UPTAKE OF MINERALS BY TREES IN SUCCESSIVE YEARS

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The uptake of mineral material by plants, as shown by foliar analyses, has been studied by many workers. Most of the studies in this connection have involved cereal and grass plants, mostly annuals. Numerous determinations of the mineral constitution of tree leaves have also been made. However, these studies reveal the mineral uptake by plants for a period of one season only. It is known that environment and heredity influence plant nutrition. Since environment changes from place to place and heredity ceases at the death of a plant, the seeming inconsistencies in mineral uptake by annual plants, as shown by foliar analyses, may be self-explanatory.

In view of such facts, it seems probable that more fundamental information regarding the influence of climate on mineral metabolism of plants could be obtained from foliar analyses by utilizing tree leaves over a period of successive years. A tree is a perennial plant whose heredity, for this purpose at least, is fixed. Its edaphic environment is also practically constant. The climate, then, is the most important variable. It is true that different trees react differently to both edaphic and climatic environment. However, this is true, doubtless, for all plants.

The choice of tree leaves as a medium of study for mineral nutrition as influenced by climate seems to have several advantages over short-lived plants, as follows:

(1) The ash content of plants can be influenced strongly by the growth of preceding crops. This is true qualitatively as well as quantitatively.

(2) Different soil physiological conditions are produced by different cultural operations.

(3) Analyses are not comparable from year to year when plants are grown on different soils.

Even should "standardized" plants be used to study mineral uptake, i.e., plants of selected and fixed heredity, they should be grown in the same spot in the soil each season in order for one to be able to draw valid conclusions. Edaphic conditions vary within narrow and unpredictable limits, even in small soil areas. Although much is known of the effect of single factors in plant growth, the anabolism of any plant involves multiple factors. Changing the site only slightly sets in action a complication of still different factors.

PRESENT STUDY

The present work was undertaken in order to learn more about the effect of the weather on the mineral uptake of plants, using the ash contents of tree leaves as evidence. The study began with thirty-six trees, representing twenty-four species, and ended with twenty-two trees of twenty species. The remainder became victims of the axe, disease, insects, and lightning. With the exception of one tree, a pecan, all trees grew on an area of land less than a quarter-section in extent. This land was originally prairie and is fairly uniform in nature. The first five trees shown in the tables grew nearly uniformly spaced on a plot of ground about fifty feet square. They are reported to be of the same age, having been started in a nursery and transplanted at the same time, while saplings about thirty years ago.

The leaves here reported were collected each autumn for five successive seasons, 1938 through 1942. They were taken mature and unweathered as follows: from the first eleven trees shown in Table II the leaves were picked each autumn from the same limbs and branches on approximately the bottom quarter of the tree when they were ready to abscise; from the remaining eleven trees leaf samples were collected daily after they fell until all leaves had fallen. In each instance they were well mixed and two-pound samples were saved. These were dried at 95° C, ground to pass through a sieve of half-millimeter mesh and 200 grams were saved for analysis. Determinations were made as shown in the tables. Weather data were taken including temperature, precipitation, and evaporation from a free water surface. Water-table levels were measured monthly.

PRESENTATION OF DATA

In Fig. I is shown the average water levels, in feet, of eight wells in the Stillwater Creek basin in which the trees studied are situated. In the same figure is also shown the cumulative departure from normal precipitation, in inches, for the period of time involved. Table I presents the precipitation, temperature, and warm-season evaporation. In Table II are given volume weight[1] of the ground leaf material, hydrogen-ion concentration expressed as pH, total nitrogen, crude ash, and eight ash constituents. All determinations were made according to recognized methods and all results are averages of at least triplicate determinations. The data for the first eleven trees shown in Table II are those for the hand-picked leaves. Table III shows the yearly distribution, or arrangement, of the various kinds of leaves accordingly as they were highest or lowest in the several elements during the different years.

DISCUSSION OF METEOROLOGICAL DATA

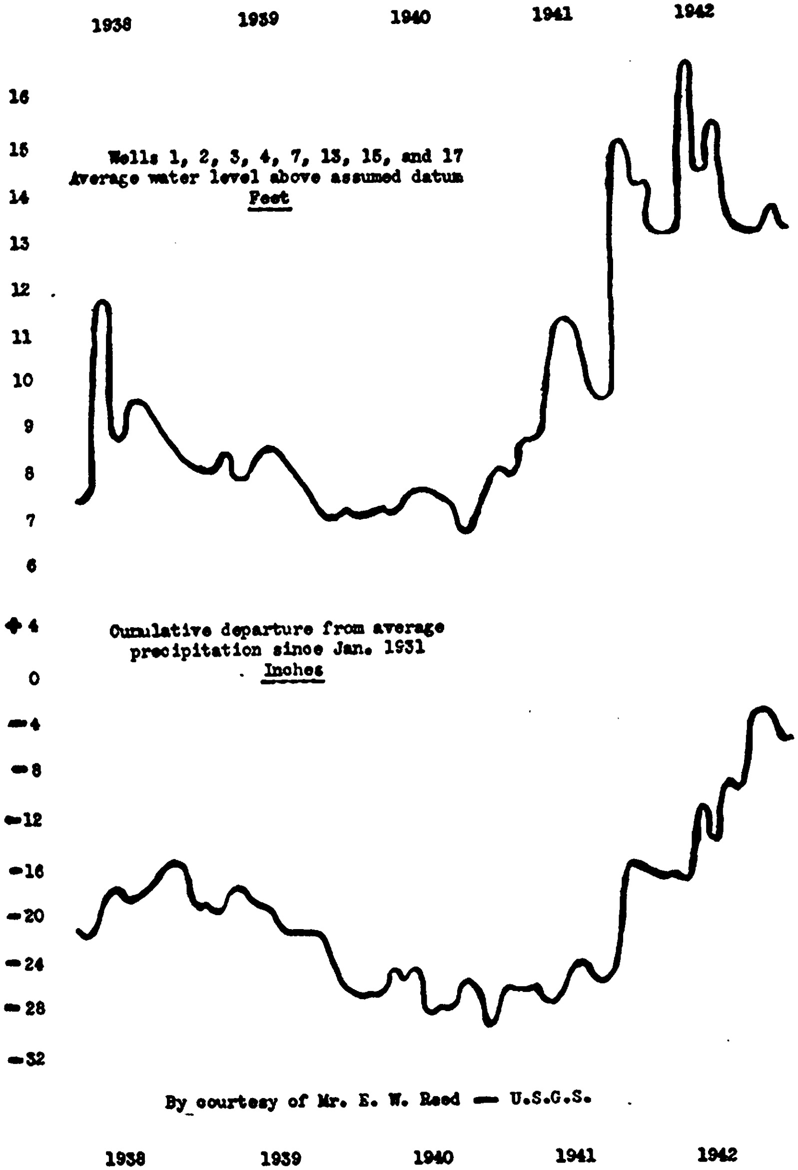
As seen in Fig. 1, after several previous low-moisture seasons, there was a sharp gain in precipitation from the beginning of 1938 until mid-summer that year. Then began an irregular drop that lasted until near the end of 1940. At this time, and continuing through 1942, there was an extremely large gain in moisture. Ground-water levels during the years followed, quite comparably, the trends for precipitation. The net gains for moisture in 1941 and 1942 were large.

Corresponding with the gain in moisture there was a definite decrease in temperature for the period. This is related to the decrease in evaporation from 1939 through 1942. It is possible that air movement is as great a factor in evaporation as temperature. Although complete data on wind mileage is not available and is not here presented, there was a very noticeable let-up in wind movement during the last few years.

During the period of the present work a complementary study of drainage water from the soil was made by use of lysimeters. From a battery of forty-eight of these the leachings of meteorological water through four fallow-soil cores were measured and averaged, and samples analyzed. The soil in these lysimeters, fine sandy loam in texture, consisted of undisturbed, natural, cylindrical cores, two and one-half by four and one-half feet in dimensions, and weighed nearly two tons each. The average amount of leachate through each core for the years 1938 through 1942 was respectively 20, 16, 134, 274, and 287 liters. The concentration of total bases in the drainage water was fairly constant regardless of the total amount of leaching; thus, the more leaching the more bases lost. Nitrates seemed to form to the greatest extent during the fall and winter. Lixiviating rains early in the spring cause the nitrates to pour out in the drainage water particularly from fallow soils. All of these conditions seem to be closely related to local and general weather patterns and these, in turn, appear to be closely related to crop yields (Bean 1942).

Conditions causing the loss of nitrates were quite noticeable during the present study. Nitrate formation was especially favored in February and March, 1938, but the following rainy May caused severe nitrate losses and tree leaves were yellowish-colored until late summer. The only drain-

FIGURE 1.



[1] Volume weight was determined by weighing the ground leaf material in a four-ounce Fairbanks official weight-per-bushel grain tester and comparing this weight with the weight of water which the scale bucket could hold. Each volume weight shown is the average of five separate weighings.

TABLE I

Weather data

Precipitation—departure from normal—inches

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Net for year	Net for growing season
1937	+0.8	—1.0	0	—1.0	—1.3	—0.1	—0.8	+0.2	+0.1	—0.4	—0.4	—0.1	—4.0	—3.4
1938	0	+3.1	+2.0	—0.4	+1.2	+0.5	—0.2	—0.9	—1.3	—2.4	+0.2	—1.0	+0.8	—1.3
1939	+1.3	+0.3	—0.4	—0.9	—1.0	+1.5	—1.2	—0.3	—2.8	—1.2	—0.6	—0.6	—5.9	—6.1
1940	—0.5	+2.4	—2.1	+2.1	—3.7	+0.6	—0.3	+2.5	—2.5	—2.0	+2.7	—1.0	—1.8	—5.5
1941	—0.4	+0.7	—1.6	+0.3	+2.6	+0.7	—1.6	—0.4	+1.5	+9.2	—0.9	—0.2	+9.9	+10.6
1942	—0.5	+0.3	—1.5	+7.3	—3.8	+5.6	—1.5	+6.1	+1.1	+0.8	—1.7	—0.8	+11.4	+12.3

Temperature departure from normal—degrees F

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Net for year	Net for growing season
1937	—6.0	+0.7	—4.0	+0.6	+2.6	+1.3	+2.4	+3.6	+0.3	—0.6	—2.9	—1.3	—3.3	+6.2
1938	+3.8	+5.4	+7.2	—0.9	+0.5	—0.2	+0.5	+2.9	+1.3	+5.5	—1.1	+2.1	+27.0	+16.8
1939	+5.9	—2.1	+3.2	—0.5	+2.7	+1.4	+2.5	+0.7	+5.7	+4.1	—1.1	+5.3	+27.8	+20.0
1940	—13.4	+0.4	+1.6	0	—0.2	—1.4	—0.8	—3.3	—2.0	+6.1	—3.0	+4.7	—11.3	0
1941	+4.7	+0.6	—4.1	+1.8	+3.4	—2.6	+0.7	+1.0	+1.4	+4.1	+1.6	+6.7	+18.3	+5.7
1942	+1.3	+2.2	+2.2	+4.2	+0.6	0	+0.5	—1.6	—2.2	+0.7	+3.9	+2.6	+14.4	+4.4

Warm season evaporation—free water surface—inches

Month	1937	1938	1939	1940	1941	1942
April	7.2	5.5	6.4	7.2	4.7	4.8
May	6.7	6.8	8.1	8.2	5.7	7.7
June	9.1	8.0	8.8	8.3	6.4	7.9
July	12.8	12.4	13.1	10.7	9.9	8.0
August	13.5	13.1	11.8	7.7	8.6	6.8
September	6.8	7.4	11.9	6.5	7.1	5.1
October	5.6	7.1	8.3	6.4	3.1	3.1
Total	61.7	60.3	68.4	55.0	45.5	43.4

TABLE II

Composition of leaves—oven-dry basis

Year	Tree species	Vol. wt.	pH	Tot. N. %	Crude ash %	SiO_2 %	Fe_2O_3 %	Al_2O_3 %	CaO %	MgO %	Mn_3O_4 %	P_2O_5 %	K_2O %
1938	Basswood	.230	5.8	2.05	14.30	1.88	0.09	0.21	4.90	1.24	0.02	0.25	1.10
1939	No. 1,	.228	5.9	2.13	12.90	1.62	0.07	0.16	4.18	1.14	0.02	0.30	1.16
1940	*Tilia*	.215	5.5	2.02	11.96	1.47	0.08	0.16	3.56	1.32	0.02	0.28	0.90
1941	*glabra*	.189	6.7	1.23	14.80	1.90	0.09	0.17	5.00	1.35	0.03	0.17	1.24
1942		.220	7.1	1.12	17.60	2.07	0.09	0.11	6.05	1.49	0.03	0.25	0.98
1938	Basswood	.238	5.6	1.85	15.65	1.97	0.09	0.19	5.41	1.33	0.03	0.29	1.05
1939	No. 2,	.236	5.7	2.16	14.76	1.88	0.07	0.12	4.75	1.07	0.03	0.35	1.00
1940	*Tilia*	.212	5.3	1.78	11.77	2.05	0.09	0.24	4.55	1.31	0.04	0.26	0.60
1941	*glabra*	.196	6.5	1.37	16.00	2.22	0.07	0.23	5.00	1.26	0.05	0.28	0.87
1942		.226	6.5	1.27	18.40	2.28	0.07	0.19	6.60	1.35	0.04	0.38	0.78
1938	Pin oak	.257	5.0	1.05	6.02	0.41	0.10	0.16	1.74	0.77	0.16	0.22	0.64
1939	No. 1,	.255	4.9	1.38	5.69	0.37	0.05	0.18	1.62	0.70	0.16	0.27	0.68
1940	*Quercus*	.250	4.8	1.01	5.05	0.54	0.09	0.20	1.31	0.54	0.18	0.14	0.47
1941	*palustris*	.252	4.7	0.86	5.55	0.49	0.05	0.10	1.90	0.80	0.22	0.15	0.66
1942		.263	4.8	0.79	7.10	0.60	0.05	0.16	2.03	0.69	0.20	0.28	0.60
1938	Pin oak	.258	5.0	1.25	6.11	0.37	0.06	0.21	1.83	0.75	0.08	0.20	0.72
1939	No. 2,	.255	5.0	1.80	5.17	0.30	0.03	0.22	1.42	0.78	0.10	0.24	0.70
1940	*Quercus*	.252	4.9	1.28	5.02	0.43	0.05	0.12	1.30	0.74	0.12	0.13	0.43
1941	*palustris*	.260	4.5	0.99	5.35	0.52	0.05	0.09	1.95	0.85	0.14	0.10	0.59
1942		.264	4.9	0.95	7.20	0.60	0.07	0.19	2.20	0.79	0.12	0.19	0.55
1938	Northern	.257	5.0	0.88	5.85	0.69	0.05	0.20	1.61	0.51	0.07	0.18	1.11
1939	red oak,	.255	5.1	1.19	5.70	0.67	0.05	0.11	1.26	0.55	0.07	0.35	1.28
1940	*Quercus*	.240	5.3	0.85	5.56	0.65	0.09	0.33	1.57	0.50	0.08	0.13	0.87
1941	*borealis*	.250	5.0	0.74	5.75	0.66	0.06	0.15	1.90	0.65	0.10	0.14	1.15
1942	*maxima*	.270	5.0	0.66	6.40	0.74	0.05	0.18	1.98	0.61	0.09	0.16	0.95

TABLE II
(continued)
Composition of leaves—oven-dry basis

Year	Tree species	Vol. wt.	pH	Tot. N. %	Crude ash %	SiO_2 %	Fe_2O_3 %	Al_2O_3 %	CaO %	MgO %	Mn_3O_4 %	P_2O_5 %	K_2O %
1938	Cypress, *Taxodium distichum*	.232	4.4	1.03	6.51	0.80	0.13	0.14	1.99	0.36	0.04	0.19	0.63
1939		.206	4.3	0.91	6.60	0.85	0.05	0.24	2.32	0.41	0.01	0.14	0.51
1940		.224	4.4	0.75	7.42	0.74	0.11	0.31	2.40	0.46	0.01	0.13	0.69
1941		.240	4.5	0.70	7.50	0.75	0.05	0.28	2.46	0.45	0.03	0.17	0.70
1942		.256	4.6	0.63	7.65	0.49	0.07	0.29	2.72	0.37	0.01	0.13	0.62
1938	Hackberry, *Celtis occidentalis*	.439	6.4	0.86	24.64	8.31	0.12	0.35	6.86	1.21	0.03	0.13	1.18
1939		.397	6.3	1.55	20.70	5.50	0.07	0.25	5.84	1.10	0.05	0.21	0.98
1940		.433	6.1	1.32	20.41	6.82	0.10	0.15	4.93	1.01	0.03	0.26	0.77
1941		.441	6.4	1.15	24.04	7.10	0.23	0.48	5.80	1.13	0.05	0.34	1.01
1942		.432	6.6	1.13	26.20	10.21	0.11	0.28	6.99	0.84	0.04	0.41	0.92
1938	Norway maple, *Acer platanoides*	.317	5.3	0.99	12.60	3.55	0.05	0.35	3.82	0.91	0.02	0.35	1.16
1939		.249	5.3	1.77	12.78	3.24	0.11	0.22	3.86	1.02	0.01	0.36	0.69
1940		.238	5.3	1.66	12.30	4.23	0.14	0.17	3.28	0.80	0.02	0.29	0.33
1941		.205	5.4	1.28	14.16	4.60	0.07	0.35	3.51	0.95	0.03	0.25	1.09
1942		.255	5.4	0.96	14.46	4.65	0.06	0.17	4.55	1.00	0.02	0.30	0.97
1938	Florida maple, *Acer floridanum*	.271	4.6	0.63	10.45	3.61	0.05	0.18	3.36	0.75	0.04	0.18	1.02
1939		.215	4.6	0.86	9.36	2.73	0.09	0.11	2.25	0.76	0.05	0.16	0.63
1940		.228	4.6	0.66	9.91	2.81	0.13	0.21	2.52	0.80	0.04	0.13	0.59
1941		.237	4.5	0.61	10.95	4.10	0.03	0.42	2.62	0.71	0.02	0.10	0.49
1942		.278	4.5	0.54	11.30	4.98	0.05	0.10	2.84	0.70	0.03	0.13	0.45
1938	Slippery elm, *Ulmus fulva*	.350	5.5	1.07	17.76	9.56	0.09	0.34	3.43	0.82	0.02	0.21	1.05
1939		.339	5.5	1.34	20.15	10.19	0.07	0.32	3.95	0.85	0.01	0.29	0.84
1940		.330	5.7	1.30	19.55	11.65	0.11	0.32	3.90	0.84	0.01	0.27	0.70
1941		.325	6.5	1.05	24.10	15.35	0.35	0.45	4.50	1.05	0.02	0.20	0.75
1942		.337	6.1	0.91	24.20	15.74	0.12	0.36	4.67	0.87	0.03	0.24	0.74

TABLE II
(continued)
Composition of leaves—oven-dry basis

Year	Tree species	Vol. wt.	pH	Tot. N. %	Crude ash %	SiO_2 %	Fe_2O_3 %	Al_2O_3 %	CaO %	MgO %	Mn_3O_4 %	P_2O_5 %	K_2O %
1938	Asiatic	.297	5.5	0.85	15.75	8.10	0.11	0.30	2.86	0.68	0.02	0.31	1.02
1939	elm,	.319	5.5	1.16	16.25	8.33	0.05	0.21	2.95	0.80	0.01	0.35	1.10
1940	*Ulmus*	.351	5.5	1.20	16.20	7.67	0.09	0.09	2.47	0.74	0.01	0.37	2.03
1941	*pumila*	.287	6.3	1.27	16.34	9.10	0.18	0.21	3.18	0.90	0.02	0.25	2.36
1942		.323	5.8	1.25	18.25	8.95	0.06	0.24	3.03	0.91	0.01	0.32	2.04
1938	Hedgeapple	.401	5.1	0.92	16.97	2.45	0.05	0.84	5.54	0.68	0.02	0.26	2.10
1939	(Osage orange),	.349	5.1	1.23	16.50	2.57	0.05	0.58	5.62	0.75	0.02	0.45	1.04
1940	*Maclura*	.335	5.2	0.95	16.17	2.61	0.09	0.40	5.77	0.81	0.01	0.40	0.96
1941	*pomifera*	.341	6.0	1.63	16.61	2.95	0.05	0.44	5.66	1.31	0.02	0.49	1.15
1942		.374	6.9	1.19	23.48	3.99	0.07	0.72	6.94	0.89	0.03	0.61	1.03
1938	White mul-	.351	6.0	0.90	19.21	7.85	0.02	0.26	5.10	0.88	0.03	0.28	2.68
1939	berry,	.340	6.1	1.09	21.02	9.20	0.07	0.58	5.15	0.80	0.02	0.37	1.62
1940	*Morus*	.342	6.6	0.95	23.44	10.10	0.09	0.84	4.85	0.82	0.01	0.69	2.67
1941	*alba*	.341	6.1	1.68	21.50	11.90	0.14	0.50	4.60	0.87	0.02	0.50	1.90
1942		.387	6.3	1.39	22.85	11.98	0.05	0.45	4.42	0.67	0.02	0.51	1.48
1938	Paper mul-	.319	6.0	2.11	16.30	3.15	0.09	0.10	4.32	1.12	0.01	0.41	2.96
1939	berry,	.316	6.1	1.35	20.43	7.20	0.16	0.13	5.50	1.43	0.02	0.29	1.37
1940	*Broussonetia*	.315	6.2	1.01	22.25	8.55	0.13	0.15	5.40	1.55	0.01	0.20	1.31
1941	*papyrifera*	.264	6.9	1.62	22.45	9.15	0.23	0.14	6.20	1.54	0.03	0.32	1.51
1942		.333	6.3	0.92	22.62	8.92	0.11	0.30	5.85	1.27	0.02	0.30	1.65
1938	Pecan,	.347	4.7	0.85	9.60	1.43	0.06	0.27	2.49	0.93	0.12	0.33	0.80
1939	*Carya*	.320	4.8	1.03	7.69	1.91	0.05	0.09	1.88	1.12	0.10	0.23	0.69
1940	*illinoensis*	.337	5.0	1.51	8.70	1.42	0.09	0.15	2.15	0.73	0.09	0.25	0.71
1941		.351	4.9	1.50	9.80	1.30	0.10	0.10	2.72	1.07	0.10	0.35	0.90
1942		.368	5.0	1.48	10.58	1.37	0.05	0.35	2.75	0.98	0.11	0.35	0.71

TABLE II
(continued)
Composition of leaves—oven-dry basis

Year	Tree species	Vol. wt.	pH	Tot. N. %	Crude ash %	SiO_2 %	Fe_2O_3 %	Al_2O_3 %	CaO %	MgO %	Mn_3O_4 %	P_2O_5 %	K_2O %
1938	Black	.314	5.0	1.45	10.50	0.47	0.05	0.22	3.61	0.81	0.01	0.20	1.23
1939	locust,	.307	5.1	1.90	9.71	0.50	0.12	0.20	2.70	0.75	0.02	0.26	1.55
1940	*Robinea*	.286	5.4	1.52	9.52	0.66	0.07	0.21	3.24	0.80	0.02	0.17	1.50
1941	*pseudo-*	.293	5.4	1.50	10.20	0.26	0.04	0.08	3.72	1.02	0.01	0.18	0.76
1942	*acacia*	.291	5.4	1.50	9.65	0.43	0.05	0.11	3.10	0.70	0.01	0.14	1.15
1938	Mimosa,	.335	5.5	2.85	10.15	0.45	0.03	0.12	3.11	0.55	0.01	0.37	1.79
1939	*Albizzia*	.326	5.4	3.26	8.47	0.38	0.05	0.09	2.91	0.68	0.01	0.36	1.42
1940	*julibrissin*	.323	5.2	2.90	7.36	0.44	0.05	0.14	2.06	0.32	0.01	0.35	1.51
1941		.291	5.2	2.38	7.70	0.30	0.03	0.12	2.70	0.58	0.01	0.25	1.10
1942		.317	5.6	2.30	10.50	0.59	0.05	0.15	2.97	0.45	0.01	0.30	1.72
1938	Burr oak	.337	5.0	1.28	9.84	3.35	0.03	0.19	1.80	0.63	0.07	0.23	1.18
1939	(Mossy-cup oak),	.253	5.1	1.40	7.60	1.56	0.05	0.29	1.95	0.86	0.05	0.21	0.66
1940	*Quercus*	.271	5.1	1.04	8.50	1.60	0.09	0.28	2.10	0.89	0.10	0.18	0.80
1941	*macrocarpa*	.290	5.1	1.13	9.20	1.75	0.05	0.34	2.00	1.02	0.05	0.20	0.87
1942		.322	5.1	0.99	9.65	1.70	0.05	0.14	2.68	0.82	0.07	0.21	0.54
1938	Loblolly	.197	4.3	0.58	3.64	0.97	0.10	0.18	0.58	0.24	0.02	0.17	0.45
1939	pine,	.219	4.4	0.75	4.07	1.15	0.07	0.22	0.63	0.27	0.01	0.08	0.33
1940	*Pinus*	.227	4.5	0.60	4.71	3.03	0.14	0.06	0.53	0.29	0.01	0.07	0.21
1941	*taeda*	.223	4.4	0.72	5.83	3.02	0.07	0.29	0.61	0.32	0.01	0.09	0.28
1942		.245	4.5	0.47	5.44	2.64	0.11	0.09	0.66	0.30	0.02	0.09	0.29
1938	Carolina	.337	5.0	0.65	15.95	5.02	0.14	0.33	4.15	0.92	0.03	0.13	1.55
1939	poplar,	.335	5.1	0.82	16.30	3.03	0.07	0.20	3.70	1.20	0.02	0.16	1.45
1940	*Populus*	.336	5.2	0.62	16.59	3.29	0.05	0.28	3.86	1.32	0.03	0.13	3.80
1941	*deltoides*	.337	5.1	1.04	11.90	2.50	0.10	0.11	3.26	1.05	0.01	0.20	1.96
1942		.325	5.1	0.95	12.16	2.30	0.05	0.05	2.59	0.81	0.02	0.21	1.56

TABLE II
(continued)

Composition of leaves—oven-dry basis

Year	Tree species	Vol. wt.	pH	Tot. N. %	Crude ash %	SiO_2 %	Fe_2O_3 %	Al_2O_3 %	CaO %	MgO %	Mn_3O_4 %	P_2O_5 %	K_2O %
1938	Sycamore,	.243	5.0	0.87	9.82	1.30	0.05	0.15	3.29	0.66	0.03	0.23	1.67
1939	*Platanus*	.230	5.1	1.14	10.70	1.49	0.05	0.09	2.50	0.65	0.02	0.24	1.52
1940	*occidentalis*	.243	5.3	1.06	11.28	2.12	0.07	0.06	2.37	0.63	0.02	0.19	3.14
1941		.227	5.5	1.28	10.20	2.10	0.05	0.10	2.60	0.75	0.01	0.30	1.69
1942		.239	5.0	0.97	8.01	0.97	0.05	0.15	2.15	0.52	0.01	0.25	0.94
1938	Apricot,	.330	4.5	1.05	10.22	0.65	0.06	0.26	1.66	0.84	0.02	0.52	3.63
1939	*Prunus*	.300	4.6	1.19	9.96	0.62	0.13	0.14	1.52	0.76	0.01	0.44	3.52
1940	*armeniaca*	.341	5.4	1.09	11.45	0.76	0.25	0.34	2.02	0.88	0.02	0.36	4.17
1941		.332	5.0	1.07	10.05	0.60	0.09	0.32	2.18	0.62	0.02	0.51	3.40
1942		.411	5.1	1.03	9.30	0.32	0.06	0.12	1.40	0.57	0.02	0.72	3.00

TABLE III

Distribution of trees with regard to highest and lowest content of the various leaf elements for the different years. For example, fifteen trees had their highest ash content in 1942 while ten had their lowest in 1940.

Year	Ash		Silica		Tot. N.		Calcium		Magnesium		Phosphorus		Potassium	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
1938	2	5	2	4	2	6	5	4	2	6	5	3	12	1
1939		4	2	8	14			4	3	3	7	1	3	3
1940	4	10	4	3	1	2		10	5	6	2	9	3	11
1941	1	1	2	3	5		4		9		1	7	4	2
1942	15	2	12	4		14	13	4	3	7	7	2		5

age that occurred in 1938 took place during that month. Favorable rains, which did not cause leaching, then caused strong accumulation of nitrates for the season of 1939 and the foliage that year had an extremely blackish-green color. Nearly all the leaves had their highest nitrogen contents in 1939. From then on, rains, which caused leaching just at the nitrate-forming periods, caused a cumulative decrease of this nutrient and foliage became continually more yellowish until, all during 1942, xanthophyll almost dominated chlorophyll in coloration effect.

DISCUSSION OF ANALYTICAL DATA—TABLE II

Volume weight. The figures for this determination tended, somewhat inconsistently, to increase with larger ash content. Probably the most outstanding discrepancies in this connection occurred in the cases of the apricot, sycamore, black locust, and loblolly pine in the fall of 1942. The leaves of these trees fell three weeks earlier than the others that year and their ash weights are lower and their volume weights are higher than for the preceding year. It has been found that volume weight, or apparent specific gravity, of ground leaf material is as highly correlated with the physical nature of the leaf as with its ash content. Early-falling, greenish-colored leaves, when finely ground give a more flaky and less fibrous product than ground ripe leaves—the latter being quite "fluffy" in comparison, thus occupying a larger volume per unit of weight.

Acidity. The hydrogen-ion concentration tended, somewhat inconsistently, to decrease (increase in pH) with larger ash content. It is quite generally presumed that the more total bases a plant material contains the lower is its resulting acidity. However, substantial data in another connection, not herewith presented, show that some tree leaves with high base content have strong acidities; conversely, some leaves with low base content show comparatively weak acidities. It seems certain that this feature is not necessarily a base-content characteristic; instead, it seems to be more closely related to anion hook-up. Anion contents vary as greatly as and more diversely than those of cations.

Total nitrogen. The data show a gradual but general decrease in nitrogen contents since 1939. This is especially true for the hand-picked samples. The explanation of this seems to be the continual loss of nitrates in drainage waters since that year. In the field of horticulture it is known that, for vegetable crops, at least, the more nitrogen plant tissue contains, the less mineral matter and fiber it contains, relatively. The same thing seems to be true for tree leaves, as the ash and mineral figures indicate herein.

Of all the trees studied, two-thirds contained their highest nitrogen values in 1939; the other third was scattered somewhat unequally through the other seasons. In 1942, two-thirds of the trees had their lowest nitrogen contents, the rest having theirs mainly in 1938 (see Table III). It has already been mentioned that 1939 was the year most favorable to nitrate accumulation.

Crude ash. With few exceptions, the ash contents of the leaves were on a downgrade from 1938 through 1940. From that time onward there was an almost exaggerated increase in this material. This variation seems to be directly correlated with moisture conditions. The precipitation curve (cumulative departure from normal) in Fig. 1 shows the moisture drop from 1938 through 1940 with the subsequent *still greater* rise from then through 1942. A curve for the ash contents would appear much the same.

There seems to be some doubt as to whether mineral uptake by trees is comparable to that by small plants as shown by foliar analysis. It is possible that the feeding propensities of the latter may differ from those of the former owing to the seeming disparity in the natures of their respective root systems. It is quite generally known that small plants, such as grasses, have shallow root systems but it is not generally recognized that, in comparison with size, the feeding zone of tree roots is mostly quite shallow.

It may be expedient to mention here that ash analyses are often misunderstood and consequently misinterpreted. That is, attempts are often made to compare the sum of the bases determined with the amount of ash obtained. A balance between the two is seldom obtainable and wide discrepancies are common. This is due to several reasons. If ashing is done carefully at a low temperature, in order to prevent volatilization of some of the constituents, some carbon is always left unburned.[2] The amounts of such residue may be as high as 15 or 20 percent of the total ash, depending on the proportion of certain mineral elements present—particularly soda, potash, and silica. Further, seldom are any but the so-called most important elements determined; anions in particular are unaccounted for. Other undetermined items, including titanium and the rare earths, may often amount to as much as five percent of the total ash. In addition, the ash consists mostly of a mixture of oxides and carbonates which, with silicates and unknown acid radicals, does not permit close calculation. In the present work the ash is, in every instance, saturated with carbon dioxide but contains indefinite amounts of unburned carbon. No determinations of uncommon elements were made.

Silica. In general, this material seems to correspond directly to the amount of ash present. Twelve trees had their highest silica contents in 1942, the other highest ones being distributed fairly uniformly throughout the years. The largest number of trees had their lowest silica contents in 1939. This, it is remembered, is the year in which available nitrogen was present in greatest amounts. Further, as already mentioned, ash constituents (particularly silica) diminish as succulence increases.

Calcium. This element is present even more nearly proportional to ash than is silica; it generally constitutes about one-third of the ash content. Thirteen of the trees had their highest lime content in 1942, the rest being nearly equally divided between 1938 and 1941. Ten trees had their lowest contents in 1940, the others being equally divided between 1938, 1939, and 1942.

Calcium is an element the availability of which is generally believed to be closely related—other things being equal—to the presence of hydrogen ions in the soil. Further, it is commonly believed that an increase in soil moisture generally results in an increase in pH, or a decrease in acidity. In the beginning of the present study the acidity of all soils involved ranged between pH 6.2 and 6.5. At the close no significant changes in this respect could be detected. A slight caliche concentration underlies this entire area at varying depths of several feet but in no instance was it observed to be in close contact with the feeding-root zones of the trees involved.

Complete agreement does not exist among workers regarding the relationship of the mineral uptake by plants to the kind of season they undergo. Other data from this station indicate that, for cereals and grasses, phosphorus and potassium are taken up more abundantly by plants in wet years (Murphy and Daniel 1936 and Daniel and Harper 1935). On the other hand, calcium is taken up to a greater extent in drier years. The present data, for trees, seem not to agree entirely with this. The difference in depths of root zones is a probable explanation.

Magnesium and phosphorus. It is difficult to deduce any clear-cut reason for the various distributions of these elements in the different years.

[2] This amount seems to be constant for the same sample of material. With full access to air, using same temperature and time for ignition, good checks are regularly obtained.

It is possible that some unobserved or undetected factor, or factors, is responsible for the seeming diversities in use of these elements by the trees. This is possibly true to a somewhat lesser extent for some of the other elements also. Further, it is true that slight increases or decreases in elemental amounts, in some instances, would have shifted the distribution standings.

Potassium. Slightly more than half of the trees contained their highest amounts of this element in 1938 and exactly half of them contained their lowest amounts in 1940. For the latter, this is in agreement with the idea of little potassium in dry years but not a single tree contained its highest potassium content in 1942. A possible explanation for this seeming impasse might be that, in the soils involved, potassium does not rapidly become available, particularly in dry seasons. The year of 1936 was quite dry; 1937 was somewhat more favorable in this respect. Then, in the early part of 1938, the weather was abnormally warm and plenty of moisture was received. Owing to this combination of favorable circumstances and to the probable small take-up of potassium during the immediately preceding years, a larger-than-ordinary amount of this element may have been available.

Of all the elements given in the analysis, iron and aluminum seem to show the least relationship to possible weather influences. Manganese is only slightly more clear in this connection. Such characteristics as high ash for hackberry, low ash for pine, and high manganese content for pin oak, etc., are species peculiarities and do not come within the purview of this study.

A further study of the chemical data shows a seemingly greater consistency and agreement of elemental uptake with weather conditions for the hand-picked leaves than for the nonpicked leaves.[3] The probable explanation of this is connected with the growth of succulent foliage, or water-sprout leaves. It was noticed that the formation of such leaves occurred each year and varied greatly in amount from tree to tree and from season to season. This condition seems to occur mainly in the top half of trees and may be restricted to a few limbs or be scattered irregularly over many limbs and branches. These succulent leaves were always higher in nitrogen and lower in ash than the normal leaves.. It is here believed that the tendency toward water-sprout formation on trees is greater in subhumid than in humid areas.

The question of differences in ash content of leaves from the bottom, middle, or top part of the tree may be apropos here. European studies in this connection are mostly of old vintage (Fliche and Grandeau 1876, Schroeder 1878, and Wolff 1880) and give conflicting results. Serex (1917) in the United States, believed that this unproved phenomenon was a species proprium; some of the trees in his study were higher in ash in top leaves and lower in the bottom leaves while other trees were the reverse. However, his data is not extensive enough to be significant. In the present work an attempt was made to answer this question. It was found that variations occurred in a few instances but were entirely inconsistent from tree to tree and year to year. As already mentioned, the prevalence of water-sprout leaves seemed to offer the most plausible explanation of these inconsistencies.

In connection with leaf analysis, in general, it has been noticed that the nitrogen content of various tree species growing west of the 95th meridian is significantly higher than for the same species growing east of this

[3] The seeming irregularities in the chemical contents of the slippery and Asiatic elm leaves in 1942 may possibly be partly due to the fact that the bottom limbs were pruned from these trees during the summer and the leaf samples were consequently taken from higher up than before.

line. The same appears to be true, also, for calcium but less consistently so (Plice, MS).

The summer of 1943 was different from other summers involved in the study in that, while it was droughty enough to injure pastures and crops badly, sufficient moisture from 1942 remained in the subsurface and subsoil to permit the trees to grow luxuriantly all season. Consequently, leaf samples from all the trees were collected again in the fall of 1943 and will be analyzed as before. Increment borings in the trees will also be taken to ascertain whether there is any correlation between annual increment of wood and the chemical content of the leaves.

Note. Since completion of the above material an article was uncovered in an old German publication (Stahl-Schroeder 1904) in which the following interesting data are given. In one experiment with oats, using potted soils with moisture content increasing gradually from 35 up to 95 percent of their water-holding capacity, it was found that as the moisture content of the soil increased there was a continuous increase in the ash, silica, and phosphorus content of the oat grain. At the same time there was a constant decrease in total nitrogen, reaching a minimum at 90 percent. At this point, however, nitrogen began to increase and continued to do so up to 95 percent of the water-holding capacity of the soil.

SUMMARY

In an effort to study mineral uptake by plants so that climate would be the only (or main) variant, analyses were made of fresh mature leaves of twenty-two trees of twenty species for five successive years. From half of the trees the leaves were picked from approximately the bottom quarter of the trees as they were just ready to abscise; from the others the leaves were collected as they fell. Weather and other data taken consisted of precipitation, evaporation, temperature, water table levels, and drainage from natural soil lysimeters.

In the early spring of 1938, after several years of droughty weather, heavy rains put soil moisture to a temporary high level. Decreased precipitation then reduced soil moisture until late in 1940. Then began greater than average rainfall and soil moisture rose to the highest levels ever measured in the Stillwater Creek basin.

Chemical analyses of the leaves show that mineral uptake seems to follow trends of soil moisture. With few exceptions, the ash materials, particularly silica and calcium, decreased from 1938 through 1940 and gradually increased to new high levels from then through 1942. Total nitrogen increased with decreasing soil moisture and vice versa; vegetation in general was quite yellowish in color all during the summer of 1942. Magnesium and manganese varied somewhat irregularly and iron and aluminum entirely so. Acidity decreased somewhat irregularly with increasing soil moisture. Volume weight increased irregularly with increasing ash content. Most trees had their highest potash content in 1938 and their lowest in 1940.

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