE.ACRES) GO TO 2000
    IF(NDA.EQ.PRODA) GO TO 2010
    NDA=NDA+1
    *****
C INITIALIZE VARIABLES FOR DAY
C *****
C OPHOUR=HOUROP
    TMUHK=0.0
    NTRACP=0
    NTRACF=1
    NTRITF=0
    NTRIFD=0
    EMTRIF=0
    NTRPTF=0
SOR00970
SOR00980
SOR00990
SOR01000
SOR01010
SOR01020
SOR01030
SOR01040
SOR01050
SOR01060
SOR01070
SOR01080
SOR01090
SOR01100
SOR01110
SOR01120
SOR01130
SOR01140
SOR01150
SOR01160
SOR01170
SOR01180
SOR01190
SOR01200
SOR01210
SOR01220
SOR01230
SOR01240
SOR01250
SOR01260
SOR01270
SOR01280

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NTRWG=0
NTRAUH=0
NFLHUF=0
NTRITT=0
WTALPR=0
NHUPTF=0
SPREAD=1.00
LD=1
NLD=0
WEIGHT(1)=0.0
TWTPRO=0.0
TWT HAR=0.0
WT PROS=0.0
WTT PRO=0.0
TWT SYS=0.0
WTHARD=0.0
WTPROL(1)=0.0
SOLWAS=0.0
NHUWG=0
NHUALP=0
TM=0.0
WGT M(1)=0.0
TMSTAR(1)=0.0
TMPREP(1)=0.0
LDP=1
LITT=0
NLITT=1
LP TT=0
LWG=1
LLD=0
NHUITF=0
NEMHUP=0

SOR01290
SOR01300
SOR01310
SOR01320
SOR01330
SOR01340
SOR01350
SOR01360
SOR01370
SOR01380
SOR01390
SOR01400
SOR01410
SOR01420
SOR01430
SOR01440
SOR01450
SOR01460
SOR01470
SOR01480
SOR01490
SOR01500
SOR01510
SOR01520
SOR01530
SOR01540
SOR01550
SOR01560
SOR01570
SOR01580
SOR01590
SOR01600

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NHUITT=0
HUMAX=0
TRMAX=0
NHUIFD=0.0
NLLD=1
NHUIHD=0
LHD=0
LLHD=0
WGTIHD=0.0
LPP=1
NETRT=1
IETRT=0
IF (ITRANS.EQ.1) NTRACF=0
C *****
C SPECIFIC GRAVITY CALCULATIONS
C *****
C SPECGR=1.03956+0.00432*(BRIX20-10.0)
C *****
C COUNT TIME OF DAY
C *****
C 120 TM=TM+0.01
C IF(TM.GT.OPHOUR) GO TO 110
C *****
C TRANSIT TO FIELD
C *****
C IF(NTRPTF.EQ.0) GO TO 122
C IF(NTRPTF.GE.NHUPTF) IITER=NHUPTF
C IF(NTRPTF.LT.NHUPTF) IITER=NHUPTF
C NITT=LITT+1
C NITTER=LITT+IITER
C DO 121 LLLL=NITT,NITTER
C PRPTTF(LLLL)=PRPTTF(LLLL)+0.01
SOR01610
SOR01620
SOR01630
SOR01640
SOR01650
SOR01660
SOR01670
SOR01680
SOR01690
SOR01700
SOR01710
SOR01720
SOR01730
SOR01740
SOR01750
SOR01760
SOR01770
SOR01780
SOR01790
SOR01800
SOR01810
SOR01820
SOR01830
SOR01840
SOR01850
SOR01860
SOR01870
SOR01880
SOR01890
SOR01900
SOR01910
SOR01920

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SOR01930
SOR01940
SOR01950
SOR01960
SOR01970
SOR01980
SOR01990
SOR02000
SOR02010
SOR02020
SOR02030
SOR02040
SOR02050
SOR02060
SOR02070
SOR02080
SOR02090
SOR02100
SOR02110
SOR02120
SOR02130
SOR02140
SOR02150
SOR02160
SOR02170
SOR02180
SOR02190
SOR02200
SOR02210
SOR02220
SOR02230
SOR02240

IF(PRPTF(LLLL).LT.PRPEMT) GO TO 122
NHUITF=NHUITF+1
NTRPTF=NTRPTF-1
NTRITF=NTRITF+1
NHUPTF=NHUPTF-1
LITT=LITT+1
LLITT=NLITT
DISRT(LITT)=0.0
121 CONTINUE
122 IF(NHUITF.EQ.0) GO TO 125
DO 123 L=LLITT,LITT
DISRT(L)=DISRT(L)+SPTOFD*0.01
IF(DISRT(L).LT.DISPLT(NFD)) GO TO 123
NHUITF=NHUITF-1
NLITT=LLITT+1
NTRITF=NTRITF-1
IF(ITRANS.EQ.1) GO TO 123
NTRACF=NTRACF+1
123 CONTINUE
C *****
C TRANSIT OF TRACTORS TO FIELD WITHOUT WAGONS
C *****
125 IF(ITRANS.EQ.1) GO TO 128
IF(NTRACP.EQ.0) GO TO 126
NTRACP=NTRACP-1
EMTRTF=EMTRTF+1
IETRT=IETRT+1
EMDISF(IETRT)=0.0
126 IF(EMTRTF.LE.0) GO TO 128
KETRT=NETRT
DO 500 MI=KETRT,IETRT
EMDISF(MI)=EMDISF(MI)+SPFRFD*0.1

```

```

SOR02570
SOR02580
SOR02590
SOR02600
SOR02610
SOR02620
SOR02630
SOR02640
SOR02650
SOR02660
SOR02670
SOR02680
SOR02690
SOR02700
SOR02710
SOR02720
SOR02730
SOR02740
SOR02750
SOR02760
SOR02770
SOR02780
SOR02790
SOR02800
SOR02810
SOR02820
SOR02830
SOR02840
SOR02850
SOR02860
SOR02870
SOR02880

IF(NDA.EQ.KDA) GO TO 129
KDA=NDA
IF(SPREAD.GT.1.00) SPREAD=1.00
GO TO 130
129 IF(SPREAD.LT.1) GO TO 130
IF(HOUROP*PLTCAP*PLTEFF.LE.(HARHR-DSBFLD(IFD)/MOVSPD)*HAREFF*HARC
1AP) GO TO 130
SPREAD=(WTTPRO-TWTSYS)/((HARHR-TM-0.10)*HARCAP*HAREFF/100.0)
*****
C HARVEST
C *****
C *****
130 IF(TM.GE.HARHR) GO TO 135
IF(TWTSYS.GT.WTTPRO) GO TO 135
IF(TACHAR.GE.ACRES) GO TO 135
IF(ACHAR.GE.ACRE(NFD)) GO TO 135
QTM=TM
IF(WEIGHT(LD).EQ.0.0) NHUIFD=NHUIFD+1
IF(WEIGHT(LD).EQ.0.0.AND.ITRANS.EQ.1) NTRIFD=NTRIFD+1
WTHAR=SPREAD*HARCAP*HAREFF*0.01/100.0
WEIGHT(LD)=WEIGHT(LD)+WTHAR
WTHARD=WTHARD+WTHAR
ACHAR=ACHAR+WTHAR/YIELD
TACHAR=TACHAR+WTHAR/YIELD
IF(WEIGHT(LD).LT.HLCAP) GO TO 140
135 IF(TM.GT.HARHR+0.01) GO TO 140
IF(WEIGHT(LD).EQ.0.0) GO TO 140
LD=LD+1
WEIGHT(LD)=0.0
NHUIFD=NHUIFD-1
IF(ITRANS.EQ.1) NTRACF=NTRACF+1
IF(ITRANS.EQ.1) NTRIFD=NTRIFD-1
NFLHUF=NFLHUF+1

```

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SOR02250
SOR02260
SOR02270
SOR02280
SOR02290
SOR02300
SOR02310
SOR02320
SOR02330
SOR02340
SOR02350
SOR02360
SOR02370
SOR02380
SOR02390
SOR02400
SOR02410
SOR02420
SOR02430
SOR02440
SOR02450
SOR02460
SOR02470
SOR02480
SOR02490
SOR02500
SOR02510
SOR02520
SOR02530
SOR02540
SOR02550
SOR02560

IF(EMDISF(MI).LT.DISPLT(NFD)) GO TO 128
NTRACF=NTRACF+1
EMTRTF=EMTRTF-1
NETRI=NETRI+1
500 CONTINUE
C *****
C CHANGE FIELD
C *****
128 IF(ACHAR.LT.ACRE(NFD)) GO TO 130
IF(INT(MOVETM*1000.0).GT.0) GO TO 134
TACHAR=0.0
KKNFD=NFD
IFD=NFD+1
DO 127 KNFD=1,KKNFD
TACHAR=TACHAR+ACRE(KNFD)
127 CONTINUE
134 IF(TACHAR.GE.ACRES) GO TO 130
MOVETM=MOVETM+0.01
DISMOV=MOVSPD*MOVETM
IF(DISMOV.LT.DSBFLD(IFD)) GO TO 135
IF(LDP.EQ.1.AND.NHUALP.EQ.0) WTTPRO=PLTCAP*PLTEFF*HOURP/100.0
DESSPR=SPREAD
OIF(OPHOUR.GE.(HARHR+MOVETM+WEIGTM+PREPTM+DISPLT(IFD)/SPFRFD)) SPRESOR02470
1AD=(WTTPRO-TWTSYS)/(HARCAP*HAREFF*(HARHR-TM-0.10)/100.0)
OIF(OPHOUR.LT.(HARHR+MOVETM+WEIGTM+PREPTM+DISPLT(IFD)/SPFRFD)) SPRESOR02490
1AD=(WTTPRO-TWTSYS)/(OPHOUR-WEIGTM-PREPTM-DISPLT(IFD)/SPFRFD-0.10-SOR02500
2MOVEITM)*HARCAP*HAREFF/100.0)
ACHAR=0.0
MOVETM=0.0
DISMOV=0.0
NFD=NFD+1
IF(DESSPR.GT.1.00) SPREAD=1.00

```



```

C *****SOR02890
C TRANSIT FROM FIELD *****SOR02900
C *****SOR02910 *****SOR02920
140 IF(NFLHUF.EQ.0) GO TO 141
IF(NTRACF.GT.0) GO TO 141
IF(ITRANS.EQ.1) GO TO 141
IF((WGTHD+WALPR).LT.((WEIGTM+PREPTM+DISPLT(NFD))/SPFRFD)*PLTEFF
1*PLTCAP/100.0)) NTRACF=1
141 IF(NTRACF.EQ.0) GO TO 142
IF(NFLHUF.EQ.0) GO TO 142
IF(NDA.EQ.KDA) GO TO 194
KDA=NDA
TWTSYS=WTHARD
WTTPRO=HOUROP*PLTEFF*PLTCAP/100.0
OPHOUR=OPHOUR+DISPLT(NFD)/SPFRFD+WEIGTM+STARTM+TM
OIF(OPHOUR.GE.(HARHR+WEIGTM+PREPTM+DISPLT(NFD))/SPFRFD)) SPREAD=(W
ITTPRO-TWTSYS)/(HARCAP*HAREFF*(HARHR-TM-0.10)/100.0)
OIF(OPHOUR.LT.(HARHR+WEIGTM+PREPTM+DISPLT(NFD))/SPFRFD)) SPREAD=(W
ITTPRO-TWTSYS)/((OPHOUR-WEIGTM-PREPTM-DISPLT(NFD))/SPFRFD-0.10)*HA
2RCAP*HAREFF/100.0)
IF(NFD.EQ.NOFLD) GO TO 193
IF((ACRE(NFD)-ACHAR)*YIELD.LT.HOUROP*PLTCAP*PLTEFF/100.0.AND.OPHOUSOR03100
1R.GE.(HARHR+WEIGTM+PREPTM+DISPLT(NFD))/SPFRFD)) SPREAD=(WTTPRO-TWTSOR03110
2YS)/((HARHR-DSBFLD(NFD+1)/MOVSPD-TM-0.10)*HARCAP*HAREFF/100.0) SOR03120
IF((ACRE(NFD)-ACHAR)*YIELD.LT.HOUROP*PLTCAP*PLTEFF/100.0.AND.OPHOUSOR03130
1R.LT.(HARHR+WEIGTM+PREPTM+DISPLT(NFD))/SPFRFD)) SPREAD=(WTTPRO-TWTSOR03140
2YS)/((OPHOUR-WEIGTM-PREPTM-DISPLT(NFD))/SPFRFD-DSBFLD(NFD+1)/MOVSPD
3-0.10)*HARCAP*HAREFF/100.0) SOR03160
193 IF(SPREAD.GT.1.00) SPREAD=1.00 SOR03170
194 NFLHUF=NFLHUF-1 NHUITT=NHUITT+1 SOR03180
NLD=NLD+1 SOR03190
SOR03200

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SOR03210
SOR03220
SOR03230
SOR03240
SOR03250
SOR03260
SOR03270
SOR03280
SOR03290
SOR03300
SOR03310
SOR03320
SOR03330
SOR03340
SOR03350
SOR03360
SOR03370
SOR03380
SOR03390
SOR03400
SOR03410
SOR03420
SOR03430
SOR03440
SOR03450
SOR03460
SOR03470
SOR03480
SOR03490
SOR03500
SOR03510
SOR03520

DISTR(NLD)=0.0
NTRACF=NTRACF-1
NTRITT=NTRITT+1
142 IF(NHUITT.EQ.0) GO TO 150
LLD=NLLD
DO 145 N=LLD,NLD
DISTR(N)=DISTR(N)+SPFRFD*0.01
IF(DISTR(N).LT.DISPLT(NFD)) GO TO 145
NLLD=LLD+1
NHUITT=NHUITT-1
NHUWG=NHUWG+1
NTRITT=NTRITT-1
NTRWG=NTRWG+1
145 CONTINUE
C *****
C WEIGH
C *****
150 IF(NHUWG.EQ.0) GO TO 155
WGTM(LWG)=WGTM(LWG)+0.01
IF(WGTM(LWG).LT.WEIGTM) GO TO 155
LHD=LWG
LWG=LWG+1
WGTM(LWG)=0.0
NHUWG=NHUWG-1
NHUIHD=NHUIHD+1
NTRWG=NTRWG-1
C *****
C DETERMINATION OF THE NUMBER OF HUALING TRACTORS AT PLANT
C *****
C IF(ITRANS.EQ.1) NTRACP=NTRACP+1
IF(ITRANS.EQ.1) GO TO 160
NTRAUH=NTRAUH+1

```

```

155 IF(NTRAUH.EQ.0) GO TO 160
    TMUHK=TMUHK+0.01
    IF(TMUHK.LT.UHKTM) GO TO 160
    TMUHK=0.0
    NTRAUH=NTRAUH-1
    NTRACP=NTRACP+1
    STOPTM=TM
    *****
C   HOLDING AREA
C   *****
C   160 IF(NHUIHD.EQ.0) GO TO 170
      IF(LLHD.EQ.LLHD) GO TO 170
      WGTIHD=WGTIHD+WEIGHT(LLHD)
      LLHD=LHD
      IF(ITRANS.EQ.1) STOPTM=TM
      *****
C   PREPARATIONS FOR PROCESSING
C   *****
C   170 IF(NHUALP.EQ.MAXPRO) GO TO 190
      IF(NHUIHD.EQ.1.AND.NHUALP.EQ.0) GO TO 180
      IF(NHUIHD.EQ.0) GO TO 190
      TMPREP(LPP)=TMPREP(LPP)+0.01
      IF(TMPREP(LPP).LT.PREPTM) GO TO 190
      WGTIHD=WGTIHD-WEIGHT(LPP)
      WTALPR=WTALPR+WEIGHT(LPP)
      LPP=LPP+1
      TMPREP(LPP)=0.0
      TMSTAR(LPP)=0.0
      NHUIHD=NHUIHD-1
      NHUALP=NHUALP+1
      GO TO 190
      *****
C
SOR03530
SOR03540
SOR03550
SOR03560
SOR03570
SOR03580
SOR03590
SOR03600
SOR03610
SOR03620
SOR03630
SOR03640
SOR03650
SOR03660
SOR03670
SOR03680
SOR03690
SOR03700
SOR03710
SOR03720
SOR03730
SOR03740
SOR03750
SOR03760
SOR03770
SOR03780
SOR03790
SOR03800
SOR03810
SOR03820
SOR03830
SOR03840

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SOR03850
SOR03860
SOR03870
SOR03880
SOR03890
SOR03900
SOR03910
SOR03920
SOR03930
SOR03940
SOR03950
SOR03960
SOR03970
SOR03980
SOR03990
SOR04000
SOR04010
SOR04020
SOR04030
SOR04040
SOR04050
SOR04060
SOR04070
SOR04080
SOR04090
SOR04100
SOR04110
SOR04120
SOR04130
SOR04140
SOR04150
SOR04160

C     PLANT START
C     *****
180  TMSTAR(LPP)=TMSTAR(LPP)+0.01
      IF(TMSTAR(LPP).LT.STARTM) GO TO 210
      WGTIHD=WGTIHD-WEIGHT(LPP)
      WTALPR=WTALPR+WEIGHT(LPP)
      LPP=LPP+1
      TMPREP(LPP)=0.0
      TMSTAR(LPP)=0.0
      NHUIHD=NHUIHD-1
      NHUALP=NHUALP+1
      STTM= TM
C     *****
C     PROCESSING
C     *****
190  IF (NHUALP.EQ.0) GO TO 210
      WTPROS=PLTCAP*PLTEFF*0.01/100.0
      WTPROL(LDP)=WTPROL(LDP)+WTPROS
      WTALPR=WTALPR-WTPROS
      TWTPRO=TWTPRO+WTPROS
      TWTSYS=WTHARD-TWTPRO
      WTTPRO=(OPHOUR-TM)*PLTCAP*PLTEFF/100.0
      IF((TM+0.01).GT.OPHOUR) GO TO 195
      IF(WTPROL(LDP).LT.WEIGHT(LDP)) GO TO 200
195  LDJ=LDP
      LDP=LDP+1
      WTPROL(LDP)=0.0
      NEMHUP=NEMHUP+1
      NHUALP=NHUALP-1
C     *****
C     JUICE AND MOLASSES YIELDS
C     *****

```

```

SOR04170
SOR04180
SOR04190
SOR04200
SOR04210
SOR04220
SOR04230
SOR04240
SOR04250
SOR04260
SOR04270
SOR04280
SOR04290
SOR04300
SOR04310
SOR04320
SOR04330
SOR04340
SOR04350
SOR04360
SOR04370
SOR04380
SOR04390
SOR04400
SOR04410
SOR04420
SOR04430
SOR04440
SOR04450
SOR04460
SOR04470
SOR04480

LBSJUC=LBSJUC+WEIGHT(LDJ)*LBSBUK
GALMOL=LBSJUC*BRIX20/909.6
GALJUC=LBSJUC/(SPECGR*8.322)
*****
C SOLID WASTE
*****
C SOLWAS=SOLWAS+WTPROS*PCNTWA
*****
C COUNT HAULING UNITS AND TRACTORS
*****
C 210 NTOOTHU=NEMHUP+NHUALP+NHUITT+NHUWG+NHUIHD+NFLHUF+NHUITF+NHUITF+NHUI
1FD+NADHAR
IF(NTOOTHU.GT.HUMAX) HUMAX=NTOOTHU
NTOTRA=NTRPTF+NTRITF+NTRACF+EMTRTF+NTRACF+NTRITT+NTRWG+NTRAUH+NTRI
1FD
IF(NTOTRA.GT.TRMAX) TRMAX=NTOTRA
*****
C IS A TRACTOR AVAILABLE FOR PULLING WAGONS TO FIELD
*****
C IF(NEMHUP.EQ.0) GO TO 220
IF(NTRACP.EQ.0) GO TO 220
NTRACP=NTRACP-1
NTRPTF=NTRPTF+1
NEMHUP=NEMHUP-1
NHUPTF=NHUPTF+1
LPTT=LPTT+1
PRPTTF(LPTT)=0.0
*****
C HAVE ALL ACRES BEEN HARVESTED
*****
C IF(NHUALP.EQ.0.AND.TACHAR.GE.ACRES.AND.LDP.GT.1) GO TO 110
GO TO 120

```


APPENDIX II

Definition of Variables Used in Computer Program

Section 1: Input Variables

Section 2: Computed Variables

Input Variables

ACRE ()* - acres in each field to be harvested

BRIX 20 - expected percent sugar or degree brix of expressed juice
at 20 degrees centigrade

DSBFLD () - distance between last field harvested and next to be
harvested, mi.

HARCAP - combined capacity of all harvesters during continuous operation,
in lbs/hr.

HAREFF - the ratio of actual harvest time to total harvest time in
percent

HARHR - time which harvesting equipment operates each day, in hrs.

HLCAP - capacity of hauling units, in lbs.

ITRANS - indicates the type of transportation equipment to be used for
transporting harvested material from fields to the plant, i.e.:

0 - tractors and wagons

1 - trucks with a driver for each truck

2 - trucks with necessary drivers only

LBSBUK - ratio of juice produced to bulk material processed

MAXPRO - the maximum number of hauling units that can be positioned
at input conveyor for processing, usually 1 or 2

MOVSPD - moving speed of harvesting equipment between fields, in mi/hr.

NOFLD - total number of fields to be harvested

NOHAR - number of harvesters to be used

* Subscripted variables are denoted by ().

Input Variables (Continued)

- OPHOUR - time that separation system will operate per day, in hrs.
(redefined in program)
- PCNTWA - 1- LBSBUK (see LBSBUK)
- PLTCAP - capacity of system to separate and express juice from stalk sections, in lbs/hr of bulk material
- PLTEFF - ratio of actual to total process time, in percent
- PREPTM - time required to prepare a load of material after weighing for unloading, in hrs.
- PRODA - number of processing days in season
- PRPEMT - time required to prepare empty hauling units for return trip to field, in hrs.
- SPTOFD - travel speed of empty hauling units returning to field, in mi/hr.
- SPFRFD - travel speed of loaded hauling units traveling to plant, in mi/hr.
- UHKTM - time required to unhitch wagons at holding area or preparation time for hauling units entering holding area, in hrs.
- WEIGTM - time in hours required to weigh a hauling unit
- YIELD - yield of chopped sorghum in lbs/ac.

Computed Variables

- ACHAR - acres of sorghum harvested from field in which harvesting is taking place
- ACRES - the sum of acres available for harvest in all fields
- DESSPR - the value of the spread factor computed prior to current spread factor (see definition of SPREAD)
- DISMOV - the distance traveled by harvesting machinery when moving from one field to another, in mi.
- DISTR () - the distance traveled by loaded hauling units in transit to plant, in mi.
- DISTR () - distance traveled by hauling units when returning from the plant to field, in mi.
- EMDISF - distance traveled by tractors when returning to field without wagons, in mi.
- EMTRIF - the number of tractors returning to field without wagons
- GALJUC - the cumulative total of juice expressed from processed sorghum, gal.
- GALMOL - the cumulative total of syrup produced, gal.
- HOUROP - the time which the processing system operates each day, in hrs.
- HUMAX - the number of hauling units required to keep system operating continuously
- HRMAN - cumulative total man-hours required to keep the systems operating
- IETRT - a counter used to determine the number of tractors returning to field without wagons

Computed Variables (Continued)

IFD - a counter used to designate the field from which harvesting will next take place

ITTER - number of empty hauling units returning to field

KDA - a decision variable used to decide when to compute variables which control harvesting operations

KETRT - a counter used to determine the number of tractors without wagons which have departed from the plant minus the number of tractors not pulling wagons in route to the field

KKNFD - designates last field harvested

LBSJUC - cumulative total of juice produced, in lbs.

LD - counter for number of loads of sorghum harvested during each day

LDJ - counter for number of loads of sorghum from which juice and syrup yields have been calculated

LDP - counter for number of loads of sorghum processed

LHD - counter for number of loads of sorghum which move into holding area

LITT - counter for number of hauling units which return to field

LLD - counter for the number of hauling units which have departed from field minus the number of hauling units which are in transit to plant

LLHD - a decision variable used to bypass holding area when $LLHD = LHD$

LLITT - a counter which determines the number of empty hauling units which have departed from plant minus the number of empty units in transit to field

Computed Variables (Continued)

LPP - a counter which identifies loads of sorghum being prepared for processing

LPTT - identifies hauling units which are preparing to return to field

LWG - identifies hauling units which are weighing

MOVETM - time elapsed when machinery moves between fields, in hrs.

NADHAR - the number of harvesters used minus 1. (NOHAR -1)

NDA - day of processing season

NEMHUP - number of empty hauling units at plant

NETRT - number of tractors which have departed from plant without wagons minus the number of tractors without wagons in transit

NFD - signifies field from which harvesting is taking place

NFLHUF - number of full hauling units in field

NHUALP - number of hauling units containing sorghum which are ready for processing

NHUIFD - number of hauling units being loaded in field

NHUIHD - number of hauling units in holding area

NHUITF - number of hauling units in transit to field

NHUITT - number of loaded hauling units in transit to plant

NHUPTF - number of hauling units being prepared to return to field

NHUWG - number of hauling units being weighed

NITT - the number of hauling units which have departed from plant minus the number in transit to field

NITTER - the number of hauling units which have departed from plant

NLD - a counter used to identify loaded hauling units in transit to plant

Computed Variables (Continued)

- NLITT - the number of hauling units which have departed from plant
 minus the number of hauling units in transit to field
- NLLD - the number of hauling units which have departed from plant minus
 the number of hauling units in transit to plant
- NTOTHU - total number of hauling units in system at any time
- NTOTTR - total number of transporting tractors in system at any time
- NTRACF - number of transporting tractors in field
- NTRACP - number of transporting tractors at plant
- NTRAUH - number of tractors unhitching at plant
- NTRIFD - the number of tractors in the field at any point in time
 NTRIFD is computed only when ITRANS = 1 or 2
- NTRITF - number of tractors in transit to field
- NTRITT - number of tractors in transit to plant
- NTRPTF - number of tractors preparing to depart to field
- NTRWG - number of tractors hitched to wagons which are being weighed
- OPHOUR - (redefined input variable) the time which the plant operates
 each day plus the time it takes to harvest, transport, weigh,
 and prepare the first load of the day for processing, in hrs.
- PRPTTF - elapsed time for preparing tractors and wagons for departure
 from plant, in hrs.
- QTM - time after start until harvesting is stopped, in hrs.
- REMAC - acres of sorghum standing in field at the end of season
- REMHRS - processing time remaining in day after entire crop has been
 harvested, in hrs.

Computed Variables (Continued)

- SOLWAS - solid by-product produced by system; includes bagasse and other solid material separated, in lbs.
- SPREAD - a variable used to spread harvesting activities over the entire day when surplus harvesting capacity is available
- STOPTM - elapsed time after start of harvesting until the last load of material arrives at plant, in hrs.
- STTM - the time it takes for the first load of sorghum to be harvested, transported, and prepared for processing, in hrs.
- TACHAR - total acres of sorghum processed from all fields at any time
- TM - time, in hrs.
- TMPREP - elapsed time for the preparation of each wagon for processing, in hrs.
- TMUHK - elapsed time for unhitching wagons at plant, in hrs.
- TRMAX - the number of tractors required to keep the system operating continuously throughout the day
- TWTHAR - the total weight of material harvested at any time during the day, in lbs.
- TWTPRD - the total weight of materials processed at any time during the day, in lbs.
- TWISYS - the weight of unprocessed material in system any time during the day, in lbs.
- WEIGHT () - weight of material in each load, in lbs.
- WGTIHD - weight of material in holding area, in lbs.
- WGTM () - time elapsed while weighing each load, in hrs.

Computed Variables (Continued)

WTALPR - weight of material ready for processing at any time during
the day, in lbs.

WTHAR - material harvested during each time increment, in lbs.

WTHARD - total material harvested at any time during the day, in lbs.

WTHARS - total material harvested at any time during the season, in lbs.

WTPROL () - total material processed from each load, in lbs.

WTPROS - weight of material processed during each time increment,
in lbs.

WTTPRO - weight of material to be processed in the remainder of the
day, in lbs.

APPENDIX III
Computer Simulation Runs

SIMULATION RUN NO.1

INPUT VALUES

PLANT CAPACITY (LBS/HR) 2880.000
 PLANT EFFICIENCY (PERCENT) 60.40
 HARVESTOR CAPACITY (LBS/HR) 9272.000
 FIELD EFFICIENCY (PERCENT) 49.13
 TYPE OF HAULING UNITS 0 (TRACTORS AND WAGONS)
 HAULING UNIT CAPACITY (LBS) 4119.0
 ACRES OF SORGHUM 2.439
 YIELD PER ACRE (LBS/ACRE) 23645.7
 PRODUCTION DAYS 30
 PROCESSING HOURS 16.00
 HARVESTING HOURS 10.00
 TRAVEL SPEED OF LOADED HAULING UNITS (MPH) 4.440
 TRAVEL SPEED OF EMPTY HAULING UNITS (MPH) 6.240
 MOVING SPEED OF FIELD EQUIPMENT BETWEEN FIELDS (MPH) 4.440
 UNHITCH TIME FOR TRACTORS ENTERING HOLDING AREA (HR) 0.100
 HITCH TIME FOR RETURNING HAULING UNITS (HR) 0.100
 WEIGH TIME (HR) 0.095
 PROCESSING PREPARTION TIME FOR EACH LOAD (HR) 0.172
 PROCESSING START UP TIME (HR) 0.308
 NUMBER OF HAULING UNITS WHICH CAN BE PROCESSED AT ONE TIME 2
 JUICE TO BULK MATERIAL RATIO 0.156
 SOLID WASTE TO BULK MATERIAL RATIO 0.844
 AVERAGE DEGREE BRIX (20 C BASE) OF JUICE 15.8
 NUMBER OF FIELDS 1
 NUMBER OF HARVESTORS 1

(CONTINUED)

SIMULATION RUN NO. 1 (CONT.)

DATA FOR FIELDS LISTED IN ORDER OF HARVEST

FIELD NUMBER	DISTANCE BETWEEN FIELDS (MILES)	DISTANCE TO PLANT (MILES)	AREA IN FIELD (ACRES)
1	0.000	0.338	2.439

SELECTED OUTPUT DATA

DAY OF SEASON	ACRES HARVESTED	BULK MATERIAL PROCESSED (LBS)	JUICE YIELD (GAL)	SYRUP YIELD (GAL)	LABOR (MAN-HRS)	NO. WAGONS	NO. TRACTORS	SPREAD FACTOR
1	1.18	27884.6	491.0	75.6	58.00	5	1	0.578
2	2.36	55769.2	982.0	151.1	116.00	5	1	0.578
3	2.44	57682.4	1015.7	156.3	119.96	1	1	0.578

PROCESSING WAS COMPLETED ON DAY NUMBER 3 OF SEASON WITH 14.93 HOURS REMAINING IN DAY

SIMULATION RUN NO. 2

INPUT VALUES

PLANT CAPACITY (LBS/HR) 2880.000
 PLANT EFFICIENCY (PERCENT) 85.00
 HARVESTER CAPACITY (LBS/HR) 9272.000
 FIELD EFFICIENCY (PERCENT) 62.50
 TYPE OF HAULING UNITS 0 (TRACTORS AND WAGONS)
 HAULING UNIT CAPACITY (LBS) 4119.0
 ACRES OF SORGHUM 2.439
 YIELD PER ACRE (LBS/ACRE) 26979.0
 PRODUCTION DAYS 30
 PROCESSING HOURS 16.00
 HARVESTING HOURS 10.00
 TRAVEL SPEED OF LOADED HAULING UNITS (MPH) 4.440
 TRAVEL SPEED OF EMPTY HAULING UNITS (MPH) 6.240
 MOVING SPEED OF FIELD EQUIPMENT BETWEEN FIELDS (MPH) 4.440
 UNHITCH TIME FOR TRACTORS ENTERING HOLDING AREA (HR) 0.100
 HITCH TIME FOR RETURNING HAULING UNITS (HR) 0.100
 WEIGH TIME (HR) 0.095
 PROCESSING PREPARTION TIME FOR EACH LOAD (HR) 0.172
 PROCESSING START UP TIME (HR) 0.308
 NUMBER OF HAULING UNITS WHICH CAN BE PROCESSED AT ONE TIME 2
 JUICE TO BULK MATERIAL RATIO 0.208
 SOLID WASTE TO BULK MATERIAL RATIO 0.792
 AVERAGE DEGREE BRUX (20 C BASE) OF JUICE 16.2
 NUMBER OF FIELDS 1
 NUMBER OF HARVESTORS 1

(CONTINUED)

SIMULATION RUN NO. 2 (CONT.)

DATA FOR FIELDS LISTED IN ORDER OF HARVEST

FIELD NUMBER	DISTANCE BETWEEN FIELDS (MILES)	DISTANCE TO PLANT (MILES)	AREA IN FIELD (ACRES)
1	0.000	0.338	2.439

SELECTED OUTPUT DATA

*****CUMMULATIVE TOTALS*****								
DAY OF SEASON	ACRES HARVESTED	BULK MATERIAL PROCESSED (LBS)	JUICE YIELD (GAL)	SYRUP YIELD (GAL)	LABOR (MAN-HRS)	NO. WAGONS	NO. TRACTORS	SPREAD FACTOR
1	1.45	39243.8	919.8	145.4	58.00	6	1	0.658
2	2.44	65831.4	1543.0	243.9	97.48	5	1	0.658

PROCESSING WAS COMPLETED ON DAY NUMBER 2 OF SEASON WITH 5.15 HOURS REMAINING IN DAY

SIMULATION RUN NO. 3

INPUT VALUES

PLANT CAPACITY (LBS/HR) 2880.000
 PLANT EFFICIENCY (PERCENT) 85.00
 HARVESTOR CAPACITY (LBS/HR) 9272.000
 FIELD EFFICIENCY (PERCENT) 62.50
 TYPE OF HAULING UNITS 0 (TRACTORS AND WAGONS)
 HAULING UNIT CAPACITY (LBS) 4119.0
 ACRES OF SORGHUM 45.000
 YIELD PER ACRE (LBS/ACRE) 26979.0
 PRODUCTION DAYS 30
 PROCESSING HOURS 16.00
 HARVESTING HOURS 10.00
 TRAVEL SPEED OF LOADED HAULING UNITS (MPH) 4.440
 TRAVEL SPEED OF EMPTY HAULING UNITS (MPH) 6.240
 MOVING SPEED OF FIELD EQUIPMENT BETWEEN FIELDS (MPH) 4.440
 UNHITCH TIME FOR TRACTORS ENTERING HOLDING AREA (HR) 0.100
 HITCH TIME FOR RETURNING HAULING UNITS (HR) 0.100
 WEIGH TIME (HR) 0.095
 PROCESSING PREPARTION TIME FOR EACH LOAD (HR) 0.172
 PROCESSING START UP TIME (HR) 0.308
 NUMBER OF HAULING UNITS WHICH CAN BE PROCESSED AT ONE TIME 2
 JUICE TO BULK MATERIAL RATIO 0.208
 SOLID WASTE TO BULK MATERIAL RATIO 0.792
 AVERAGE DEGREE BRIX (20 C BASE) OF JUICE 16.2
 NUMBER OF FIELDS 6
 NUMBER OF HARVESTORS 1

(CONTINUED)

SIMULATION RUN NO. 3 (CONT.)

DATA FOR FIELDS LISTED IN ORDER OF HARVEST

FIELD NUMBER	DISTANCE BETWEEN FIELDS (MILES)	DISTANCE TO PLANT (MILES)	AREA IN FIELD (ACRES)
1	0.000	0.500	5.000
2	0.600	1.000	10.000
3	4.125	5.000	5.000
4	5.250	10.000	5.000
5	10.750	20.000	10.000
6	11.500	30.000	10.000

(CONTINUED)

SELECTED OUTPUT DATA --- SIMULATION RUN NO. 3

DAY OF SEASON	ACRES HARVESTED	BULK MATERIAL PROCESSED (LBS)	JUICE YIELD (GAL)	SYRUP YIELD (GAL)	LABOR (MAN-HRS)	NO. WAGONS	NO. TRACTORS	SPREAD FACTOR
1	1.45	39243.8	919.8	145.4	68.00	6	1	0.658
2	2.91	78487.6	1839.7	290.8	136.00	6	1	0.658
3	4.36	117731.3	2759.5	436.1	204.00	6	1	0.658
4	5.82	156997.9	3680.0	581.6	272.00	7	1	0.670
5	7.27	196241.7	4599.8	727.0	340.00	6	1	0.658
6	8.73	235485.4	5519.6	872.4	408.00	6	1	0.658
7	10.18	274729.2	6439.5	1017.7	476.00	6	1	0.658
8	11.63	313972.9	7359.3	1163.1	544.00	6	1	0.658
9	13.09	353216.7	8279.1	1308.5	612.00	6	1	0.658
10	14.54	392460.4	9198.9	1453.9	680.00	6	1	0.658
11	16.00	431738.4	10119.5	1599.4	768.00	7	3	0.734
12	17.44	470982.2	11039.3	1744.7	846.00	7	2	0.658
13	18.89	510225.9	11959.1	1890.1	924.00	7	2	0.658
14	20.36	549506.4	12879.7	2035.6	1012.00	9	3	0.763
15	21.80	588750.1	13799.5	2181.0	1110.00	8	4	0.658

(CONTINUED)

SELECTED OUTPUT DATA -- SIMULATION RUN NO. 3 (CONT.)

DAY OF SEASON	ACRES HARVESTED	BULK MATERIAL PROCESSED (LBS)	JUICE YIELD (GAL)	SYRUP YIELD (GAL)	LABOR (MAN-HRS)	NO. WAGONS	NO. TRACTORS	SPREAD FACTOR
16	23.25	627993.9	14719.3	2326.4	1208.00	8	4	0.658
17	24.69	667237.6	15639.1	2471.7	1306.00	8	4	0.658
18	26.09	704334.6	16400.3	2592.0	1444.00	10	8	0.897
19	27.54	743578.4	17320.1	2737.4	1572.00	10	7	0.658
20	28.98	782822.1	18239.9	2882.8	1700.00	10	7	0.658
21	30.43	822065.9	19159.7	3028.1	1828.00	10	7	0.658
22	31.88	861309.6	20079.5	3173.5	1956.00	10	7	0.658
23	33.32	900553.4	20999.3	3318.9	2084.00	10	7	0.658
24	34.77	939797.1	21919.0	3464.3	2212.00	10	7	0.658
25	36.06	973522.9	22709.5	3589.2	2350.00	9	8	0.936
26	37.51	1012766.0	23629.3	3734.6	2488.00	10	8	0.658
27	38.95	1052010.0	24549.1	3879.9	2626.00	10	8	0.658
28	40.40	1091253.0	25468.9	4025.3	2764.00	10	8	0.658
29	41.84	1130496.0	26388.7	4170.7	2902.00	10	8	0.658
30	43.29	1169739.0	27308.5	4316.1	3040.00	10	8	0.658

THE SEASON EXPIRED WITH 1.71 ACRES OF SORGHUM STANDING

SIMULATION RUN NO. 4

INPUT VALUES

PLANT CAPACITY (LBS/HR) 2880.000
 PLANT EFFICIENCY (PERCENT) 85.00
 HARVESTOR CAPACITY (LBS/HR) 9272.000
 FIELD EFFICIENCY (PERCENT) 62.50
 TYPE OF HAULING UNITS 1 (TRUCKS - A DRIVER FOR EACH)
 HAULING UNIT CAPACITY (LBS) 9000.0
 ACRES OF SORGHUM 45.000
 YIELD PER ACRE (LBS/ACRE) 26979.0
 PRODUCTION DAYS 30
 PROCESSING HOURS 16.00
 HARVESTING HOURS 10.00
 TRAVEL SPEED OF LOADED HAULING UNITS (MPH) 30.000
 TRAVEL SPEED OF EMPTY HAULING UNITS (MPH) 35.000
 MOVING SPEED OF FIELD EQUIPMENT BETWEEN FIELDS (MPH) 4.440
 UNHITCH TIME FOR TRACTORS ENTERING HOLDING AREA (HR) 0.100
 HITCH TIME FOR RETURNING HAULING UNITS (HR) 0.100
 WEIGH TIME (HR) 0.095
 PROCESSING PREPARTION TIME FOR EACH LOAD (HR) 0.172
 PROCESSING START UP TIME (HR) 0.308
 NUMBER OF HAULING UNITS WHICH CAN BE PROCESSED AT ONE TIME 2
 JUICE TO BULK MATERIAL RATIO 0.208
 SOLID WASTE TO BULK MATERIAL RATIO 0.792
 AVERAGE DEGREE BRUX (20 C BASE) OF JUICE 16.2
 NUMBER OF FIELDS 6
 NUMBER OF HARVESTORS 1

(CONTINUED)

SIMULATION RUN NO. 4 (CONT.)

DATA FOR FIELDS LISTED IN ORDER OF HARVEST

FIELD NUMBER	DISTANCE BETWEEN FIELDS (MILES)	DISTANCE TO PLANT (MILES)	AREA IN FIELD (ACRES)
1	0.000	0.500	5.000
2	0.600	1.000	10.000
3	4.125	5.000	5.000
4	5.250	10.000	5.000
5	10.750	20.000	10.000
6	11.500	30.000	10.000

(CONTINUED)

SELECTED OUTPUT DATA --- SIMULATION RUN NO. 4

DAY OF SEASON	ACRES HARVESTED	BULK MATERIAL PROCESSED (LBS)	JUICE YIELD (GAL)	SYRUP YIELD (GAL)	LABOR (MAN-HRS)	NO. TRUCKS	NO. DRIVERS	SPREAD FACTOR
*****CUMMULATIVE TOTALS*****								
1	1.46	39273.5	920.6	145.5	98.00	4	4	0.623
2	2.91	78546.9	1841.1	291.0	196.00	4	4	0.623
3	4.37	117820.4	2761.7	436.5	294.00	4	4	0.623
4	5.82	157095.9	3682.3	582.0	392.00	4	4	0.636
5	7.28	196333.3	4602.0	727.3	490.00	4	4	0.623
6	8.73	235570.6	5521.7	872.7	588.00	4	4	0.623
7	10.19	274807.9	6441.4	1018.1	686.00	4	4	0.623
8	11.64	314045.2	7361.1	1163.4	784.00	4	4	0.623
9	13.09	353282.5	8280.8	1308.8	882.00	4	4	0.623
10	14.55	392519.8	9200.5	1454.1	980.00	4	4	0.623
11	16.00	431791.5	10119.1	1599.3	1078.00	4	4	0.703
12	17.45	471064.9	11039.6	1744.8	1176.00	4	4	0.623
13	18.89	510338.4	11960.2	1890.3	1274.00	4	4	0.623
14	20.37	549618.6	12880.8	2035.8	1382.00	5	5	0.734
15	21.81	588855.9	13800.5	2181.1	1480.00	4	4	0.623

(CONTINUED)

SELECTED OUTPUT DATA -- SIMULATION RUN NO. 4 (CONT.)

DAY OF SEASON	ACRES HARVESTED	BULK MATERIAL PROCESSED (LBS)	JUICE YIELD (GAL)	SYRUP YIELD (GAL)	LABOR (MAN-HRS)	NO. TRUCKS	NO. DRIVERS	SPREAD FACTOR
*****CUMMULATIVE TOTALS*****								
16	23.26	628093.2	14720.2	2326.5	1578.00	4	4	0.623
17	24.70	667366.9	15640.8	2472.0	1676.00	4	4	0.878
18	26.04	702843.3	16472.3	2603.4	1774.00	4	4	0.888
19	27.49	742116.8	17392.8	2748.9	1872.00	4	4	0.623
20	28.93	781390.2	18313.3	2894.4	1970.00	4	4	0.623
21	30.37	820663.6	19233.9	3039.9	2068.00	4	4	0.623
22	31.82	859937.1	20154.4	3185.4	2166.00	4	4	0.623
23	33.26	899210.5	21074.9	3330.9	2264.00	4	4	0.623
24	34.71	938482.3	21995.4	3476.3	2372.00	5	5	0.904
25	36.03	972361.1	22789.5	3601.8	2470.00	4	4	0.916
26	37.47	1011598.0	23709.2	3747.2	2568.00	4	4	0.623
27	38.92	1050835.0	24628.9	3892.6	2666.00	4	4	0.623
28	40.36	1090072.0	25548.6	4037.9	2764.00	4	4	0.623
29	41.80	1129309.0	26468.3	4183.3	2862.00	4	4	0.623
30	43.24	1168546.0	27388.0	4328.6	2960.00	4	4	0.623

THE SEASON EXPIRED WITH 1.76 ACRES OF SORGHUM STANDING

SIMULATION RUN NO. 5

INPUT VALUES

PLANT CAPACITY (LBS/HR) 2880.000
 PLANT EFFICIENCY (PERCENT) 85.00
 HARVESTOR CAPACITY (LBS/HR) 9272.000
 FIELD EFFICIENCY (PERCENT) 62.50
 TYPE OF HAULING UNITS 2 (TRUCKS - NECESSARY DRIVERS)
 HAULING UNIT CAPACITY (LBS) 9000.0
 ACRES OF SORGHUM 45.000
 YIELD PER ACRE (LBS/ACRE) 26979.0
 PRODUCTION DAYS 30
 PROCESSING HOURS 16.00
 HARVESTING HOURS 10.00
 TRAVEL SPEED OF LOADED HAULING UNITS (MPH) 30.000
 TRAVEL SPEED OF EMPTY HAULING UNITS (MPH) 35.000
 MOVING SPEED OF FIELD EQUIPMENT BETWEEN FIELDS (MPH) 4.440
 UNHITCH TIME FOR TRACTORS ENTERING HOLDING AREA (HR) 0.100
 HITCH TIME FOR RETURNING HAULING UNITS (HR) 0.100
 WEIGH TIME (HR) 0.095
 PROCESSING PREPARTION TIME FOR EACH LOAD (HR) 0.172
 PROCESSING START UP TIME (HR) 0.308
 NUMBER OF HAULING UNITS WHICH CAN BE PROCESSED AT ONE TIME 2
 JUICE TO BULK MATERIAL RATIO 0.208
 SOLID WASTE TO BULK MATERIAL RATIO 0.792
 AVERAGE DEGREE BRUX (20 C BASE) OF JUICE 16.2
 NUMBER OF FIELDS 6
 NUMBER OF HARVESTORS 1

(CONTINUED)

SIMULATION RUN NO. 5 (CONT.)

DATA FOR FIELDS LISTED IN ORDER OF HARVEST

FIELD NUMBER	DISTANCE BETWEEN FIELDS (MILES)	DISTANCE TO PLANT (MILES)	AREA IN FIELD (ACRES)
1	0.000	0.500	5.000
2	0.600	1.000	10.000
3	4.125	5.000	5.000
4	5.250	10.000	5.000
5	10.750	20.000	10.000
6	11.500	30.000	10.000

(CONTINUED)

SELECTED OUTPUT DATA -- SIMULATION RUN NO. 5

*****CUMMULATIVE TOTALS*****										
DAY OF	ACRES	BULK	MATERIAL	JUICE	SYRUP	LABOR	NO.	NO.	NO.	SPREAD
SEASON	HARVESTED	PROCESSED	YIELD	YIELD	YIELD	(MAN-HRS)	TRUCKS	DRIVERS	DRIVERS	FACTOR
		(LBS)	(GAL)	(GAL)	(GAL)					
1	1.45	39243.8	919.8	145.4	58.00	6	1	0.658		
2	2.44	65831.4	1543.0	243.9	97.48	5	1	0.658		
1	1.46	39273.5	920.6	145.5	78.00	4	1	0.623		
2	2.91	78546.9	1841.1	291.0	156.00	4	1	0.623		
3	4.37	117820.4	2761.7	436.5	234.00	4	1	0.623		
4	5.82	157095.9	3682.3	582.0	312.00	4	1	0.636		
5	7.28	196333.3	4602.0	727.3	390.00	4	1	0.623		
6	8.73	235570.6	5521.7	872.7	468.00	4	1	0.623		
7	10.19	274807.9	6441.4	1018.1	546.00	4	1	0.623		
8	11.64	314045.2	7361.1	1163.4	624.00	4	1	0.623		
9	13.09	353282.5	8280.8	1308.8	702.00	4	1	0.623		
10	14.55	392519.8	9200.5	1454.1	780.00	4	1	0.623		
11	16.00	431791.5	10119.1	1599.3	858.00	4	1	0.703		
12	17.45	471064.9	11039.6	1744.8	936.00	4	1	0.623		
13	18.89	510338.4	11960.2	1890.3	1014.00	4	1	0.623		
14	20.37	549618.6	12880.8	2035.8	1092.00	5	1	0.734		
15	21.81	588855.9	13800.5	2181.1	1170.00	4	1	0.623		

(CONTINUED)

SELECTED OUTPUT DATA -- SIMULATION RUN NO. 5 (CONT.)

*****CUMMULATIVE TOTALS*****

DAY OF SEASON	ACRES HARVESTED	BULK MATERIAL PROCESSED (LBS)	JUICE YIELD (GAL)	SYRUP YIELD (GAL)	LABOR (MAN-HRS)	NO. TRUCKS	NO. DRIVERS	SPREAD FACTOR
16	23.26	628093.2	14720.2	2326.5	1248.00	4	1	0.623
17	24.70	667366.9	15640.8	2472.0	1326.00	5	1	0.878
18	26.04	702843.3	16472.3	2603.4	1404.00	4	1	0.888
19	27.49	742116.8	17392.8	2748.9	1482.00	4	1	0.623
20	28.93	781390.2	18313.3	2894.4	1560.00	4	1	0.623
21	30.37	820663.6	19233.9	3039.9	1638.00	4	1	0.623
22	31.82	859937.1	20154.4	3185.4	1716.00	4	1	0.623
23	33.26	899210.5	21074.9	3330.9	1794.00	4	1	0.623
24	34.71	938482.3	21995.4	3476.3	1872.00	5	1	0.904
25	36.03	972361.1	22789.5	3601.8	1950.00	4	1	0.916
26	37.47	1011598.0	23709.2	3747.2	2028.00	4	1	0.623
27	38.92	1050835.0	24628.9	3892.6	2106.00	4	1	0.623
28	40.36	1090072.0	25548.6	4037.9	2184.00	4	1	0.623
29	41.80	1129309.0	26468.3	4183.3	2262.00	4	1	0.623
30	43.24	1168546.0	27388.0	4328.6	2340.00	4	1	0.623

THE SEASON EXPIRED WITH 1.76 ACRES OF SORGHUM STANDING

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EVALUATION
AND SIMULATION OF A HARVESTING
AND JUICE EXPRESSION SYSTEM FOR SWEET SORGHUM

by

Othel Donald Bowling

(ABSTRACT)

A project was undertaken to compile and evaluate a computer program to simulate a system developed by the Agricultural Engineering Department at Virginia Polytechnic Institute and State University to harvest, transport and express juice from sweet sorghum for syrup production. Time study and product data were taken for approximately 29 tons of sweet sorghum processed during the 1976 season.

Material, consisting of standing sorghum chopped into 5" lengths, was separated by a pneumatic system and analyzed to determine effectiveness of separation. Up to 85 percent of the stalk sections were separated from the bulk material. Most of the unseparated stalks were undesirable for the production of quality syrup.

The computer model simulated harvesting, transportation, stalk separation, juice expression from the stalks and syrup production. It was dynamic and deterministic in nature. Harvesting from any number of fields with known areas, yields, locations, and order of harvest could be simulated. Transportation could be simulated using any of three types of labor and equipment combinations. The program had the

capability of determining required transportation equipment to keep separation and milling system operating continuously. Other principal parameters computed were labor requirements, juice expressed, and syrup yields.

Simulation indicated that 40 to 45 acres of sorghum could be harvested and processed during a 30-day season. The amount of labor required using the VPI & SU system was approximately 50% of that required for conventional hand methods for harvesting and expressing juice for sorghum syrup.