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Studies on the Sugars of Sorghum

A Thesis Submitted to the Faculty of the
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STUDIES on the SUGARS of SORGHUM.

Introduction.

The manufacture of sorghum sirups is a widely spread industry but is not well developed at present. The experience of successful manufacturers shows that the making of sorghum sirups is profitable, and in view of the fact that the product is in great demand it is a highly desirable industry to establish on a firm basis.

The following research was instituted as an aid in furthering the growth of the industry in Minnesota and to gather as much information as possible in regard to the theoretical and practical aspects of the situation.

Scope of the Work.

The scope of the work includes a qualitative investigation of the kinds of sugar found in sorghum juice, their distribution in the plant and in its cane, their development during the growth of the cane, the amounts present in the sirups made from the juice, and the effect of the sugars on the quality of the product.

Literature.

The literature on sorghum is quite extensive, but the actual number of references having a bearing on this investigation is small. The sorghum plant is a member of the Andropogon genus of the grass family, the cultivated varieties having originated from Andropogon halepensis, according to Ball.[1] It will be compared from time to time with the sugar cane, Saccharum officinarum, to which it is closely related, and in some respects with corn.

The juice of sorghum compares favorably with that of sugar cane, especially for sirup making. [2]

[1] Bur. Pl. Ind. Bul. 175, p. 8
[2] Collier, Sorghum, p. 187, Cincinnati, Robt. Clarke & Co.

The great number of analyses published from widely different sources of both, show quite large variations, due to climate and other causes, but on the average the composition of the two are similar. The sorghum juice has a lower purity coefficient, however, which makes it less favorable for sugar manufacture, but does not detract from its value as a source of sirup. The greater number of references given in the Experiment Station Record of analyses are merely reports of sugar content and as such the majority have no bearing upon this work and are not cited. Other references will be cited as foot notes under the various subdivisions of this paper.

Methods of Procedure.

Plots were planted to sorghum about May 20th, of the following varieties, plots 3 and 15, Early Amber, plots 7 and 16, Early Rose, plots 11 and 17, South Dakota (a variety of Early Amber from South Dakota). These were used for most of the experiments.

Others will be mentioned where it becomes necessary. The actual experimental work began when the panicles were just appearing, at which time the first samples were taken. Work in the earlier stages of growth would have little significance for the purpose of this investigation as the major development of the sugars takes place after the panicles appear and the percent sugar content of the growing plants would be fairly constant previous to this time. Samples were taken at the various stages mentioned below, distributed over the time up to maturity.

The samples consisted of six to twelve (or rarely more) stalks in the same stage of growth, which were cut off near the ground, weighed, stripped and topped and weighed again, run through a roller mill, the resulting juice weighed and analysed.

The Brix reading was taken on the juice and double normal weight taken for analysis. Sucrose was determined by the Clerget method and reducing sugar determined by reduction of Fehling solution

containing a known quantity of copper in a graduated flask. After cooling, making up to volume and standing, an aliquot of the solution was made acid with a definite amount of concentrated sulphuric acid,[1] and the copper which remained unreduced determined by the Low volumetric method. The fructose and glucose content were calculated from the formula given by Wiley.[2]

The sirups were collected from various points in the state (mostly in the southern half) and analysed in the same way except that lead acetate was used in clarification. This did not remove the color as well as the subacetate and frequently fuller's earth had to be resorted to in order to read the polarization of the juice. The reducing power of the inverted solution was also omitted.

Kinds of Sugars Present.

The presence of the three sugars, sucrose, glucose, and fructose was already known and in

[1] A.W.Peters, Jour. Am. Chem. Soc. 34 (1912) p. 422.
[2] H.W.Wiley, Principles and Practice of Agricultural Analysis: Agricultural Products, Vol. 3 (1914), p. 360

regard to other sugars, tests were made which yielded negative results. Thus raffinose could not be detected by the mucic acid test, nor maltose by the osazone reaction.

If these are present at all, they are in too small amounts to be detected even in the sirup, where they would be the most concentrated. No maltose is found in sugar cane by Prinsen-Geerligs.[1] Browne and Blouin[2] say that maltose and raffinose have been reported in sugar cane but that their presence required confirmation.

Distribution of the Sugars.

In the plant:

The sugar of sorghum is distributed throughout the plant in varying amounts, according to the stage of growth. In general, the stalks will contain the most sugar, the leaves next, then the tops and finally, the roots--variations depending upon the maturity of the different parts. Actual analyses

[1] Jahrbücher für Wissenschaftliche Botanik, 31 (1898) No. 3, p. 291.
[2] Louisiana Stat. Bul. 91, p. 9.

of the parts, except stalks, have not been made, as such analyses have no useful purpose for this investigation. The leaves contain two to five per cent sucrose and one to three percent reducing sugar[1] and on account of high content of non-sugar solids, their juice is not suited for sirup making, and even when mixed with cane juice, the resulting sirup is apt to be of lower quality.

The composition of sorghum is probably similar to that of sugar cane. Went finds for sugar cane that the growing-points (meristem) contain no sugar, the rapidly stretching parts (stalks in particular) contain the maximum amount of reducing sugar and little sucrose and the older parts, the maximum sucrose and minimum amount of reducing sugar.

The leaves contain sucrose, glucose, and fructose in the ratio 4:2:1, the roots very little or none, and the cane constantly increasing amounts.[2] The fructose decreases in the mature internodes more than the glucose and becomes nil or very nearly so.[3]

[1] Bur. Chem. Bul. 18, p. 65.
[2] Jahrbücher (see previous ref.) pp. 289-344.
[3] Wiley, Jour. Am. Chem. Soc. 25 (1903) p. 855
Went, loc. cit. 2.
See Louisiana Stat. Bul. 91, p. 14.

TABLE I.

Percent Sugars--Dry Matter Basis

Sample No.	Description Plot	Stage	% Dry Matter	Sucrose	Fructose	Glucose	Total	% Juice Extr.	Parts Sugar per 1000 cane.
3008	7	canes dry dough	10.9	46.1	14.1	16.6	76.8	39	32.6
3009	7	suckers full bloom to milk	9.1	24.6	21.0	36.5	82.2	36	27.3
3010	8	main canes full bloom	12.9	54.8	14.9	18.0	87.7	35	39.9
3092	8	soft--hard dough misc.	11.4	55.8	12.6	17.0	85.4	34	33.3
3097	8	main canes soft dough	14.5	64.1	12.0	14.8	90.8	39.	51.5
3098	8	secondary canes	14.3	56.4	14.7	18.6	89.7	36.	46.4

In table I, analyses are shown of canes and their suckers separately. The difference shows the great immaturity of the suckers. The composition of suckered and unsuckered cane is reported in several analyses and shows a marked decrease in sucrose and purity, and an increase in reducing sugar. The total sugar is higher, but the sugar extracted is less.[1] Removal of suckers during growth results in a slightly heavier cane, although the composition of the juice is not changed materially.[2] According to Harper, canes without suckers are the best[3] and the growth of suckers should be prevented. Patrick[4] claims a beneficent effect of suckering. Collier[5] discusses this and says that suckers should not be included for sugar manufacture. It would appear, however, that they probably would make poor sirup, and even when mixed with the main canes would decrease the quality of the sirups. In secondary canes (table I) there seems to be less sucrose and more reducing sugars, probably due to greater immaturity. The main canes are taken to be

[1]Bur. Chem. Bul. 18, p. 63.
[2]Bur. Chem. Bul. 37, p. 69.
[3]Minn. Bul. 21, p. 108.
[4]Iowa Stat. Bul. 5, p. 157.
[5]Collier, p. 133, loc. cit.

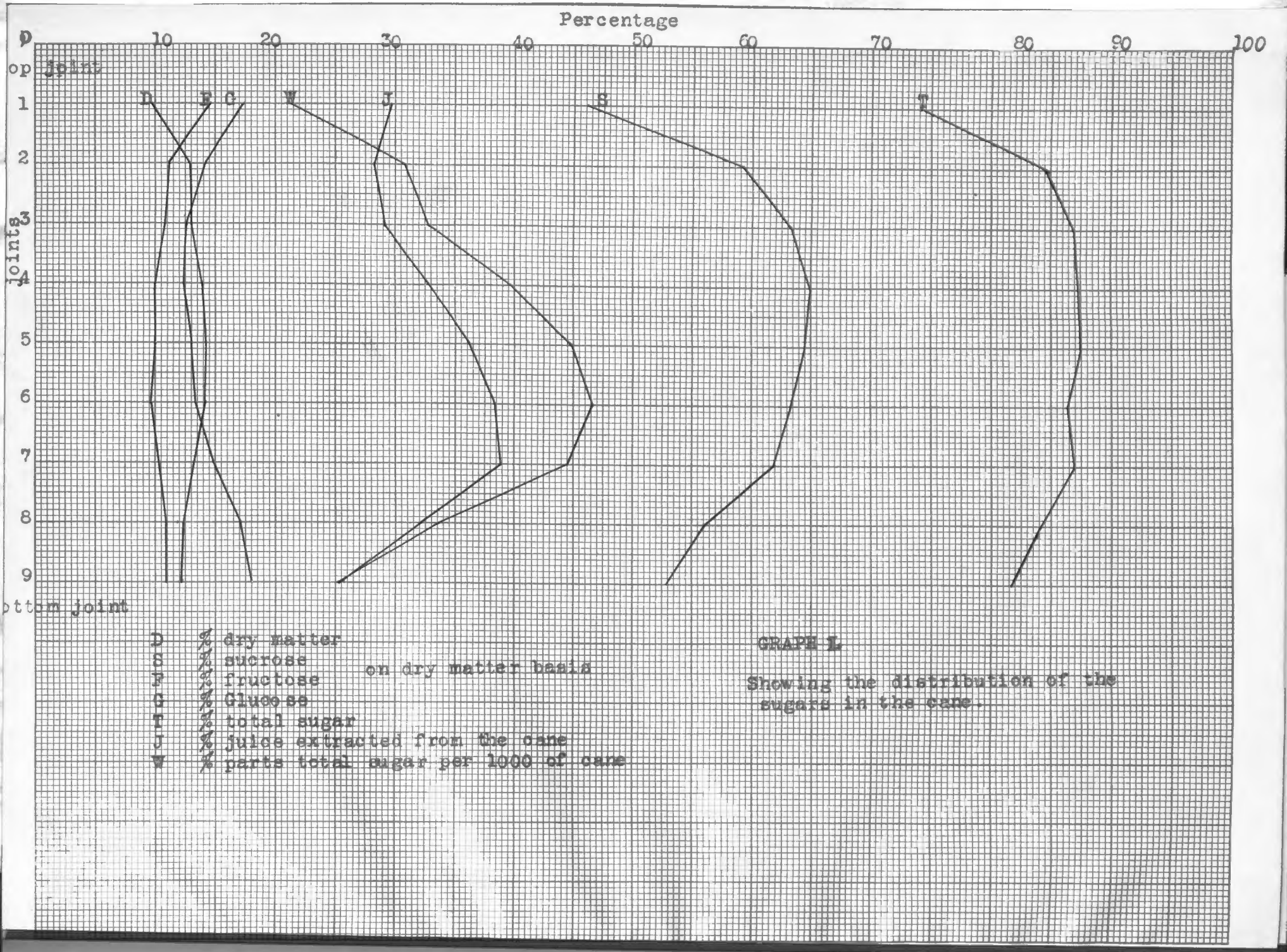
Those which grow up first and the secondary, the underground off-shoots from these. There is not sufficient difference in sugar content between them to be in any way significant.

In the cane:

The sugar content also varies in the various joints of the cane. No analyses were made of the nodes and internodes separately, but undoubtedly the nodes contain less sugar (more fibre) than the internodes, which are more pithy. This is shown by Beeson[1] for sugar cane. The sucrose is somewhat higher in the internodes and the reducing sugars considerably higher.

See Graph.

[1]Louisiana Stat. Bul. 38, 1341-42.



D % dry matter
S % sucrose
F % fructose on dry matter basis
G % Glucose
T % total sugar
J % juice extracted from the cane
W % parts total sugar per 1000 of cane

GRAPH L

Showing the distribution of the sugars in the cane.

With respect to the different joints, examination of the graph (and supplementary tables in the appendix) reveals that as we go from either end of the stalk to the middle, the dry matter, sucrose, and total sugar increase considerably. The reducing sugar, on the other hand, decreases as the sucrose increases, the fructose tending to remain low at the bottom. The sucrose and glucose, however, are lowest at the top. The percentages of juice in the top and bottom are also somewhat less than in the middle, the bottom containing more fibre. The top is usually drier than the lower joints and having a smaller diameter contains relatively less pith.

The other data supports that actually plotted.

Collier[1] determined the amount of sugar in the top and bottom halves of the cane and finds relatively little difference. In other experiments, he divides the cane into three parts, and again concludes that there is little difference. The small differences found, however, in his tables are in some cases directly opposite to those reported here and are not concordant

[1]Collier, pp. 225-237, loc. cit.

among themselves. They are, moreover, not strictly comparable, not being calculated on the dry matter basis.

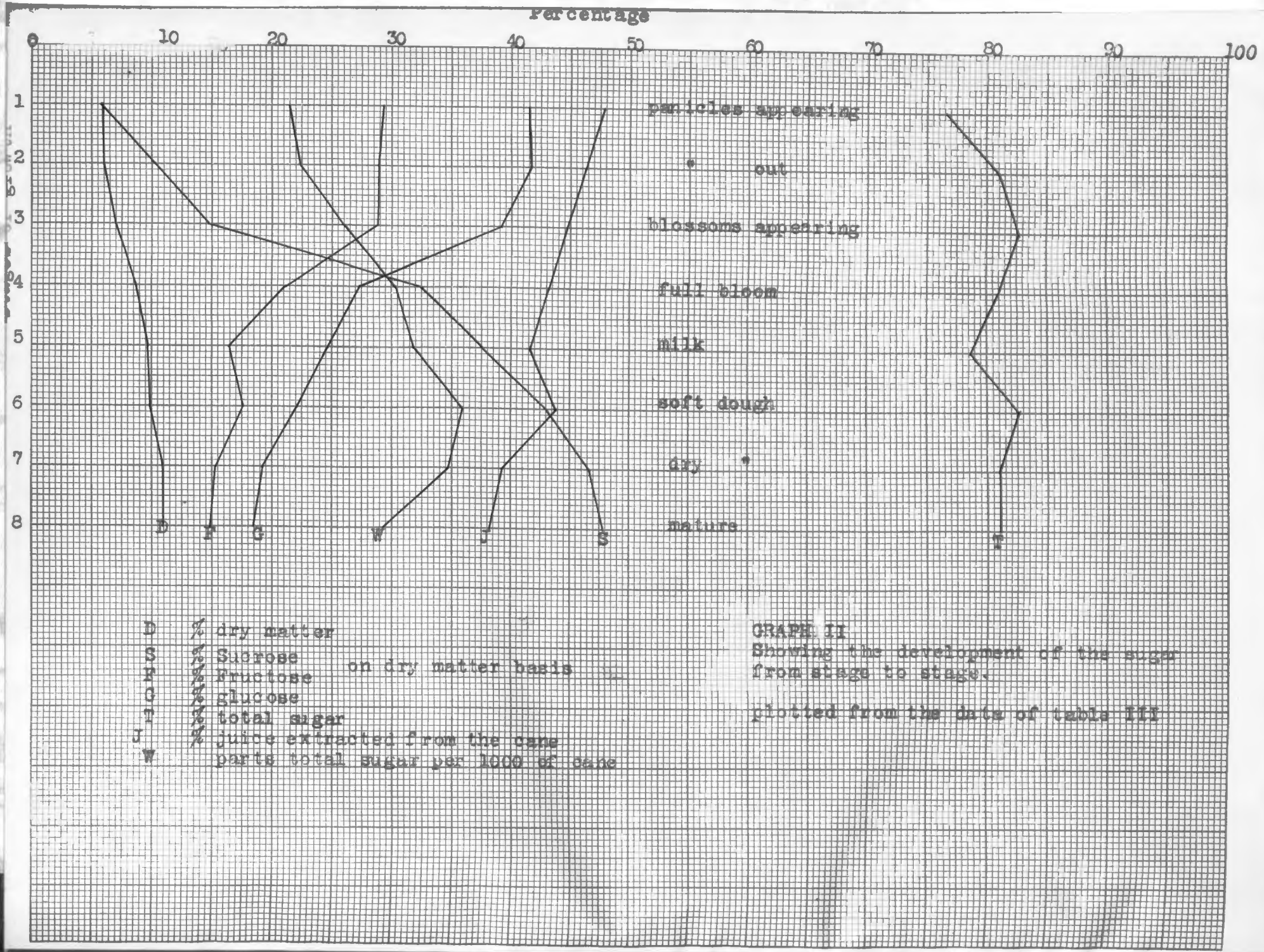
In practice, the uppermost joints contain the least sugar and juice. They might, apparently, well be dispensed with and cut off with the tops. In uniform lengths of cane, it would be advantageous to do this by suitable mechanical means for a large number at one operation, thus saving both labor and time. Calculations of the actual weight of sugar extracted from the different joints show, however, that the amount of loss due to cutting off the whole joint would be about five per cent of the total sugar extracted from the stalk. This would be too great a loss and shows that as much as possible of the upper joint must be included to give the maximum yield of sirup.

Much the same is true of sugar cane[1]. The sucrose here steadily increases from top to bottom and the lowermost joints, with exception of one, (in

[1] Jahrbücher, see previous reference.
Louisiana Bul. 91, p. 29
See also reference given to the Louisiana Planter.

some cases) contain the most sugar. The reducing sugar is highest at top and steadily decreases to the bottom. In the first reference, Went reports similar results and gives the physiology of sugar cane in detail.

See Tables and Graph.



GRAPH II
Showing the development of the sugar from stage to stage.

plotted from the data of table III

TABLE II.

Averages of Analyses of Juice for all Plots at the Different Stages of Growth.

1913.

Stages		% Dry Matter	Sugars in % Dry Matter: Su-crose	Reducing Sugar	Total Sugar	% Juice Extr.	Parts total sugar extr. per 1000 cane
Panicles Appear	1	5.36	4.3	70.9	75.2	34.4	13.9
Panicles Out	2	5.54	7.0	68.8	75.8	36.7	15.4
Blossoms Appear	3	6.01	13.0	64.1	77.1	37.7	17.5
Full Bloom	4	7.26	19.8	58.7	78.5	36.8	20.9
Milk	5	10.69	44.8	40.0	84.8	37.1	33.5
Dough	6	10.89	45.9	36.9	82.8	37.2	33.6
Dry dough	7	11.79	51.7	33.1	84.8	37.0	37.0
Mature	8	12.25	55.9	29.1	85.0	36.8	38.3

Table III.

Averages of Analyses of Juice for all Plots at the Different Stages of Growth.

1914.

Stages	%Dry Matter	Sugars in % Dry Matter: Su-crose	Fruc-tose	Glu-cose	Total Sugar	% Juice Extr.	Parts total sugar extr. per 1000 cane
Pan.Appear	5.9	5.8	29.3	41.5	76.6	47.8	21.5
Pan.Out	6.0	10.3	28.9	41.7	81.0	46.3	22.4
Bloss.Appear	7.0	14.7	28.8	39.2	82.7	44.7	25.9
Full Bloom	8.7	32.5	21.2	27.3	81.0	43.2	30.3
Milk	9.7	37.6	16.5	24.7	78.7	41.6	31.8
Soft dough	9.9	43.0	17.6	22.1	82.7	43.8	35.9
Dry dough	10.9	46.6	15.3	19.2	81.1	39.3	34.7
Mature	10.9	47.8	14.9	18.5	81.1	33.2	29.3

Development of the Sugars.

The development of the sugars as the plant grows and matures is shown in Graph II and accompanying tables II and III. This graph is plotted from the averages of sugar content of samples from six plots (three varieties) at the various stages of growth. The detailed analyses are shown in the appendix. It is seen that the sucrose steadily increases. Parallel, to this, the reducing sugars decrease to about half their original values. The sucrose and glucose content change the most rapidly during blossoming, while the percentage of fructose changes more uniformly. Compare this with the table for 1913, where a slightly later but similar change takes place. On the other hand, the total sugar is quite constant with the greatest variation in the first stage.

The results by plots, as shown in the detailed tables in the appendix, tend to substantiate these results, although here the variety and climatic deviations are more apparent.

Considerable has been done on the development of sugar in sorghum.

Collier[1] has probably done the best work up to the present time. His results are not strictly comparable to those reported here, but they are in agreement in general. He worked from the standpoint of available sugar (sucrose) while that of this investigation is rather the making of sirups. Many tables and graphs are presented which show the composition about a week earlier than the stage at which the panicles first appear, to a time longer after maturity than is usually reached in Minnesota on account of earlier frost. The maximum percent of total sugar (sucrose and reducing sugar) seemed to be at about his 17th stage, corresponding to a week or so after what is here called the mature stage, although the average maximum was attained somewhat earlier and retained until frost.

A search among the numerous analyses reported from various other sources yields some further data

[1] p. 185--225, loc. cit.

on the development of the sugars, but a comparison can hardly be drawn, as the analyses are reported differently, and were made for different purposes. Only a few instances will be cited or referred to. We can, incidentally, find series of analyses showing development of the sugar content, but the results are not uniform in different series.[1] Other tables[2] yield fairly satisfactory results. Good tables are found in other bulletins[3], although even here, the figures are not calculated on a dry matter basis and are, therefore, not comparable to those of this investigation. They show practically the same result, however. Wiley claims that improvement takes place even after the seed has become hard.and brittle. From the trend of our results, even if later analyses have not been made, we could not substantiate any marked improvement. Furthermore, the length of season in Minnesota hardly permits of this. Other tables indirectly indicating the trend of development can be found in other bulletins of the Department of Agriculture[4].

[1]Ky.Stat. Rpt. 1892, p. 14.
[2]Mass. Stat. Ann. Rpt. 8, p. 309; 10, p. 332,
[3]Bur.Chem. Bul. 20, p. 122, 123.
Bur.Chem.Bul. 18, p. 64.
[4]Bur. Chem. Bul. 34, p. 75
Bur. Chem. Bul. 37, p. 66, et seq.
Bur. Chem. Bul.103, p. 11

The development of sugars in sugar cane is very similar[1]. The sucrose steadily increases and the reducing sugars decrease, the fructose nearly or entirely disappearing. Wiley reports one sample of mature cane which contained no reducing sugar.[2] A graph is given in both references from Louisiana, showing this development and various tables are given the Louisiana Planter.

The yield of juice affords an interesting comparison. It is apparent from the table (or graph) that the percentage of juice in the cane decreases with maturity. This would lead one to suspect that the actual amount of total sugar obtainable from the cane was decreasing, especially as the percent of total sugar is quite constant. A glance at the tables for 1913-14 shows that this is not the case and that the amount of sugar in a thousand parts of cane steadily increases from stage to stage, except in the last two of the 1914 series. This would seem unexplainable. Seasonal climatic conditions are a

[1]Louisiana Stat. Bul. 91, pp. 12-17 or
Louisiana Planter, 32 (1904) No. 3, pp. 47-51, and
34 (1905) No.15, pp. 236-240.
[2]Jour. Am. Chem. Soc. 25 (1903) p. 859.

cause which can (and probably does) have an enormous bearing in this regard. A larger, more powerful mill than the one used would possibly have reversed the result or decreased the difference considerably, as the maximum extraction was impossible.

A practical application of this can be found in the fact that the later stages are about equally adapted on the average for the purpose of making sirup, so that if necessary to close the season quickly on account of danger from freezing the cane can be equally well cut at an earlier stage and profitably used. The lengthening of the sirup making season as a result of this is also distinctly advantageous. Of course, different varieties will not always follow this relationship depending upon climate, etc., and can sometimes cause slight reduction in quality of juice for sirup making, if the cane is not sufficiently mature when out. On the other hand, the statement is made by Neumann[1] that sorghum should be cut well in dough and before seed becomes hard or mature. Why this should be done is

[1] Ark. Stat. Bul. 22, p. 76

not mentioned. It has been established that the effect of climate is a very important determiner of the composition of cereals, sugar beets, sugar cane, and also somewhat for sorghum. In the literature, one frequently finds climate mentioned as the cause of a crop failure of one kind or another (or also of good crops) but it is possible that in any case it is the cause of smaller variations, even from day to day. Certain small inconsistencies appear in the tables, which, if the particular climatic factors that prevailed at the time of the analysis were known could possibly be explained. It is stated[1] that parallel fluctuations (decreases in this case) in sucrose content and purity are probably due to dilution of the juice, but that no connection could be found between this and the rainfall, admitting, however, that humidity (which is a directly resulting condition) must have an effect.

Similar fluctuations[2] were noted in passing from drought to rain, and from morning to evening, under drouth conditions, the cane at evening ~~having~~

[1]Del. Bul. 27, p. 20.
" " 39, p. 8.
[2]Bur. Chem. Bul. 34, p. 15.

having lost some moisture due to evaporation. Variations in composition from year to year are also mentioned as being due to climate.[1]

Collier[2] takes up the subject of climate. He discusses the seasonal differences but does not believe that the composition of the juice is materially changed in wet weather. He gives a table showing decreases in sugar content, amount of juice, and specific gravity, with a relatively large gain of solids, not sugar, as a result of a heavy rain after drought. This would seem unexplainable and opposite to what would be expected. In a wet year on the other hand, juices were obtained with lower sugar content which would indicate dilution, or unfavorable conditions for photosynthesis.

Although no detailed account was taken of the weather in our experiments, certain decreases seemed to be explainable by wet weather.

Mention is also made of climatic effects upon sugar cane--the leaves vary in composition

[1]Bur. Chem. Bul. 37, p. 20.
[2]Collier, pp. 145-154, loc. cit.

from night to morning due to translocation, and in consequence thereof the canes must vary. The effect of seasonal differences is noted also.[1]

Topping.

Topping has been reported as beneficial in sorghum, sugar cane, and corn culture, in that it increases the sugar content of the stalk. It is claimed that the material which would otherwise go into the seeds is put into the stalk as sugar. Accordingly, stalks were topped and others tagged, which were in the same stage of growth at the time on plots 8 and 2.--Orange Sorgho, 3, Early Amber, and 11 South Dakota.

The results are shown in table VIII. The dry matter is increased in all cases. The percentage of sucrose is increased, in all but one case, in which an increase in reducing sugars is equally abnormal, but even here the percentage of sugar extracted is slightly, although probably not significantly, increased. The percentage of reducing sugars decreases parallel with the increase of sucrose. Too late to make any

[1]Louisiana Stat. Bul. 91, p. 21, or
Louisiana Planter, 32, p. 48, and 34, p. 239.

conclusive analyses, indications were found that the starch present in the juice was apparently increased in topped canes over those with tops. What appeared to be starch under the microscope with the iodine test was observed. Starch occurs in sorghum juice[1], but it is rare in the ripe internodes of the sugar cane.[2]

The percentage of juice in the cane is about equally divided in favor or cutting and not cutting the tops, although the percentage of sugar extracted would favor it in all but one case.

Collier[3] states that topping hastens the maturity of the cane and, that later the untopped canes would become mature and about equal in sugar content. This is apparently what takes place according to our tables, as the percentage of sugar extracted becomes nearly equal and quite constant in the mature stage. The greatest variations occur in the previous stages. Moreover, earlier topping would apparently simply serve to bring the plant to earlier maturity, and would have no advantage except in short seasons,

[1] H.W. Wiley, Div. Chem. Bul. No. 34, p. 77.
[2] Went, p. 297, loc. cit.
[3] Collier, pp. 138-140, loc. cit.

but at any time would destroy the crop of seed which is valuable. From the standpoint of sirup making the high percent of sucrose would tend to cause the sirup to crystallize, which is usually objected to. An interesting fact may be observed that head smut, by preventing the formation of seed, causes the same effect as topping. Other reports on this subject yield conflicting results. Wiley reports analyses[1] which show very slight differences in favor of topping. Analyses by Collier already mentioned are not conclusive, and experiments in Iowa[2] indicate no favorable effect.

Heckel[3] reports that an increase takes place in sugar content in sorghum and in corn, to the maximum of thirteen per cent of sucrose. It is definitely stated[4], however, that fructose and glucose decrease while sucrose increases on removal of ears and tops, so that possibly, also in this case, the total sugar remains the same. Yields of sugar are also given[5]. The juices of corn compare quite favorably with sorghum, although the yields are higher with sorghum.[6]

[1]Bur. Chem. Bul. 18, p. 68.
[2]Iowa Stat. Bul. 5, p. 158.
[3]Compt. Rend. Acad.Sci (Paris) 155 (1912), No. 6, pp. 686-90, from abstract in Chem. Ztg. 36 (1912) No. 66, Repert. p. 314.
[4]Chem. Abst. Vol. 7, Pt. 2, p. 1739.
[5]Chem. Abst. Vol. 6, Pt. 2, p. 1861.
[6]Collier, p. 443, 445, loc. cit.

Blading for from ten to seventeen days before cutting is reported as increasing the percent of sucrose, purity, and weight of cane[1], but the truth of this would seem doubtful.

Sirups.

There are three general methods of manufacturing sorghum sirup, those carried on by farmers for themselves or others, in which simple boiling of the juice is carried on in a small and primitive manner; those in which lime is used as clarifier with subsequent simple boiling; and those in which lime, or other methods of clarification are used with rapid evaporation of the juice in a steam evaporator, used in larger factories. The lime, or other clarifying agent, when used, precipitates various impurities, (which are allowed to settle out) and the method yields a sirup of better quality. Boiling of the raw or clarified juice removes further impurities which are skimmed from the surface during evaporation. The methods are as yet by no means standardized, and sirups of various qualities are obtained. Sorghum

[1]Del. Stat. Bul. 44, p. 16.

sirup when properly made can surely compete with cane sirup and is preferred above corn sirup or molasses of any kind.

Accordingly analyses were made upon a fairly large number of sirups for the purpose of this and other investigations.

See Table.

TABLE IV.

Showing the Average Sugar Content of Sirups as Obtained by Different Methods of Defecation.

No. Samples		% Dry Matter:	Sugar Content in % Dry Matter. Su-crose	Fruc-tose	Glu-cose	Total Sugar:	Quality (Taste)
3	Phosphate	68.6	49.9	19.9	24.7	94.9	Best
20	Lime used	75.4	54.9	17.2	21.3	93.3	Next best.
17	No lime	75.6	49.2	19.8	24.1	93.2	Poorest
1	Bicarbonate of Soda	70.0	50.5	19.6	26.2	96.3	
1	Heat only and crystallized badly	82.5	67.3	13.6	17.9	98.8	
11	Crystallized	78.3	57.3	15.8	19.1	92.2	

Examination of the table above (see appendix, also) shows in general little variation in the average sugar content. The sucrose makes up about half the dry matter, the glucose being always a little in excess of the fructose, both varying inversely as the sucrose, so that it needs must be concluded then that quality is not greatly affected by the sugars. This statement is further strengthened by the fact that the best and poorest sirups have almost identical sugar content.

According to the table, crystallization would seem to be caused by a high sugar content. This is one of the contributing factors, but the absence of solids not sugar is probably the real cause, coupled with the minimum reducing sugar content which is of lesser importance.

That quality is dependent to a large extent upon the non-sugar solids would also be indicated by the comparison of the effect of the methods of defecation upon quality. The sirups made by the phosphate

method are found to be superior to the others. This method removes much of the non-sugar solid matter. In the methods where lime is not used at all, the quality is relatively poor. Suffice it to say, however, that some sirups made in this way are very good. This problem is complex and possibly depends also on the chemical composition of the non-sugar solids, as well as the amounts present.

The method used in making the sirup has a slight effect on the sugar content in that the acid methods tend to hydrolyze sucrose. The acid phosphate in the method using it and the naturally occurring acids in the lime-free method, invert some of the sucrose during the boiling of the juice. Where lime is used, the sucrose remains slightly higher.

Boiling tends to cause a dark color in the sirup which is one disadvantage of the phosphate method. These sirups, in spite of their good quality, are too dark.

The best conditions for a sirup of light

color, pleasing taste, and continued freedom from crystals, are a short boiling period, the removal of the objectionable non-sugars by the use of lime, etc., and keeping the sugars (sucrose expecially) in the correct concentration by inversion if necessary, to retard crystallization.

Summary and Conclusions.

1. The purpose of this investigation is a study of the sugar content of the sorghum plant, in its relation and application to the sorghum sirup industry in Minnesota.

2. The principal sugars present in sorghum juice are sucrose, fructose, and glucose. The presence of maltose and raffinose could not be detected.

3. The stalk of the plant contains the bulk of the sugar which is distributed in its joints as follows: the upper and lower joints contain the least sugar; the amounts of sucrose gradually increase and the reducing sugars decrease toward the middle of the cane.

4. A loss of about five per cent of sugar extracted would occur if the upper node were cut off with

the tops, thus necessitating the use of the whole cane for maximum yield of sirup.

5. The sugars develope during the growth of the plant as follows: sucrose steadily increases and the reducing sugars as steadily decrease up to maturity. The percentage of total sugar remains fairly constant but the actual weight of sugar increases.

6. The later stages of growth are nearly equally well suited for sirup making. The cane could therefore be cut earlier and the sirup making season lengthened, thus saving overhead expenses. This, at the same time, would decrease the possibility of damage by frost.

7. Climatic factors undoubtedly play a part in the development and growth of sorghum, as well as of other plants. They possibly can explain the variations in composition from day to day also.

8. Removing the tops from sorghum tends to advance

the time of maturity, but as the plant would later reach the same sugar content with the tops left on, there is little gained by this practice. Topping has no advantage unless the lengthening of the season for sirup manufacture resulting from this proves of greater value than the seed crop.

9. The quality of the sirup is little affected, if at all, by its sugar content, but rather by the non-sugar solids present. The methods used in making sirups have a small influence on the percentage of sucrose and reducing sugars due to hydrolysis.

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APPENDIX

TABLE V.

Analyses showing the distribution of the sugars in the cane.

Sample No.		Description		% of Dry Matter	Sugars in % of dry matter: Sucrose	Fructose	Glucose	Total sugar	% Juice extr. from cane	Parts total sugar per 1000 of cane
3013	2	Milk upper third		12.7	59.4	12.4	13.7	85.4		
3022	"	" middle	"	14.9	66.1	9.3	12.8	88.2		
3011	"	" lower	"	13.8	58.0	12.0	16.4	86.4		
		In different joints. (see graph)								
3022	2	Early soft dough 1st.		9.7	46.1	14.6	17.4	74.1	29.6	21.2
3021		upper joints	2	12.9	59.2	11.2	14.2	84.6	28.2	30.8
3020			3	13.0	63.3	10.8	12.7	86.9	29.1	32.8
3019			4	13.9	64.9	10.0	12.4	87.3	32.8	39.7
3018			5	14.2	64.5	10.0	13.0	87.5	36.2	44.9
3017			6	14.1	63.4	9.7	11.3	86.4	38.4	46.7
3016			7	13.2	61.9	10.3	14.8	87.0	38.9	44.5
3015			88	12.4	56.1	10.9	17.1	84.1	32.1	33.6
3014		bottom joints	9	12.2	52.9	10.9	18.0	81.7	25.3	25.2
3073	2	milk upper joint		11.3	49.4	13.3	15.3	78.0		
3074			2	13.4	61.5	10.6	13.5	85.5		
3075			3	14.1	65.7	9.7	11.6	87.0		
3076			4	14.9	69.7	8.7	10.2	88.6		
3077			5	15.6	70.5	7.9	10.1	88.5		
3078			6	15.8	69.2	8.2	10.6	88.0		
3079			7	15.8	71.5	9.3	9.9	90.7		
3080			8	15.1	66.7	8.9	12.5	90.1		
3081			9	14.2	62.9	10.3	14.7	87.9		
3082		bottom joint	10	14.0	58.5	11.3	15.7	85.5		

TABLE VI.

Detailed Analyses of Canes Showing Sugar Content at Different Stages of Growth.

Sample No.	Plot		% Dry Matter	Sugar content in % of Dry Matter				% Juice extracted from the cane.
				Sucrose	Fructose	Glucose	Total sugar	
				Pannicles Appearing				
2923	3		6.3	11.7	27.7	37.3	76.6	49.9
2924	7		5.4	2.9	29.4	43.0	75.4	45.4
2925	11		5.7	2.8	31.1	42.9	76.8	49.4
2926	15		6.0	7.1	30.2	40.5	77.9	51.0
2927	16		5.3	1.5	29.0	44.0	74.5	44.2
2928	17		6.5	8.5	28.7	41.1	78.3	47.1
		Ave.	5.9	5.8	29.3	41.5	76.6	47.8
				Pannicles Out.				
2929	3		7.1	20.5	26.8	32.6	79.8	48.4
2930	7		5.5	4.9	26.4	43.6	74.9	46.0
2931	11		5.5	2.9	32.1	44.8	79.7	45.5
2932	15		7.2	17.5	27.1	35.1	79.6	49.7
2933	16		4.4	4.4	33.9	57.2	95.4	43.2
2934	17		6.2	11.9	27.3	37.1	76.3	44.1
		Ave.	6.0	10.3	28.9	41.7	81.0	46.3
				Blossoms Appearing.				
2966	3		8.7	23.1	23.1	28.0	88.2	47.7
2967	7		6.7	12.1	27.6	43.6	83.3	44.4
2968	11		6.7	11.1	30.5	41.4	83.0	43.3
2969	15		7.6	14.9	31.4	37.7	83.9	44.9
2970	16		6.0	7.9	29.0	43.8	80.7	43.1
2971	17		6.5	9.7	31.4	40.8	81.9	44.5
		Ave.	7.0	14.7	28.8	39.2	82.7	44.7

TABLE VI (Continued)

Sample No.	Plot	% Dry Matter	Sugar content in % of Dry Matter				% Juice Extracted from the cane.
			Sucrose	Fructose	Glucose	Total sugar.	
				Full Bloom			
2976	3	9.5	41.4	17.6	21.4	80.4	48.6
2977	7	8.9	37.6	17.2	23.4	78.1	38.6
2978	11	8.2	29.0	23.2	30.9	83.1	42.4
2979	15	8.8	33.9	21.6	29.0	82.5	48.1
2980	16	8.3	29.1	22.0	29.7	80.8	38.0
2981	17	8.2	24.1	25.0	31.3	81.1	43.4
	Ave	8.7	32.5	21.2	27.3	81.0	43.2
				Milk			
2983	3	9.4	35.9	15.0	24.7	75.6	-
2984	7	9.9	40.4	15.5	23.6	79.5	38.6
2985	11	10.4	45.0	13.3	20.0	78.3	45.2
2986	15	9.1	31.2	20.2	27.7	79.1	46.3
2987	16	10.1	32.4	17.5	27.9	77.7	36.0
2988	17	10.4	40.6	17.2	24.5	82.2	42.0
	Ave.	9.7	37.6	16.5	24.7	78.7	41.6
				Soft Dough			
2995	3	9.3	40.7	18.1	22.4	81.2	38.7
2997	7	10.7	48.3	15.3	19.6	83.1	43.0
2989	11	10.7	53.4	13.5	17.1	84.0	44.3
2999	15	8.8	32.5	21.6	26.0	80.1	44.8
2991	16	9.6	37.0	20.5	25.7	83.3	45.9
2993	17	10.4	45.9	16.7	21.8	84.4	45.8
	Av.	9.9	43.0	17.6	22.1	82.7	43.8

TABLE VI (continued)

Sample No.	Plot		% Dry Matter	Sugar content in % of Dy Matter				% Juice extracted from the sugarcane
				Sucrose	Fructose	Glucose	Total	
				Dry Dough.				
3023	3		9.8	42.4	16.9	20.5	79.8	34.7
3008	7		10.9	46.1	14.1	16.6	76.8	39.1
3006	11		12.0	54.2	12.5	16.3	83.0	37.4
3028	15		9.7	39.0	19.0	24.1	82.1	40.4
3004	16		11.1	45.4	16.6	21.3	83.3	43.6
3005	17		11.9	52.7	12.9	16.2	81.9	40.3
		Ave.	10.9	46.6	15.3	19.2	81.1	39.3
				Mature				
3165	3		10.4	45.4	13.3	16.4	75.1	39.4
3043	7		11.1	52.9	13.3	16.1	82.3	24.9
3041	11		11.2	52.5	13.6	17.0	83.1	33.2
3095	15		10.0	38.0	18.3	23.4	79.7	38.4
3033	16		10.5	42.5	17.3	21.5	81.4	34.6
3034	17		12.2	55.6	13.3	16.4	85.2	28.5
		Ave	10.9	47.8	14.8	18.5	81.1	33.2

TABLE VII.

Analyses Showing the Development of Sugar Content for Individual Plots.

Sample No.	Stages	% Dry Matter	Sugar content % of Dry Matter				% Juice extracted from the cane
			Sucrose	Fructose	Glucose	Total sugar	
Early Amber							
2923	1	6.3	11.7	27.7	37.3	76.6	49.9
2929	2	7.1	20.5	26.8	32.6	79.8	48.4
2966	3	8.7	32.1	23.1	28.0	83.2	47.7
2976	4	9.5	41.4	17.6	21.4	80.4	48.6
2983	5	9.4	35.9	15.0	24.7	75.6	--
2995	6	9.3	40.7	18.1	22.4	81.2	38.7
3023	7	9.8	42.4	16.9	20.5	79.8	34.7
3165	8	10.4	45.4	13.3	16.4	75.1	39.4
Early Rose							
2924	1	5.4	2.9	29.4	43.0	75.4	45.4
2930	2	5.5	4.9	26.4	43.6	74.9	46.0
2967	3	16.7	12.1	27.6	43.6	83.3	44.4
2977	4	8.9	37.6	17.2	23.4	78.1	38.6
2984	5	9.9	40.4	15.5	23.6	79.5	38.6
2997	6	10.7	48.3	15.3	19.6	83.1	43.0
3008	7	10.9	46.1	14.1	16.6	76.8	39.1
3043	8	11.1	52.9	13.3	16.1	82.3	24.9
South Dakota							
2923	1	5.7	2.8	31.1	42.9	76.8	49.4
2931	2	5.5	2.9	32.1	44.8	79.7	45.5
2968	3	6.7	11.1	30.5	41.4	83.0	43.3
2978	4	8.2	29.0	23.2	30.9	83.1	42.4
2985	5	10.4	45.0	13.3	20.0	78.3	45.2
2989	6	10.7	53.4	13.5	17.1	84.0	44.3
3003	7	12.0	54.2	12.5	16.3	83.0	37.4
3041	8	11.2	52.5	13.6	17.0	83.1	33.2

TABLE VII. (continued)

Sample No.	Stages	% Dry Matter	Sugar content % of Dry Matter				% Juice extracted from the cane.
			Sucrose	Fructose	Glucose	Total Sugar	
	Early Amber						
2926	1	6.0	7.1	30.2	40.5	77.9	51.0
2932	2	7.2	17.5	27.1	35.1	79.6	49.7
2969	3	7.6	14.9	31.4	37.7	83.9	44.9
2979	4	8.8	33.9	21.6	27.0	82.5	48.1
2986	5	9.1	31.2	20.2	27.7	79.1	46.3
2999	6	8.8	32.5	21.6	26.0	80.1	44.8
3028	7	9.7	29.0	19.0	24.1	82.1	40.4
3095	8	10.0	38.0	18.3	23.4	79.7	38.4
	Early Rose						
2927	1	5.3	1.5	29.0	44.0	74.5	44.2
2933	2	4.4	4.4	33.9	57.2	95.4	43.2
2970	3	6.0	7.9	29.0	43.8	80.7	43.1
2980	4	8.3	29.1	22.0	29.7	80.8	38.0
2987	5	9.1	32.4	17.5	27.9	77.7	36.0
2991	6	11.1	37.0	20.5	25.7	83.3	45.9
3004	7	10.5	45.4	16.6	21.3	83.3	43.6
3033	8		42.5	17.3	21.5	81.4	34.6
	South Dakota						
2928	1	6.5	8.5	28.7	41.1	78.3	47.1
2934	2	6.2	11.9	27.3	37.1	76.3	44.1
2971	3	6.5	9.7	31.4	40.8	81.9	44.5
2981	4	8.2	24.1	25.7	31.3	81.1	43.4
2988	5	10.4	40.5	17.2	24.5	82.2	42.0
2993	6	10.4	45.9	16.7	21.8	84.4	45.8
3005	7	11.9	52.7	12.9	16.2	81.9	40.3
3034	8	12.2	55.6	13.3	16.4	85.2	28.5

TABLE VIII.

Analyses showing changes in the sugar content resulting from topping the canes.

Sample No	Plot	Description	Stage of growth when topped	% Dry Matter	Sugar content in % of dry matter			% Juice extracted from the cane.	Parts sugar per 1000 cane
					Sucrose	Fructose	Glucose	Total sugar	
3172	8	hard dough	tops cut	full bloom	71.71	4.4	5.7	81.8	32.1	47.3
3171	"	"	uncut	" "	65.31	8.0	10.5	83.9	35.7	44.7
			difference		6.4	-3.6	- 4.8	-2.1	-3.6	2.6
3025	3	soft dough	tops cut	early milk	56.9	13.3	16.7	87.0	37.4	42.4
3024	"	"	uncut	" "	47.4	16.7	20.3	84.4	35.	33.2
			difference		9.5	-3.4	-3.6	2.6	2.4	9.2
3040	3	dry dough	tops cut	early milk	60.8	12.3	15.2	88.3	32.4	41.0
3039	"	"	uncut	" "	50.6	16.1	19.5	86.1	31.0	28.1
			difference		10.2	-3.8	-4.3	2.2	1.4	11.9
3170	3	mature	tops cut	early milk	64.9	7.8	10.2	82.9	33.6	43.8
3169	"		uncut	" "	56.7	10.7	13.7	81.0	41.6	43.3
			difference		8.2	- 2.9	-3.5	1.9	-8.0	.5
3027	11	dry dough	tops cut	soft dough	50.9	13.3	17.7	83.9	34.2	33.4
3026	"	"	uncut	" "	57.0	12.7	14.5	84.2	33.8	32.5
			difference		6.1	2.6	3.2	-.3	.4	.9
3042	11	mature	tops cut	soft dough	62.8	9.7	12.3	84.8	26.6	28.8
3041	"		uncut	" "	52.5	13.6	17.0	83.1	33.2	31.0
			difference		10.3	10.3	-4.7	1.7	-6.6	-2.2
3166	2	with head smut		17.2	70.1	5.8	7.3	83.2	31.4	44.8

TABLE IX.

Analyses of Individual Sugars

No.	Description	% Dry Matter	Sugar content % of Dry Matter			
			Sucrose	Fructose	Glucose	Total
3314	Phosphate	72.7	65.8	10.2	15.0	91.0
3315	Theoretical lime	72.5	66.9	9.7	14.8	91.4
3316	Lime to neutral slightly cryst.	77.2	66.4	10.3	14.9	91.6
3317	Lime nearly neutral after heating	64.7	68.5	10.3	15.2	94.0
3318	Factory method lime cryst.	76.8	47.2	20.7	24.9	92.8
3319	Theoretical lime very slight.	75.6	57.6	17.2	18.9	93.7
3320	Factory method lime cryst.	73.8	64.1	11.0	12.9	88.0
3321	Heat only	78.7	47.3	18.7	21.9	87.9
3322	" " 1912 cryst.	82.5	67.3	13.6	17.9	98.8
3323	No lime	73.1	48.8	20.3	24.1	93.2
3324	" "	73.6	53.2	17.3	21.4	91.9
3325	" "	72.1	55.6	17.0	21.1	93.7
3326	" "	78.8	38.6	23.2	30.6	92.4
3327	" "	76.3	52.6	17.7	21.6	91.9
3328	" "	70.1	51.4	19.0	26.3	96.7
3329	" " cryst.	81.0	47.9	19.8	23.4	91.1
3330	" "	76.1	54.0	17.3	22.3	93.6
3331	" " cryst.	78.1	55.8	16.7	20.4	92.9
3332	" "	76.1	56.9	16.7	19.7	93.3
3333	Lime cryst.	78.7	64.4	13.2	16.6	94.2
3334	No lime	76.9	44.5	21.6	27.6	93.7
3335	Lime neutral to litmus cryst.	80.0	55.7	16.2	18.2	90.1
3336	No lime slightly fermented	78.8	42.5	22.8	27.4	92.7
3337	" " (best) moldy	71.7	64.5	14.2	17.0	95.7
3338	" " "	76.1	52.2	19.5	25.1	96.8
3339	" " evap. slowly	75.3	34.2	28.5	30.1	92.8
3340	Lime cryst.	79.9	54.8	17.8	22.6	95.2
3341	" in excess cryst.	80.3	53.2	19.3	23.0	95.5
3342	Bicarbonate soda	70.0	50.5	19.6	26.2	96.3
3343	Lime used cryst.	79.4	57.4	15.2	18.7	91.3
3344	" " "	77.3	52.9	17.1	21.0	91.0
3345	" " pan evap.	77.2	48.8	20.4	25.0	94.2
3346	" "	77.7	45.2	20.9	27.3	93.4
3347	Excess lime	68.8	59.4	15.4	20.1	94.9
3348	Slight excess lime	75.7	44.7	20.1	26.9	91.7
3349	Lime left acid	69.9	54.9	18.7	23.1	96.7
3350	Neutral to litmus	75.5	40.9	25.3	29.2	95.4
3351	Lime used	75.8	54.4	18.0	21.5	93.9
3352	Phosphate	66.7	41.1	25.9	29.7	96.7
3352	"	66.5	41.9	25.7	29.5	97.1
3353	Lime nearly neutral	71.2	40.5	26.4	30.3	97.2
3354	No lime	73.0	35.7	27.3	30.3	93.3