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The Ecophysiology of Corn:
Floral Morphogenesis and Mineral Ion Transport

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Final Report U.S. Atomic Energy Commission
Contract AT-(11-1)-1596

The Ecophysiology of Corn: Floral Morphogenesis and Mineral Ion Transport

Dr. Theodore Sudia, the principal investigator under this contract, has resigned from the staff of the University of Minnesota. Therefore, this project has been terminated and the following constitutes the final report on the work done under the contract.

This report is in four sections. The first section gives results of analysis of samples collected during the 1966 growing season. The procedures for the experiments and the manner in which the samples were collected were reported in the December 1966 Annual Progress Report.

Section II is a report of experiments on the uptake of mineral ions by silks of corn ears.

Section III contains the results of the greater part of the work and experiments conducted since the last Annual Report in December, 1966.

Section IV is an evaluation of the accomplishments under this contract and a discussion of the extent to which the original goals of the project were completed.

Section I Results of 1966 Field Experiments.

Strontium-85, Zinc-65, and Cesium-134 were applied to corn plants and samples taken after 24 hours and at maturity. Treatments were applied on separate plants to the 10 uppermost leaves and at weekly intervals. The procedure is identical to that described in Section III of this report for the work in 1967 except that 5 Lambda (μc) were spotted on each leaf. Sufficient Cs-134 was available for only 1 application series while Sr-85 and Zn-65 were applied on 5 different weeks. A total of 6000 samples from 500 plants were thus obtained.

The large volume gamma counter was not operative until late 1966. Therefore, all samples were taken and stored. These samples were then prepared for counting by pressing to a standard density in the air press described in the 1966 report and their radioactivity determined using the large volume gamma counter.

Only small amounts of the isotopes were taken up by the plants. Therefore, none of the data are included in this report for the 1966 experiments. As it turned out the value of these experiments was to indicate a better design for the 1967 field experiments. The procedures used in 1967 resulted from the experience gained from the 1966 experiments.

Section II Mineral uptake by corn ear silks.

One of the goals of the experiments under this contract was to determine the uptake and distribution within the plant of externally applied minerals. It was the aim to simulate conditions one might expect if the minerals came from radioactive fallout. As part of the overall picture the uptake by corn ear silks was determined. This was done in a separate experiment because the silks, in contrast to the leaves, are alive for only a very short time.

The uptake by silks was determined by immersing a portion of the silks in a cup containing 25 μ c of either Zn^{65} , Cs^{134} , or Ba^{133} for two hours. The solution was then removed and the silks allowed to hang in another cup containing no solution until samples were taken. Ears were harvested either after 24 hours or at maturity.

Silks were treated 2, 3, and 4 days after emergence which occurred at 70 days after planting. The ears sampled at maturity remained on the plant for approximately 1 month. Three ears were treated with each isotope at 3 ages for 2 harvests (24 hours and maturity) for a total of 54 ears. Each ear was divided into husk, silk, shank, and cob and grain at harvest.

The 216 samples were dried, weighed, and their radio-activity determined on the Tobar system.

There was no translocation of any of the isotopes by the vascular system in the silks. The only activity found in any of these samples was contained in that portion of the silks which had been immersed in the isotope solution. Thus, it is clear that translocation of minerals out of the silks did not occur.

Section III Uptake by leaves and transport within the plant of mineral ions by corn: Results of 1967 experiments.

From the results of the 1966 field experiments it was clear that a larger volume of liquid containing isotopes should be applied to provide a longer period of liquid contact with the leaf. Therefore, the experimental procedure was altered to include more solution of Cs containing the isotope. With these changes, uptake and translocation within the plant were readily determined. This procedure did not work well for Ba, however.

For these experiments the sweet corn variety Green Giant 41 was planted May 29, 1967 at the Rosemount Branch Experimental Station of the University of Minnesota. Treatments were begun at (tasseling) (July 31) and repeated each week for five weeks on a new set of plants. In this report we have included data from the first, third and fifth week treatments. Plants were harvested 24 hours after treatment or at maturity which was two weeks after the last treatment series and 7 weeks after flowering.

Two isotopes, Cesium 134 and Barium 133, were made up in a solution of phosphate buffer (pH 5.6) to a specific activity of 500 $\mu\text{c/ml}$. This solution was applied at two adjacent spots on the mid-leaf to one side of the midvein. A total of 25 μc was applied to each treated leaf. After 2 hours, the solution had dried on the leaf surface and the application spots were then covered with a waterproof glue which remained in place until

harvest.

Treatments were applied to a single leaf on a plant and the uppermost ten leaves were treated. There were two series of treatments, one harvested after 24 hours and the second series harvested at maturity. The entire series was repeated each week for 5 weeks beginning at flowering when vegetative productive growth was complete. There were three replications of all treatments. Treated leaf #1 was the uppermost leaf on the plant (Fig. 4). Each week the #1 leaves on six plants were treated with Cs^{134} and on another six with Ba^{133} . On another 12 plants the #2 leaves were treated with Cs^{134} or Ba^{133} and so on for each of 10 leaves. Thus 120 plants were treated each week for a total of 600 plants during the season. At harvest, the plants were divided into from 14 to 23 parts (depending on the size of the ears). Each part was analyzed separately for radio-activity for a total of about 12,000 samples. (See Figure 4)

At harvest each plant was cut off at the ground and dissected into the following parts:

- Tassel
- Leaves above and opposite treated leaf (Opposite)
- Leaves above and same side as treated leaf (Direct)
- Stem above treated leaf
- Spot treated.
- Treated leaf
- Leaves below and opposite treated leaf (Opposite)
- Leaves below and same side as treated leaf (Direct)
- Stem below treated leaf
- Ear at leaf 6 Husk
- Seed + Cob
- Ear at leaf 7 Husk
- Seed + Cob
- Ear at leaf 8 Husk
- Seed + Cob
- Ear at leaf 9
- Ear at leaf 10

The parts were oven-dried for 10 days at 130F. Dry weights were taken, the parts were pressed to a uniform density and their radioactivity determined on a tobar large volume counter. Samples were counted either

4 minutes or for 200,000 counts. Samples were assumed to be infinitely thick. In the case of the ears at 8, 9, and 10, however, the samples were too small for that assumption to be valid.

Summary data for the 1967 experiments are given in Tables 1 and 2, for treatments applied July 31, August 14 and August 28. The mature harvest was made September 11. The data in Tables 1 and 2 are in concentration of isotope (nanocuries per gram—NC/g) in the various plant parts. Figures 1-3 show the concentration of Cs^{134} in the ears at each node for three treatment dates when the isotope was applied to each of ten leaves. From these data we can draw the following conclusions:

- 1) Cs^{134} applied to and absorbed by any leaf is distributed generally throughout the plant. Isotope applied to leaf 10 was present in the tassel after 24 hours and at maturity. Likewise, Cs^{134} applied to leaf one was readily detected in bottom leaves or in the ear at node 10 after 24 hours.

- 2) The concentration of isotope after 24 hours is greatest in those tissues nearest the spot of application. Because of the way the plant was dissected it would appear from Tables 1 and 2 that movement was upward from top leaves and downward from lower leaves. For instance the concentration in the stem above the leaf when the treated leaf is #2 is always much higher than in the concentration in the stem below the leaf. However, the stem above leaf 2 is a short piece near the leaf. The stem below is of much greater weight and extends a greater distance from the treated spot. Therefore, its average concentration of isotope is less. The same argument holds for leaves above and below the treated leaf. The reverse is true if the treated leaf is leaf 10.

- 3) Very little Ba^{133} was absorbed by the plants. Most of the activity remained on the spot where the sample was applied. Even at maturity, the concentration of Ba^{133} was hardly detectable in plant parts other than the

treated leaf. There was some movement into other leaves on the plant but the most striking fact about the Ba^{133} data in Table 2 is the almost complete absence of the isotope in the ears. (As pointed out, above the data for ears at nodes 9 and 10 are unreliable because of the small sample size).

Because of the very small amount of uptake of Ba^{134} the remainder of this report will be concerned with Cs^{134} data.

4) There is little or no active accumulation of Cs in the ear of grain during much of the filling process. The concentration in the stem was always higher than that in the ear. This is not to say that isotopes do not move into the ear during the grain filling period. In fact, the weight of the ear increases greatly while the concentration remains slightly below that found in the stem. Thus it is clear that isotope is being translocated into the ear during its maturation process. The ear does not accumulate isotope against a concentration gradient during this time although it is rapidly growing in size.

5) The concentration of isotope in the ear was greatest when the treated leaf was attached to the node immediately above and opposite the point of attachment of the ear. This is shown clearly in Figures 1-3. The vascular traces of leaves in maize connect to the stem vascular bundle at the node below the node of leaf attachment and often on the opposite side. (K. Esau, Plant Anatomy. Wiley & Sons N.Y. 1965). Thus, it is probable that the leaf above the ear has the most direct vascular connection with the ear itself. Again, it is clearly seen that the concentration of isotope in any tissue is highest near the point of application of the isotope.

Section IV Evaluation of results

In the December 1966 request for renewal of Contract AT-(11-1)-1596,

two objectives were listed:

1) To ascertain which leaves of corn supply minerals to the developing fruits and to evaluate the role of morphological structures directly associated with the fruit as possible pathways for entry of minerals to the developing fruit.

2) To ascertain the time course of accumulation of mineral ions in the fruit of corn at critical stages in the life of the plant: floral initiation, floral abortion, emergence of styles, anthesis, fertilization, seed and fruit maturation.

These objectives were completed to the extent discussed hereafter.

Objective 1 was completed in total with Cs¹³⁴. Since so little Ba¹³³ penetrated the leaf epidermis those data are not very useful. It is clear that all leaves may supply mineral elements to any developing ear but that the leaf nearest the ear via vascular connections may more readily do so. The silks did not supply mineral to the ear.

From these data there is little evidence of mobilization of mineral ions or of polar transport. The tissue nearest the spot of application had the highest concentration of isotope and there was a concentration gradient away from the spot throughout the plant. There is slight evidence of downward transport in that ears at or below the point where the leaf vascular strands anastomose with the stalk vascular system had higher concentrations of C¹³⁴ than ears above that point. This is somewhat difficult to interpret, however, because of the large error in counting the very small lower ears where uniform density and infinite thickness cannot be assumed.

Under objective 2 information was gained on the time course of accumulation only during seed and fruit maturation since the first treatment was not applied until tasseling had occurred. From Figures 1 to 3 it is clear that isotope is found first in the ear below the treated leaf (24 hrs).

By maturity, however, the concentration is more uniform throughout the plant. It would appear that Cs^{134} continued to accumulate in ears at nodes 8, 9 and 10 as the plant matured. Again, however, the extremely small size of these parts results in large errors of analysis.

These experiments indicate that foliar absorption of minerals is mediated most rapidly through a liquid phase and uptake is very slow after the liquid on the spot has evaporated. They also clearly show that Cs enters much more readily than Ba.

In terms of the health hazard of radioactive fallout contaminating food supplies by accumulating in corn grain these experiments indicate that the accumulation will depend on the mineral species. Some may be readily absorbed by plant leaves, others may be largely excluded. Once in the plant, however, there is little indication that the grain is a particular sink for deposition of the mineral. The concentration in the grain will tend to be near that of the surrounding tissue. Thus, active accumulation in grain against a concentration gradient does not appear to be a problem. However, approximately one-half of the dry weight of a corn plant at maturity will be grain. Thus, even in the absence of active accumulation in the grain, a large part of the isotope which is absorbed by the plant will be found in the grain.

Table 1. The concentration of Cs¹³⁴ (NC/g) in the different plant parts from the treatment of leaf 1, 5, and 10. Mature harvest was September 11.

Plant Part	Treated Leaf					
	1		5		10	
	24 hrs.	Maturity	24 hrs.	Maturity	24 hrs.	Maturity

July 31 Treatment

Tassel	915	1,985	362	393	22	100
Leaves Above, Opposite			314	332	77	158
Leaves Above, Direct			472	533	131	199
Stem Above			3,188	447	229	115
Spot	468,011	5,827	215,798	1,036	398,145	174,923
Treated Leaf	27,765	14,345	7,201	1,819	17,797	7,579
Leaves Below, Opposite	99	549	63	172	1,470	209
Leaves Below, Direct	91	432	110	142	218	292
Stem Below	583	412	960	360	1,847	739
Ear at Node 6	56		1,587		42	
Husk		309		609		65
Cob		215		182		37
Seed						
Ear at Node 7	50		257		186	
Husk		202		670		167
Cob		258		84		146
Seed						
Ear at Node 8	67	385	336	673	44	82
Husk						
Cob						
Seed						
Ear at Node 9	143	319	56	702	89	219
Ear at Node 10	327	613	106	816	97	1,015

August 14 Treatment

Tassel	102	685	17		3	65
Leaves Above, Opposite			33		77	143
Leaves Above, Direct			39		11	193
Stem Above			104		11	92
Spot	417,651	13,967	96,110		50,340	16,706
Treated Leaf	11,800	16,670	6,388		17,479	6,726
Leaves Below, Opposite	21	525	16		34	261
Leaves Below, Direct	15	755	22			
Stem Below	218	590	221		491	460

Table 1. (con't)

Plant Part	Treated Leaf					
	1		5		10	
	24 hrs.	Maturity	24 hrs.	Maturity	24 hrs.	Maturity

August 14 Treatment (con't)

Ear at Node 6	56		536		3	
Husk		220				69
Cob		234				44
Seed						
Ear at Node 7	6		62		13	
Husk		105				109
Cob		127				134
Seed						
Ear at Node 8	3	369	40		10	219
Husk						
Cob						
Seed						
Ear at Node 9	5	447	43		74	256
Ear at Node 10	0	453	247		400	2,370

August 28 Treatment

Tassel	383	816	8	169	7	38
Leaves Above, Opposite			28	545	19	155
Leaves Above, Direct			61	751	13	198
Stem Above			51	969	30	343
Spot Treated	374,765	63,448	263,605	43,358	298,620	106,513
Leaf Treated	17,288	27,920	8,209	11,422	4,492	12,426
Leaves Below, Opposite	14	686	19	340		297
Leaves Below, Direct	29	525	19	513	91	
Stem Below	153	1,033	110	947	519	1,535
Ear at Node 6						
Husk	28	485	153	913	4	75
Cob	25	316	169	485	3	31
Seed						
Ear at Node 7						
Husk	7	92	5	205	10	156
Cob	3	37	0	152	2	64
Seed						
Ear at Node 8	4	204	17	840	10	94
Husk						
Cob						
Seed						
Ear at Node 9	50	114	12	232	31	556
Ear at Node 10	37	347	27	229	41	527

Table 2. The concentration of Ba¹³³ (NC/g) in the different plant parts from the treatment of leaf 1, 5, or 10. Mature harvest was September 11.

Plant Part	Treated Leaf					
	1		5		10	
	24 hrs. Maturity		24 hrs. Maturity		24 hrs. Maturity	

July 31 Treatment

Tassel	17	641	1	3	1	1
Leaves Above, Opposite			6	32	8	31
Leaves Above, Direct			5	29	7	7
Stem Above			7	8	9	3
Spot Treated	535,862	298,247	289,727	5,056	353,300	168,649
Treated Leaf	522	2,004	3,636	1,670	2,211	1,559
Leaves Below, Opposite	9	104	13	87	11	268
Leaves Below, Direct	23	107	1,027	123	6	
Stem Below Treated	3	9	2	4	5	19
Ear at Node 6	4		5		1	
Husk		39		23		1
Cob		4		0		0
Seed						
Ear at Node 7	4		3		1	
Husk		48		60		3
Cob		0		0		0
Seed						
Ear at Node 8	12	177	12	253	10	48
Husk						
Cob						
Seed						
Ear at Node 9	5	377	30	360	20	7
Ear at Node 10	15	123	177	375	83	290

August 14 Treatment

Tassel	14	522	2	6	3	18
Leaves Above, Opposite			4	166	13	70
Leaves Above, Direct			3	20	7	50
Stem Above			1	23	1	21
Spot	261,594	100,399	98,410	55,289	185,154	116,674
Treated Leaf	252	5,217	2,940	1,564	53	7,013
Leaves Below, Opposite	71	208	7	321	8	54
Leaves Below, Direct	139	234	16	361		
Stem Below	30	8	1	14	2	194

Table 2. (con't)

Plant Part	Treated Leaf					
	1		5		10	
	24 hrs.	Maturity	24 hrs.	Maturity	24 hrs.	Maturity

August 14 Treatment (con't)

Ear at Node 6	22		2		1	
Husk		21		54		14
Cob		1		0		9
Seed						
Ear at Node 7	13		4		2	
Husk		43		107		32
Cob		1		0		42
Seed						
Ear at Node 8	49	973	4	952	12	87
Husk						
Cob						
Seed						
Ear at Node 9	106	1,334	0	2,203	16	254
Ear at Node 10	375	635	172	1,982	0	213

August 28 Treatment

Tassel	57	233	20	5	2	2
Leaves Above, Opposite			283	59	8	4
Leaves Above, Direct			514	53	9	24
Stem Above			2	11	1	2
Spot Treated	446,013	220,431	280,968	1,873	345,456	108,938
Treated Leaf	728	4,969	83	144	199	3,384
Leaves Below, Opposite	10	186	46	137	4	11
Leaves Below, Direct	18	118	4	454		
Stem Below	1	7	1	10	4	5
Ear at Node 6						
Husk	4	36	10	14	7	3
Cob	3	1	1	1	1	0
Seed						
Ear at Node 7						
Husk	3	24	5	146	16	3
Cob	2	1	0	0	1	0
Seed						
Ear at Node 8	39	942	3	667	24	15
Husk						
Cob						
Seed						
Ear at Node 9	78	450	11	5,086	57	76
Ear at Node 10	13	2,060	81	1,051	89	130

Figure 1. The concentration of Cs^{134} in ears of corn when the treatment was applied to each of the ten uppermost leaves. Treatment date - July 31. Harvest August 1 (lower) and September 11 (upper).

Figure 3. The concentration of Cs^{134} in ears of corn when the treatment was applied to each of the uppermost ten leaves. Treatment date - August 28. Harvests August 29 (lower) and September 11 (upper).

Figure 4. The numbering of the corn leaves for treatment and sampling. When the treatment was applied to leaf 3, the sample "leaves above and opposite" consisted of leaf 2 only, the sample "leaves above and same side" consisted of leaf 1 only, the sample "leaves below and opposite" consisted of leaves 4, 6, 8, and 10, etc. Likewise the sample "stem above treated leaf" was a short section when the treated leaf was #1, but was a long section when the treated leaf was #10, etc.