

THE CHEMICAL COMPOSITION
OF THE
VARIOUS ORGANS OF THE CORN PLANT

by

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INTRODUCTION

This investigation was started for the purpose of securing more complete information relative to the composition of the corn plant. A great deal of work has been done on some parts of the corn plant, especially the portions of value for feeding purposes. However, little if any work has been done on the complete analyses of all the organs of the corn plant as here presented.

The great lack of complete information of this nature, and its value to investigators and agriculturalists was emphasized by Dr. Edwin C. Miller, Botany Department, Kansas State Agricultural College, and it was at his suggestion and with his promise of cooperation that this work was started.

The samples were grown, harvested, measured, weighed and prepared for the laboratories by him. The figures representing weights and dimensions of the green and dry plants are his.

A popular variety of corn known as Pride of Saline was selected for the investigation. The corn was cut when

the ears were fully glazed. Some of the stalks were more advanced than others. They had, however, all reached the stage just mentioned. This period was selected as it was considered that all of the elements were now a part of some organ of the plant.

Five plants were selected in order to secure a good average for the corn plants in general.

The dimensions of the five plants selected are as follows:-

Number	Height	Number of Leaves	Length of Ear	Green Weight
1	8' 6"	15	12"	2540 grams
2	8' 0"	16	13"	2923 "
3	8' 6"	14	11½"	2277 "
4	9' 0"	14	11"	2716 "
5	10' 0"	17	13"	3095 "

The samples were taken to the laboratory, separated into their various organs, and dried.

The following table represents the dry weight in grams:-

Number	Leaves	Stems	Grain	Roots	Cobs
1	209.4	154.3	320.0	59.5	92.6
2	252.4	191.2	272.2	62.4	75.3
3	195.8	161.0	232.0	60.7	70.7
4	235.5	233.0	212.0	53.7	65.3
5	279.7	263.5	268.8	66.0	87.3
Average	234.56	200.6	261.0	60.5	78.24

Average total weight per plant 834.9.

These samples, representing the dry material of the various organs, were ground to pass a one-half millimeter sieve and prepared for analyses. The results of these analyses are recorded in TABLE I.

Table I.

ELEMENTAL COMPOSITION OF THE VARIOUS ORGANS OF THE CORN PLANT. DRY BASIS PERCENT.

Sample No.	Organs	C	O	H	N	P	K	Ca	Mg	S	Fe	Si	Al	Cl	Mn
1	Leaves	41.18	45.28	5.75	1.16	0.169	1.57	0.56	0.25	0.25	0.070	2.44	0.075	0.34	0.031
2	"	40.35	44.49	6.20	1.40	0.202	1.57	0.38	0.23	0.23	0.073	2.20	0.086	0.43	0.023
3	"	42.25	43.35	5.77	1.43	0.225	1.32	0.46	0.20	0.23	0.081	2.69	0.074	0.073	0.036
4	"	40.35	44.24	5.82	1.21	0.186	1.54	0.49	0.17	0.24	0.058	2.57	0.071	0.154	0.044
5	"	41.22	41.95	5.78	1.32	0.256	1.38	0.47	0.20	0.23	0.070	3.05	0.063	0.115	0.025
6	Stems	43.96	43.91	5.66	0.88	0.073	1.64	0.14	0.14	0.15	0.052	0.43	0.016	0.40	0.016
7	"	44.08	42.90	5.83	0.94	0.093	1.09	0.19	0.18	0.13	0.040	0.30	0.014	0.40	0.010
8	"	46.35	42.50	6.00	0.50	0.072	1.12	0.14	0.12	0.16	0.046	0.41	0.012	0.13	0.023
9	"	44.35	45.00	5.93	0.85	0.081	1.13	0.20	0.14	0.17	0.046	0.49	0.012	0.072	0.017
10	"	43.80	45.20	6.08	1.02	0.124	1.16	0.20	0.21	0.17	0.074	0.47	0.012	0.12	0.018
11	Grain	45.25	45.05	7.01	2.14	0.31	0.37	0.035	0.20	0.12	0.049	0.018	0.020	0.026	0.027
12	"	44.48	45.42	7.02	2.14	0.33	0.51	0.028	0.20	0.18	0.030	0.014	0.036	0.031	0.044
13	"	44.75	45.31	6.93	2.22	0.33	0.43	0.023	0.19	0.12	0.028	0.021	0.033	0.031	0.050
14	"	45.10	44.67	6.94	2.24	0.40	0.45	0.021	0.19	0.14	0.055	0.016	0.014	0.031	0.043
15	"	44.00	46.04	6.92	2.03	0.34	0.34	0.019	0.21	0.12	0.055	0.011	0.013	0.046	0.023
16	Roots	42.50	46.14	5.93	1.27	0.141	0.27	0.58	0.18	0.28	0.43	6.63	0.89	0.12	0.045
17	"	43.37	45.80	5.79	1.24	0.122	0.57	0.56	0.17	0.25	0.44	4.89	0.94	0.09	0.088
18	"	43.35	43.15	6.01	1.27	0.121	0.56	0.64	0.18	0.23	0.45	3.38	0.89	0.10	0.056
19	"	42.65	42.05	5.56	1.40	0.102	0.37	0.72	0.15	0.24	0.50	4.17	1.15	0.12	0.089
20	"	39.70	40.78	5.33	1.16	0.113	0.65	0.56	0.16	0.23	0.76	3.13	1.02	0.11	0.055
21	Cobs	45.75	45.89	6.36	1.38	0.094	0.46	0.022	0.11	0.021	0.025	0.133	0.052	0.12	0.031

The percentage composition of the five samples of the various organs as recorded in TABLE I. were averaged to make TABLE II. which represents the average percentage of elements in the various organs of the five corn plants.

Table II.

AVERAGE PERCENT OF ELEMENTS IN THE VARIOUS ORGANS OF FIVE CORN PLANTS.

Organs :	C	O	H	N	P	K	Ca	Mg	S	Fe	Si	Al	Cl	Mn
Leaves	: 41.27	: 43.86	: 5.86	: 1.30	: .207	: 1.48	: .470	: .21	: .24	: .070	: 2.59	: .074	: .238	: .032
Stems	: 44.51	: 43.90	: 5.90	: .84	: .089	: 1.23	: .170	: .16	: .16	: .052	: .42	: .013	: .179	: .017
Grain	: 44.72	: 45.30	: 6.96	: 2.15	: .340	: .42	: .025	: .20	: .14	: .043	: .016	: .023	: .033	: .035
Roots	: 42.31	: 43.58	: 5.72	: 1.27	: .120	: .48	: .610	: .17	: .25	: .520	: 4.44	: .980	: .110	: .066
Cobs	: 45.75	: 45.89	: 6.36	: 1.38	: .094	: .46	: .022	: .11	: .021	: .025	: 1.33	: .052	: .120	: .031

The figures in TABLE II. represent more nearly the percentage of elements to be found in corn plants in general. A figure representing the average analyses of five different corn plants should form a reliable basis for computing results where the elements composing a corn plant are involved.

From the percentage composition of the various organs as recorded in TABLE I. and the dry weight of the different organs, TABLE III. was calculated.

Table III.

ELEMENTAL COMPOSITION OF THE VARIOUS ORGANS OF FIVE CORN PLANTS IN GRAMS.

Sample No.	Organs	Dry Weight	C	O	H	N	P	K	Ca	Mg	S	Fe	Si	Al	Cl	Mn
1	Leaves	209.4	86.23	94.81	12.04	2.42	.353	3.28	1.17	.523	.523	.146	5.10	.157	.711	.065
2	"	252.5	103.10	112.29	15.64	3.53	.510	3.96	.96	.581	.581	.184	5.55	.217	1.085	.058
3	"	195.8	82.72	84.87	11.29	2.79	.440	2.58	.90	.391	.450	.158	5.27	.144	.142	.070
4	"	235.5	96.20	104.18	13.71	2.84	.438	3.62	1.15	.400	.565	.136	6.05	.167	.362	.104
5	"	279.7	115.29	117.33	16.16	3.69	.716	3.86	1.31	.559	.643	.195	8.53	.176	.321	.069
6	Stems	154.3	67.83	67.75	8.73	1.36	.112	2.53	.21	.210	.231	.080	.66	.024	.617	.024
7	"	191.2	84.28	82.02	11.14	1.79	.177	2.08	.36	.344	.248	.076	.57	.026	.760	.019
8	"	161.0	74.62	68.42	9.66	.81	.115	1.80	.23	.193	.257	.074	.66	.019	.209	.037
9	"	233.0	103.33	104.85	13.81	1.98	.188	2.63	.46	.326	.396	.107	1.14	.027	.167	.039
10	"	263.5	115.40	119.10	16.02	2.68	.126	3.05	.52	.553	.447	.194	1.23	.031	.316	.047
11	Grain	320.0	144.80	144.16	23.43	6.84	.990	1.18	.112	.640	.384	.156	.057	.064	.083	.086
12	"	272.2	121.07	123.63	19.10	5.82	.890	1.38	.076	.544	.489	.082	.038	.098	.084	.119
13	"	232.0	103.82	105.11	16.07	5.15	.760	1.00	.053	.440	.278	.065	.049	.076	.072	.116
14	"	212.0	95.61	94.70	14.71	4.74	.850	.96	.045	.406	.299	.117	.034	.029	.066	.092
15	"	268.8	118.27	123.75	18.60	5.45	.910	.91	.051	.564	.322	.147	.029	.035	.123	.061
16	Roots	59.5	25.28	27.45	3.53	.75	.083	.160	.345	.107	.166	.255	3.94	.529	.071	.027
17	"	62.4	27.06	28.57	3.61	.77	.076	.355	.349	.106	.156	.274	3.05	.586	.056	.055
18	"	60.7	26.31	26.19	3.64	.77	.073	.339	.388	.109	.139	.273	2.05	.540	.061	.034
19	"	53.9	22.98	22.66	3.00	.75	.054	.199	.388	.081	.129	.269	2.24	.619	.064	.048
20	"	66.0	26.20	26.91	3.51	.76	.074	.429	.369	.105	.151	.501	2.06	.673	.073	.036
21	Cobs	92.6	42.36	42.49	5.88	1.27	.087	.425	.020	.101	.019	.023	.123	.048	.111	.027
22	"	75.3	34.44	34.55	4.78	1.03	.071	.346	.017	.083	.016	.018	.100	.039	.090	.023
23	"	70.7	32.34	32.44	4.49	.98	.066	.325	.015	.078	.015	.018	.094	.037	.085	.022
24	"	65.3	29.87	29.96	4.15	.90	.061	.30	.014	.072	.014	.016	.086	.034	.078	.020
25	"	87.3	39.93	40.06	5.55	1.20	.082	.40	.019	.096	.018	.022	.116	.045	.104	.027

TABLE III. represents the total number of grams of the elements found in the different organs of the five plants from analyses.

The figures in TABLE III. were used to calculate the average number of grams of the different elements found in the five plants and the results are given in TABLE IV.

Table IV.

AVERAGE WEIGHT OF ELEMENTS IN THE VARIOUS ORGANS OF FIVE CORN PLANTS, IN GRAMS.

Organs	: Dry	: C	: O	: H	: N	: P	: K	: Ca	: Mg	: S	: Fe	: Si	: Al	: Cl	: Mn
	: Weight														
Leaves	: 234.56	: 96.65	: 102.69	: 13.77	: 3.05	: .491	: 3.40	: 1.100	: .491	: .554	: .164	: 6.10	: .172	: .544	: .073
Stems	: 200.60	: 89.09	: 88.43	: 11.87	: 1.72	: .184	: 2.42	: .360	: .325	: .316	: .106	: .85	: .025	: .414	: .033
Grain	: 261.00	: 116.71	: 118.27	: 18.38	: 5.60	: .880	: 1.09	: .067	: .519	: .354	: .113	: .041	: .060	: .086	: .095
Roots	: 60.50	: 25.57	: 26.36	: 3.46	: .76	: .072	: .296	: .068	: .102	: .172	: .290	: 2.67	: .589	: .065	: .040
Cobs	: 78.24	: 35.79	: 35.90	: 4.97	: 1.08	: .075	: .359	: .017	: .086	: .016	: .019	: .104	: .041	: .094	: .033
Grams per															
Plant	: 834.90	: 363.81	: 371.65	: 52.45	: 12.21	: 1.702	: 7.565	: 1.912	: 1.523	: 1.412	: .692	: 9.765	: .887	: 1.203	: .274
Average total dry weight per plant in grams	834.90														
Average total dry weight per plant from analyses in grams	827.06														
Difference representing undetermined elements in grams	7.84														

Some explanation of TABLE IV. is considered advisable as it represents a check on the limits to which the chemical analyses were carried.

The sum of the column headed as dry weight represents the average total dry weight per plant (834.90 grams). The sum of the various other columns is the average number of grams per plant of the various elements determined. The sum of these figures, provided everything in the plant had been determined, and provided the analyses were perfect, should be a figure corresponding to the dry weight of the plant. The sum of the figures here recorded from the analyses is 827.06 grams. The difference between the dry weight, - 834.90 grams, and the weight of the material from analyses, - 827.06 grams, is 7.84 grams or less than one percent of the dry weight. The latter figure represents the undetermined elements, the bulk of which was supposed to be sodium, and was not determined.

As this thesis is essentially one of analyses, no attempt will be made here to discuss the relation of the figures represented to soil fertility or problems concerning corn.

Some difficulties were experienced in securing uniform results where the elements to be determined were in

very small amounts. Where differences appeared in the analyses that were out of harmony with similar determinations on the same material, redeterminations were made and the figures verified. The figures for chlorin are the most irregular. A careful recheck on the material was made for this element and the results were found to be correct. It was then concluded that the amount of chlorin found in the same kind of plant material is variable. The figures for silica in the roots show some variation. This, no doubt, is due to more sand adhering to one sample than to another.

METHODS OF ANALYSES.

As this thesis is essentially one of analyses, it is important to give an accurate account of the methods used and the manner of arriving at the data presented. The most recent and reliable methods that could be found have been used.

The methods used for making the various determinations that comprise the table on percentage composition are as follows:-

I. CARBON and HYDROGEN. These elements were determined together and will be so considered. The regular procedure (1) used in organic analyses was followed. An artificial supply of oxygen was used to hasten the oxidation of the organic matter. In the case of hydrogen, a correction had to be made for the water in the samples at the time the analyses were made.

II. OXYGEN. This element was determined in the usual manner, by difference. However, the determination of oxygen in plant material presented a different problem from the one usually met with in organic analyses. It was necessary to determine both the ash and the moisture before

these figures could be secured by subtracting the carbon, ash, nitrogen, moisture and hydrogen from one hundred percent. The result was a figure for the oxygen of organic combination to which was added the oxygen that is a part of the various mineral elements recorded here when they are converted to their oxides. The figures for oxygen represent not only the oxygen of organic combination, but that of inorganic combination as well.

III. NITROGEN. The determination of this element was carried out by the usual Gunning Method (2 a) with such minor modifications as have been found to be advantageous for local laboratory conditions.

IV. POTASSIUM. This element was determined by the method (2 b) advocated for potassium in organic compounds.

V. CALCIUM and MAGNESIUM. These elements will be classed together as the latter was determined on the filtrate from the former. The analyses of these elements was made on the ash of the plant by the methods (2 c) advocated for their analyses in plant materials.

VI. PHOSPHORUS and SULFUR. The determination of these elements will be discussed along with the development of the magnesium nitrate method, explanation of which follows:-

The determination of phosphorus and sulfur in plants has been for some time a troublesome feature of the analytical work in connection with the analyses of plant constituents. This difficulty has been due largely to the very unsatisfactory methods existing for the conversion of the organic phosphorus and sulfur into soluble phosphates and sulfates.

Until recently our best available methods (2 d) advocated the burning of plant material, followed by the determination of the phosphates in the ash. This method is satisfactory as long as there are base or alkali metals in the plant to combine with the phosphates. Otherwise it would be possible for serious losses to take place. This method has long since been abandoned as unsatisfactory for the determination of sulfur. However, a number of our early investigators working with plant and animal materials were led to make statements that have since been found to be erroneous, due to the use of this method in the determi-

nation of sulfur. Some of the other methods that have been tried are the well known Eschka Method (3) used for the determination of total sulfur in coal; the oxidation method (4) in a bomb by means of oxygen, also used in coal analysis and the sodium peroxide method (2 c). This method has probably been used more than any other. It is, however, very tedious and cumbersome, requiring expensive chemicals and consuming a great amount of time in its manipulation. Its greatest objections are:-

- 1 - Due to the too rapid oxidation of the organic matter by the sodium peroxide, spontaneous flames and explosions take place with violence, making it necessary to start the determination anew.
- 2 - It requires the use of a sulfur free flame.
- 3 - Owing to the large amount of sodium peroxide necessary for the oxidation, great care must be exercised to secure a uniform precipitate of barium sulfate owing to the adsorption of sodium salts (5).
- 4 - The great amount of salt present prevents the successful use of the filtrate for the de-

termination of phosphorus, making it necessary to start a new determination for this element. There are a number of other objections to this method, the most important of which is the great length of time and care necessary to secure reliable and uniform results.

Another procedure tried was a fusion method (6) that had suggested itself, having been previously used for the conversion of organic iodine compounds in powdered thyroids into soluble iodates. This method is carried out in a nickle crucible using a fusion mixture composed of sodium and potassium carbonates and potassium nitrate. This method proved successful with some materials, but it offered about the same objections as the sodium peroxide fusion method just mentioned. Difficulty was also experienced in securing chemicals sufficiently free from the element to be determined.

Still another method tried was the bomb method (7) using a Parr sulfur bomb with sodium peroxide as an oxidizing agent and potassium chlorate as an accelerator, firing the charge by the application of a hot flame to the wall of the bomb. This method has the advantage of being rapid, but the disadvantage of being dangerous; uses

an expensive bomb; and has the added disadvantage of contamination with the abundance of sodium salts present at the time of precipitation of barium sulfate.

The use of magnesium nitrate as an oxidizing agent is more or less recent. Its use was originally suggested for the determination of phosphorus (8) in fertilizers high in organic matter. The sample is weighed into a small porcelain dish, treated with magnesium nitrate solution and ignited over a low flame until free from carbon. This was satisfactory and gave good results. Its use for the determination of sulfur and phosphorus in plants, especially where these elements were liable to be in organic combination, had not suggested itself, at least reference to its having been so used has not been found. It was tried on plant material using porcelain ash dishes, but owing to the fluffiness of the resulting oxidized charge, some difficulty was experienced in preventing losses. Accordingly, a plan was agreed upon and tried, and the following is the perfected method. (The presentation of this method is given in the form approved and used by the Association of Official Agricultural Chemists.)

METHOD

Magnesium Nitrate Beaker Method.

Reagent.

Magnesium Nitrate Solution.

Dissolve 320 grams of calcined magnesia in nitric acid, avoiding an excess of the latter; then add a little calcined magnesia in excess. Boil filter from the excess of magnesia, iron, alumina, etc. and dilute to two liters.

Preparation of Solution.

A one gram sample of the material (note 1) under examination is weighed into a 250 cc. low form Pyrex beaker, to which is added 7.5 cc. magnesium nitrate solution (prepared above). The material is brought into intimate contact with the solution and placed on an electric hot plate at full heat (180°C.) until no further action takes place. The beaker, while hot, is transferred to an electric muffle furnace at low heat (note 2), where they are allowed to remain until the charge is thoroughly oxidized and no black particles remain. The beaker is removed from the

Note 1 - Ground to pass a one-half millimeter sieve.

Note 2 - Muffle furnace must not show any red.

muffle (note 3), allowed to cool, water is added, then hydrochloric acid in slight excess. The solution is then brought to a boil and filtered. The filtrate is now ready for the determination of sulfur.

Determination of Sulfates.

The solution as prepared above is diluted to 150 cc the acidity regulated to from one to two per cent acid with hydrochloric acid, avoiding the use of acid in excess of two per cent. (9). The solution is brought to a boil and 10 cc. of barium chloride solution (one part barium chloride and nine parts water) added with constant stirring. The solution is allowed to remain at or near the boiling point for five hours (care being exercised to maintain its original volume as nearly as possible); then allowed to stand over night (9). Decant the liquid on a tared Gooch crucible, wash the precipitate with 15cc. to 20 cc. of boiling water and transfer to the filter. Remove the filtrate from the suction flask, wash out the latter and save it for the determination of phosphorus. The barium sulfate is now brought upon the Gooch crucible and washed free from

Note 3 - Reasonable care should be exercised in handling the hot Pyrex beakers coming from the muffle, and the cooler ones going into the muffle.

chlorides with boiling water. Dry, ignite and weigh as barium sulfate.

Determination of Phosphorus.

Evaporate the solution from the sulfur determination to 75 cc. and proceed as directed under (1), 9 Page 3, Official and Tentative Methods of Analyses, Association of Official Agricultural Chemists, Revised to November 1, 1919.

This method has proved very successful wherever tried and has the following advantages:-

- 1 - The oxidation takes place slowly and does not require any watching.
- 2 - It does away with the presence of a large amount of salts in solution, thus avoiding contamination from sodium salts, as magnesium salts are not adsorbed to any great extent by barium sulfate (5).
- 3 - Gives more uniform results than other methods.
- 4 - Entire operation can be carried out with the aid of electrical appliances, thus avoiding contamination with sulfur from gas flames.

- 5 - Permits the successful determination of phosphorus on the filtrate from the sulfur determination.
- 6 - It permits the determination of sulfur to be made in quantity with no more expensive materials than a Pyrex beaker and a small amount of magnesium nitrate solution.

The determinations of phosphorus and sulfur herein recorded have been done by this method. Its use is recommended for the determination of sulfur and phosphorus in plant material. It is predicted that it can be used for the determination of sulfur in organic materials high in organic sulfur.

VII. IRON and ALUMINA. These elements were determined as combined oxides by the usual method (2 f) advocated in the analyses of plant material. The combined oxides were fused with potassium persulfate and brought into solution. The iron was then determined colorimetrically by the thio-cyanate method (2 g) advocated for water analyses. The aluminum was figured by subtracting the iron

last determined from the oxides first determined.

VIII. SILICON. This element was determined as the oxide by the method (2 h) advocated for plant material. The figures so secured were further verified by treating the determined product with hydrofluoric acid and determining the silicon dioxide by difference in weight.

IX. CHLORIN and MANGANESE. These elements were determined by the methods (2 i) advocated for plant material, the only variation being that the silver chloride precipitate was weighed as such, instead of being titrated by difference.

SUMMARY

1 - Five samples of a representative variety of corn were selected and separated into their various organs, - leaves, stems, roots, grain and cobs.

2 - Twenty-one samples, representing the different organs of the corn plant, were analyzed (TABLE I.) for carbon, oxygen, hydrogen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, silicon, aluminum, chlorine and manganese.

3 - A new method is presented for the determination of sulfur and phosphorus in plant material. It has been found that this method has a number of advantages over other methods now in use.

4 - The methods used to make the other determinations are those approved and now in use and are either discussed or referred to in the Bibliography.

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