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DISTRIBUTION OF FLUORINE IN UTAH COUNTY, UTAH, SOILS AND UPTAKE OF FLUORINE BY PLANTS

by

E. Don Hansen

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of

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in

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INTRODUCTION

Fluorine released from industrial operations is eventually deposited on the surface of the earth, intercepted by plants, or absorbed in open bodies of water. The term fluorine as used in this thesis will be considered to refer to fluorine in combined form.

Industrial expansion has caused atmosphere pollution from fluorine in many parts of the United States. Utah County, Utah, is one of the affected area, and is the principal area of concern in this thesis.

In the spring of 1951, Utah Agricultural Experiment Station initiated a broad investigation on soil, water, plant, and animal problems arising from fluorine atmospheric pollution. The study of the soil in the affected area is part of the broader investigations jointly conducted by the departments of Chemistry, Veterinary Science, Botany, and Agronomy.

The objectives of the soils phase of the study were two-fold:

1. A study of the distribution of fluorine in soils as related to industrial contamination sources in Utah County.

2. A greenhouse study of uptake of fluorine by plants grown on soils treated with soluble fluoride salts.

REVIEW OF LITERATURE

Naturally occurring sources of fluorine in the soil

Since fluorine is one of nature's most active elements, it is almost universally found in combined forms. Igneous rocks usually contain this element in varying amounts (0.01 to 3.36 per cent) and its compounds have been found widely distributed in many types of rock formation. Clark and Washington (1924) report that fluorine averages 290 parts per million in the 10 mile deep crust of igneous and sedimentary rocks. Jefferies (1951) found the average limestones contain from zero to 1030 parts per million of fluorine. Occasionally samples were found with higher fluorine contents. One such sample contained 2.11 per cent.

The most important fluorine bearing minerals include fluorite or fluorspar (CaF_2), apatite ($3Ca_3(PO_4)_2CaF_2$), cryolite (Na_3AlF_6), and sedimentary phosphate. Several minor minerals that contain fluorine (Rogers, 1921) are topaz ($Al_2(FOH)_2SiO_4$); phlogopite ($H_2KMg_3Al(SiO_4)$) which also contains fluorine and iron; lepidolite ($LiKAl_2(OH,F)(SiO_3)_3$); hornblende ($nCa(MgFe)_3SiO_3)_4 + n(Al,Fe)(F,OH)(SiO_3)_3$); vesuvianite ($Ca_6Al_3(OH,F)(SiO_4)_5$); and chondrodite ($Mg_5(F,OH)_2(SiO_4)_2$). A table of analysis (Clark, 1924, p. 363) of hornblende indicates a fluorine content varying from 0.1 per cent to 1.8 per cent fluorine.

Robinson and Edgington (1946) indicated that the common soil minerals, biotite and muscovite, are the main natural source of fluorine in soils. Steinkoenig (1919) concluded from his observation and those of others that the origin of the natural occurring fluorine in the soil is contributed by such minerals as biotite, tourmalin, muscovite, apatite, fluorite, and phlogopite. Of the surface and subsoil samples of nine different types of soil analyzed, fluorine occurred in amounts averaging 0.03 per cent. He noted that a higher content may be expected in soils carrying larger amounts of mica.

MacIntire, Winterberg, Thompson, and Hatcher (1942) estimated that the annual rainfall brings down 0.15 pounds of fluorine per acre at a certain place in Tennessee.

Artificial sources of fluorine in soil

There are four sources of artificial fluorine additions to the soil:

1. Fluorine in superphosphate fertilizers used extensively for fertilizing cultivated soils in the United States.
2. Local effluents of fluorine from various manufacturing processes.
3. Use of certain insecticides having a fluorine base.
4. Limestone used in liming acid soils.

Fluorine compounds are liberated into the air by industrial processes, which make use of high temperatures in the treatment of materials containing fluorine, either as a natural impurity, or added as fluorspar for fluxing processes, as in some metallurgical processes, the ceramic industry, and others.

Cryolite is important in the production of aluminum by the widely used electrolytic process. Apatite and sedimentary phosphate rock are used in the manufacture of superphosphates and phosphorus. Some compounds of fluorine may be liberated into the surrounding atmosphere by industries using these compounds unless adequate equipment is installed to collect them.

The burning of coal by homes and industries liberates small quantities of fluorides into the atmosphere. The most common forms of liberated fluorine compounds are hydrogen fluoride and silicon tetrafluoride, which are colorless gases and solid particulate fluorides. (Greenwood, 1940; Robinson and Edgington, 1946; and Roholm, 1937).

Of perhaps minor consequence, fluorine is added to the soil by the application of certain insecticides. This, however, is presumed to be confined to small local areas.

Limestone, when used for liming acid soils, may contribute artificially added fluorine in varying amounts, depending on the natural content. The amount of fluorine is variable in limestones from different localities.

Fluorine content of soils

Naturally occurring fluoride sources and artificially produced sources are both contributors to the total fluorine content of soils. Both vary considerably, depending on the difference in local areas in soil parent materials and type and extent of industrialization.

Steinkoenig (1919) was perhaps the first individual to make an analysis of soil for fluorine. He found from a trace to 1500 p.p.m. of fluorine in fourteen samples from nine locations in eastern United States. Following Steinkoenig's early studies, no record is evident from the literature of soil analyses for fluorine content until MacIntire and Winterberg (1942) published analyses for six soil types. Although it is not given, it is presumed the samples were of surface soil. One soil was a fine sandy loam and the other five were silt loams. The fine sandy loam had a fluorine content of 93 p.p.m., while the silt loams--each a different soil type and presumably non-calcareous--had fluorine contents respectively of 80, 103, 109, 125, and 338 p.p.m. of fluorine.

Analyses (McHargue and Hodgkiss, 1939) of two lysimeter soils, 83 p.p.m. and 411 p.p.m. of fluorine, are reported. In a red clay subsoil, 45 p.p.m. of fluorine was found.

Robinson and Edgington (1946) made a notable contribution to the data available on the fluorine content of soils. This was the first purposeful attempt to supply more information in this field. The fluorine content of 30 profiles, 137 samples in all, representing soils of varied texture, parent material, and geographic distribution, are given, as well as location and respective profile depths of sampling. The fluorine content varied from a trace to 7,070 p.p.m. in an unusual Tennessee soil, Maury silt loam, containing phosphate rock. The average for the surface soils was 292 p.p.m., and the average for subsoils (Maury silt loam excepted) was 393 p.p.m. of fluorine below six inches. The profile depths of sampling varied from 19 inches to 108 inches, with the average depths of profile observations being approximately 60 inches. In general, the sandy soils were found to be low in fluorine content and the heavier textured soils were found to be high. Another characteristic feature of fluorine distribution in these soil profiles was the tendency, generally, for the fluorine content to increase with the depth of the profile.

Prince, Bear, Brennan, Leone, and Daines, 1949, reported naturally occurring fluorine of 113 and 181 p.p.m. in Sassafras sandy loam and loam soils.

Another important contribution by Robinson and Edgington (1946) is the analyses of certain micaceous clays, purified and submitted to them by Dr. C. S. Ross of the Geological Survey for analysis. Table 1 shows the results of the analyses of these clays.

Table 1. Fluorine content of certain micaceous clays

Mineral	Location	Fluorine
		p.p.m.
Hydrous mica	Platteville, Wisconsin	5800
Muscovite	Staley, North Carolina	400
Ordovician bentonite	Chattoga County, Georgia	4500
Ordovician bentonite	Sevier Dam, Tennessee	7400
Serecite	Guanajuato, Mexico	1800
Serecite	Staley, North Carolina	300

Further evidence of the degree to which the colloidal fraction of the soil contributes to the total fluorine in the soils is shown in table 2, below, also from Robinson's and Edgington's (1946) publication.

Table 2. Fluorine content of soil and extracted colloid

Soil	Location	Colloid	F in soil	F in colloid
		per cent	p.p.m.	p.p.m.
Caribou loam	Presque Isle, Maine	18.2	390	850
Decatur clay loam	Near Decatur, Alabama	40.9	178	268
Herrick silt loam	Carlinsville, Illinois	17.9	311	664
Sable silty clay loam	Aledo, Illinois	25.9	220	530
Wooster silt loam	Wooster, Ohio	14.6	184	831
Hagerstown silt loam	State College, Pa.	22.9	316	578

The above data show a considerable concentration of fluorine in the colloidal fraction of the soil. With the exception of Sable silty clay loam, part of the fluorine present in all the soils had been contributed by added superphosphate fertilizer. The great complexity of the study of the effect of fluorine additions to the soil by natural and artificial means is apparent from the above considerations.

Dickman and Bray (1941) demonstrated the replacement of hydroxyl of the clay fraction by fluorine. Marshall (1949) also discussed the phenomenon of absorption and liberation of anions by the exchange complex. Since OH^- and F^- are practically the same size, their exchange involves no lattice arrangements. The only factor preventing complete substitution of F^- for OH^- lies in the inaccessibility of most of the OH^- groups. In clays of the kaolinite group, only OH^- groups on outer planar surfaces and edges are accessible. However, in the hydrated halloysite known as endellite, all OH^- groups should eventually be accessible, since the kaolinite units are separated by double layers of water molecules into which the F^- ions might readily penetrate. In the montmorillonite clays accessible OH^- groups are only on the crystal edges.

Quantitative evidence demonstrating the stoichiometric replacement of hydroxyl ions by fluorine was presented (Dickman and Bray, 1941). They recovered absorbed phosphate on kaolinite by shaking with solutions of ammonium fluoride, and found that complete recovery of added phosphate was obtained by shaking 1 gm. of kaolinite with 50 ml. of 0.1N neutral NH_4F for one minute.

Dean and Rubins (1947) used a fluoride solution as a means of studying anion-exchange capacity and the exchangeable phosphorus of soil in particular. These investigators found this solution gave a satisfactory estimate of exchangeable phosphorus. The phosphorus retained by soils as an exchangeable anion is virtually completely removed by fluoride, hydroxide, and citrate solutions.

MacIntire and associates (1949), in their 20 year review of the effects of fluorine on soils and crops in Tennessee, reported that a mean of 0.059 per cent fluorine content and 0.05 per cent calcium carbonate was found for nine samples of phosphatic soils collected on and near the Middle Tennessee Experiment Station farm. Eight similar Maury County field soils gave a mean content of 0.053 per cent of fluorine and a mean content of 0.05 per cent calcium carbonate. Six Kentucky soils supplied to the Tennessee station contained 0.06 per cent fluorine and 0.025 per cent $CaCO_3$.

Although it was not possible to review the original publication in the Russian language (Vinogradov and Danilova, 1948), these investigators reported a series of analyses of soils from various regions of Russia with fluorine contents ranging from 0.01 to 0.03 per cent, the average being 0.02 per cent.

Of perhaps even greater difficulty than ascertaining the source of fluorine in soils is an attempt to appraise the final effect of all artificial additions to our soils, particularly if the rate at which they are reaching our soils is maintained or accelerated in the future. In most cases, however, real efforts are being made to prevent excess fluorine contaminants from reaching plants, soils, and animals in toxic levels.

Fluorine uptake by plants

The major portion of the investigations concerning fluorine uptake by plants has been undertaken since the end of World War II.

Steinkoenig (1919) reports that the French workers Gautier and Clausman in 1919 found an average of 26.5 p.p.m. of fluorine in the dried material of 63 food plants. Some of their analyses on a fresh weight basis were: potatoes, 8 p.p.m.; tomatoes, 20 p.p.m.; buckwheat, 127 p.p.m.; carrot tuber, 4 p.p.m.; asparagus, 52 p.p.m.; peach fruit, 29 p.p.m.; French turnip tuber, 14 p.p.m.; alfalfa, 130 p.p.m.; cabbage, 9 p.p.m.; strawberry, 12 p.p.m.; asparagus (young shoot), 52 p.p.m.; apricot fruit, 30 p.p.m. These values undoubtedly include contaminant amounts on the surfaces of the leaves and are not all accounted for by physiological uptake.

The work of Hart, Phillips, and Bohstedt (1934) showed very low values of fluorine in the air dry samples of alfalfa, clover and timothy, mixed hay, cow pea hay, wheat, oat grain, and straw. The highest value was approximately 2.0 mgm. per kilogram of air dry alfalfa. The main contribution intended by their paper was to call to the attention of public health officials, agronomists, and fertilizer manufacturers the problem that confronts them in the practice of adding fluorine to our soils.

A primary contribution of uptake studies of fluorine by plants was contributed by Bartholomew (1935). He also made an important study of the effect of varying concentrations of fluorine compounds on the germination of seeds, using varying amounts of NaF, CaF_2, and Na_2SiF_6 up to 50 p.p.m. fluorine. Seeds used to check germination were Sudan grass, cowpeas, soybeans, white dutch clover, and red clover. Results showed little or no injurious effects on the seeds used. His results from solution culture studies using cowpeas as a crop and the three chemicals in concentrations of the above salts up to 10 p.p.m. F produced fluorine content of tops of 33, 5.5, and 445 p.p.m. F respectively.

Mitchell and Edman (1945) made a rather complete review of fluorine in soils, plants, and animals up to the time of their publication.

Considerable new material has been added since.

MacIntire and Winterberg (1942) made the first extensive effort to study fluorine uptake from soils. Additive fluorides were in the form of phosphates and slags. The fluorine content of nine successive crops (6 crops Sudan grass, 2 crops red clover, 1 crop radishes) grown in pot cultures of Montevallo silt loam was determined. The source of fluorine in the soil was 1150 lb./acre of fluorine added in a large application of superphosphate, plus a "protective" application of a 20 ton equivalent per acre of wollastonite ($CaCO_3$). The mean content of fluorine for the 9 crops was only four parts per million.

Another study was made using Hartsells fine sandy loam and Fullerton silt loam in greenhouse cultures and also in 36 outdoor concrete frames filled with soil 18 years previously to a 30 inch depth. The above soils were limed at equivalent rates of 4500 and 2250 lbs. per acre of $CaCO_3$ respectively, and fluorine was added in slags and phosphatic materials, or precipitated CaF_2. The highest fluorine content of plants obtained was for red clover grown on Montevallo silt loam treated with a large amount of slag containing 2.3 per cent fluorine. This was only 29 p.p.m. fluorine. Radish tops contained up to 25 p.p.m. fluorine on the same soil. Sudan grass, the third crop used in these extensive experiments, attained the highest content grown on Hartsells fine sandy loam treated with slag and phosphatic material. The entire range of values obtained in these uptake studies was only one to 29 p.p.m.

These authors conclude that there is no significant uptake by sweet clover, red clover, and Sudan grass from conventional use of fluoride-bearing fertilizers and liming materials. This would seem a reasonable conclusion, inasmuch as the fluoride form added is relatively insoluble and the higher rainfall of humid areas does not allow accumulation of the soluble sodium and potassium fluorides in the soil profile.

MacIntire, Winterberg, Clements, and Durham (1947) extended the field of knowledge of fluorine uptake with studies on the effects of calcium fluoride on soil. Uptake studies were carried out in the greenhouse on Hartsells fine sandy loam in 2-gallon glazed pots. Source of fluorine was precipitated CaF_2 and fluorspar at rates up to 3040 pounds of fluorine per acre, with and without applications of 83 pounds of P_2O_5 per acre. Limestone and two experimental calcium slags were used as controls. It will be seen from these data that because of the relatively higher availability of the fluorine from the fluorine sources added, the uptake of fluorine by the plants is considerably greater than that reported by MacIntire and Winterberg, et al, 1942, above.

Sudan grass grown on the Hartsells fine sandy loam, treated with 3040 pounds per acre of precipitated CaF_2 and 83 pounds per acre of P_2O_5 as superphosphate, produced foliage of 170 p.p.m. On the same soil, but treated with fluorspar, the Sudan grass tops attained a content of 1000 p.p.m. Grown on the same soil, under the same treatments, rye grass tops attained a content of 330 p.p.m. and 600 p.p.m. respectively. The lowest uptake value obtained was 110 p.p.m. for the Sudan grass grown on the soil treated with fluorspar at the rate of 2040 pounds of fluorine per acre and an application of superphosphate (83 pounds P_2O_5 per acre). The high level of uptake is noteworthy in this study.

MacIntire, Winterberg, et al (1947) found that when the soils of the above pots were composited, and two pots of each four were limed at the rate of two tons of $CaCO_3$ per acre, the level of uptake was much less. On the two pots that were left unlimed, the level of uptake was only 38 p.p.m. fluorine, while the limed pots indicated an uptake value of only 12 p.p.m. fluorine. These same authors analyzed alfalfa roots under the 3040 pounds of fluorine per acre incorporations and reported them as containing 70 p.p.m. fluorine compared to the controls averaging about 18 p.p.m. fluorine. The authors conclude there were no detrimental effects of calcium fluoride upon plant growth and composition when incorporated in soils with lime added.

Studies with nutrient solutions (Leone, Brennan, Daines and Robbins, 1948) containing fluorine in quantities from 0 to 40 p.p.m. were conducted using peach seedlings, tomato, and buckwheat plants. In all three plant species accumulation in the tissues increased as the fluorine concentration in the substrate was increased. Table 3 summarizes their uptake values.

Table 3. Nutrient solution fluorine uptake studies with peach seedlings, tomato, and buckwheat plants (Leone, et al 1948)

Plant	Substrate concentrations of F	Range of uptake F
	p.p.m.	p.p.m.
Peach leaves	10-25	220-261
Peach leaves	50-400	232-1442
Tomato leaves	10-25	82-277
Tomato leaves	50-400	379-2179
Buckwheat	10-400	101-1910

The general pattern of foliage injury in the above study for the medium concentrations of fluorine appeared to be similar for all three species. For actively grown plants, the authors observed, injury first appeared on the tips of the younger leaves, then extended along the leaf margin, and finally inward toward the midrib. The injury, according to the authors, appeared as a scorching of the affected areas. At the highest fluorine concentrations, necrosis was preceded by a general wilting of the plant as a result of root injury. The injury in this case progressed from the petioles and veins toward the leaf blades.

To ascertain whether the addition of mineral fluorides to soil would affect the fluorine content of grass, Churchill, Rowley, and Martin (1948) determined the fluorine content of grass from lawns of the Aluminum Research Laboratories. Chemically treated plots cut in June, 1946, gave high values, caused in a large part by dusting of the grass blades and retention of dusts in the intercepts. A September cutting gave less for the average of the treated than the untreated, so the authors conclude that the addition of mineral fluorides to the soil did not appreciably affect the fluorine content of grass. No record is given, however, of careful washing of the soluble fluorides off of the grass blades before analysis was made to get a more accurate measure of fluorine content by uptake from the soil.

In a twenty-year report on the effects of fluorine on Tennessee soils and crops, W. H. MacIntire and associates (1949) reported briefly on uptake studies. A review of the literature of the Tennessee group reported above leads to the following conclusions:

1. A good supply of calcium in the soil serves to assure that forage crops will not acquire a harmful content, either from components native to the soil, or from fluorine incorporations many times those from additive insecticide materials, fertilizers, or increments from the atmosphere.

2. In every instance of incorporation of fluorine compounds into soils of reasonable calcium carbonate content, no significant enhancement

of fluorine content in vegetation grown in the greenhouse under experimentally imposed conditions was found, even when conditions were not conducive to uptake.

3. Forage may acquire relatively heavy fluorine contamination from the atmosphere and yet show no effects upon leaf structure.

4. Fluorides native in phosphatic soils do not induce abnormal contents of fluorine in forage grown thereon.

5. Incorporated fluorine compounds do not cause fluorine to migrate into the crop on soils that contain calcium in adequate proportions.

In the above studies by MacIntire, et al, however, most of the fluorine sources were relatively insoluble compared with other soluble forms known to be in existence. These undoubtedly have a lesser effect on uptake than the more soluble forms of incorporated fluoride salts.

Annie M. Hurd-Karrer (1950) determined the extent to which fluorine can be absorbed from a soil by plant roots and the extent to which absorption can be controlled by liming. Sassafras loamy sand was used for the uptake studies. This was an acid soil (pH 5.0) containing 12 p.p.m. of naturally occurring fluorine. Soils were limed and unlimed and fluorine sources included HF, NaF, and CaF_2. Collards and buckwheat were used to study the uptake of fluorine. Table 4 gives the fluorine in two crops of collards and one crop of buckwheat, grown on limed and unlimed soils treated with three different chemicals as fluorine sources. Three levels of fluorine, 50, 78, and 102 p.p.m., were added to the soil.

Table 4. Fluorine contents of plants grown on limed and unlimed greenhouse soils treated with fluorides (Hurd-Karrer, 1950)

Soil treatment	Fluorine content of dry tissues: Collards Crop 1 (50 p.p.m. F added to soil)	Collards Crop 2 (78 p.p.m. F added to soil)	Buckwheat Crop 3 (102 p.p.m. F added to soil)
	p.p.m.	p.p.m.	p.p.m.
Check unlimed	3.7	4.0	59
Check limed	3.2	3.0	10
HF	96	262	9900
HF plus lime	43	31	900
NaF	68	111	2450
NaF plus lime	45	18	87
CaF_2	37	21	-
CaF_2 plus lime	5	5	-

Buckwheat may be considered an accumulator of fluorine. Injury was not manifest in the 900 p.p.m. level, but collards were stunted severely with the uptake values of 96, 111, and 262 p.p.m., respectively. Fluorine uptake was greater from the HF treatment than from the NaF treatment of the soil. Unlimed soil also showed greater uptake than the limed soil. However, even on the limed soils, fluorine uptake showed a significant value for the collards under the 50 p.p.m. of fluorine and 78 p.p.m. of fluorine soil treatments when compared with the untreated soil.

The uptake of fluorine from soil is reported (MacIntire, Winterberg, Clements, Jones, and Robinson, 1951) in three successive crops of soybeans, lespedeza, and oats. Table 5 briefly summarizes their results, two soils having been previously treated with 3 to 4.5 tons of limestone per 3,000,000 pounds of soil, with added sources of fluorine being cryolite, rock phosphate, MgF_2, NaF, and Na_2SiF_6.

Table 5. Uptake of fluorine from Clarksville silt loam and Hartsells fine sandy loam by soybeans, lespedeza, and oats (MacIntire, et al, 1951)

Crop	Rate of fluorine added to 3,000,000 lbs. soil	Uptake of F (range of values)
		p.p.m.
Soybeans	300 lbs. F	6 to 8
Lespedeza	675 lbs. F	6 to 10
Oats	975 lbs. F	4 to 6

Apparently the added lime was sufficient to keep the uptake of fluorine for all three crops from both soils to a minimum. The authors, in studying groundwater leachings under the various treatments, conclude that groundwater did not dissolve a harmful concentration of fluorides.

Working with hydrogen fluoride as a source of soluble fluorine additive to soils, MacIntire, Winterberg, Clements, Hardin, and Jones, 1951, report their work in an important paper. They studied uptake of fluorine by clover. Soils used were Hartsells fine sandy loam, naturally containing 169 p.p.m. fluorine, and Clarksville silt loam, containing naturally 160 p.p.m. fluorine. Both soils were treated with hydrogen fluoride in 100, 400, and 800 pound applications per acre of surface soil. Part of each soil was limed with 2 to 4 tons of $CaCO_3$ per acre surface, and other parts were left unlimed. These results are summarized in table 6.

Table 6. Effects of applications of hydrofluoric acid to the surface of two soils (MacIntire, et al, 1951)

Fluorine applications	F in clover tops unlimed	F in clover tops limed (Range of 3 liming treatments)
lb/acre	p.p.m.	p.p.m.
On Hartsells fine sandy loam		
No treatment	16	11-20
100	19	12-21
400	82	19-24
800	(lethal)	23-44
On Clarksville silt loam		
No treatment	14	13-15
100	19	15-20
400	86	22-29
800	150	43-92

From the above results, the fluorine content of the clover grown on the unlimed soils is in significant amounts for the 400 and 800 pound treatments of fluorine. For the 800 pound fluorine treatment on the limed soils the level is significant, especially for the Clarksville silt loam.

W. H. MacIntire (1952) reported on "air versus soil as channels for fluoric contamination of vegetation in two Tennessee locales." He stated that "...any plant uptake of fluorine from additive fluorine in soil can be established precisely." In 20 years' studies he concludes that soils possess distinctive capacities to fix additive fluorides against rainwater leachings, and against migration of the fluorine ion into the above-ground forage crops; and that such migration is repressed in soil systems that contain adequate calcium supplies. He also stated that high soil pH reduces the movement of the fluoride ion into plant tops.

In the two widely separated counties of Blount and Maury in Tennessee, MacIntire found the major sources of fluoric contamination to be atmospheric rather than the uptake of fluorides from the soil.

Daines, Leone, and Brennan (1952) reported on the effect of fluorine on plants as determined by uptake from sand cultures and fumigation studies. Fluorine as NaF was applied in concentrations of 0-400 p.p.m. to a variety of plants in sand culture. Tomatoes treated with these varying concentrations produced foliage ranging from 10 p.p.m. at the lowest to 2,179 p.p.m. at the highest fluorine treatment. These workers used fluorine analyses of leaves and roots of plants grown on New Jersey soils to distinguish between atmospheric enrichment of plant tissue by fluorine compounds and fluorine absorbed by the roots from the substrate. Atmospheric fluorine results in high leaf and low root fluorine content; soil fluorine causes a high leaf and even higher root content. Also, in soil studies, the authors found that as the pH of the soil was increased the degree of fluorine toxicity and the amount of fluorine by plants were minimized. These workers also recognized that a high fluorine content was not always accompanied by definite signs of fluorine injury. Gladiolas and peach exhibited severe foliage injury with low foliage fluorine (30-50 p.p.m.). On the other hand, such plants as bean, spinach, plantain, ragweed, and petunia were capable of absorbing foliage contents of 200 to 600 p.p.m. without showing fluorine injury.

Conclusions from the literature reviewed

1. The migration of the fluorine ion into the foliage by root absorption is minimized in heavily limed soils.

2. No difference has been expressed in uptake abilities of plants to extract fluorine from limed eastern soils and normally calcareous western soils.

3. Increased soil pH decreases the toxicity of fluorine compounds as well as the amount absorbed by plant tissues through the roots.

4. The colloidal fraction of the soil is responsible for absorption and fixation of some of the fluorine in soils. Lime may also fix fluorine in soils.

5. Uptake from soils is materially greater when the source of fluorine is in a soluble form, such as NaF, KF, or HF, rather than CaF_2 or phosphatic slags, even though lime may be present.

6. Plants differ in their abilities to absorb fluorine from soils or nutrient solutions.

7. Large quantities of fluorine in plant tissue can be present without any indication of tissue injury.

8. There is little evidence in the literature as to what amounts in plant tissue, on either dry weight basis (e.g., as cured hay) or moist weight basis (e.g., as pasture plants) start being toxic to animal bodies when taken in as food. Plants may not show evidence of any tissue injury and yet may be able to absorb fluorine in quantities from the soil alone to exert the same physiological effect on animal bodies as those plants which may be completely contaminated with fluorine from the atmosphere.

9. Air contamination accounts for a greater amount of fluorine

in plant tissues than does uptake from soil, but uptake alone is sometimes significant without any air contamination of plant tissues.

10. There is no evidence in the literature as to the levels of fluorine in calcareous or non-calcareous soils required to induce enough fluorine uptake into plant tissues to cause physiological effects in animals.

Correlation of fluorine in plants, especially forage crops, with physiological symptoms of fluorosis in animals, should be made in order for the results of uptake studies to be intelligently interpreted.

11. Atmospheric fluorine results in high leaf and low root content; soil fluorine causes high leaf content and even higher root content. This criteria may or may not always be true.

12. In the majority of uptake studies, neither high nor low values of fluorine contents have been supported by a statistical analysis of the results for significance.

13. In general, fluorine content in a soil profile increases with depth and is usually greater in the heavier textured soils than the sandy or light textured soils.

14. In a field soil, several sources may contribute to the total soil fluorine:

(a) parent material
(b) phosphatic fertilizers
(c) insecticides
(d) atmospheric effluents from industry

Phosphatic fertilizers and insecticides, in most cases, will be minor contributors. The predominant task is in appraising the amounts contributed by either parent material or atmospheric effluents.

EXPERIMENTAL METHODS AND RESULTS

General objectives

The main objective of the field studies was to ascertain the extent of the fluorine content of soils in Utah County and to discover whether there were diminishing amounts as distance was increased from a reference point near Provo, Utah. The fluorine content was determined on soil profile samples obtained in 1951 and on profile samples from approximately the same locations taken by the Utah Agricultural Experiment Station in 1938. This was to ascertain if there had been any significant increase in fluorine content of soils since industrial expansion had created a major fluorine contamination problem.

The main objective of the greenhouse studies was to establish any important relationships between chemical and physical characteristics exhibited by different soils and fluorine uptake by plants. This was accomplished by setting up a randomized block experiment so that significant differences in uptake could be analyzed statistically from values obtained by chemical analysis of plant tissues for fluorine. The plants were grown on different soils treated with different amounts of the soluble fluorides, NaF and $NaSiF_6$.

Preparation for analysis of vegetative and soil samples

Because of the care involved and the time-consuming characteristic of fluorine analysis, especially for a large number of analyses, a fluorine laboratory was set up in the chemistry building by the Utah Agricultural Experiment Station for the fluorine analysis of large numbers of materials such as vegetation, soils, bones, animal tissue, urine, milk, and water. The fluorine analysis of the turnip leaves and petioles, turnip tubers, whole alfalfa, and the soils in this investigation were made in this laboratory.

The preparation of both vegetative and soil samples followed closely the methods as outlined in the Stanford Research Institute, Analytical Section Method, "Preparation of Various Materials for Fluorine Analysis," (mimeographed), 1951:

> Vegetation: The sample of vegetation was washed and air dried on paper towels to remove rinse water from green plant material. The plant material was then cut up, mixed thoroughly and a portion weighed into an airtight container for freezing storage. A moisture sample was taken at the same time, or the moisture can be calculated directly from the green sample at the same time it was removed, for fluorine analysis from the plastic container. When the sample was ready for analysis the sample was transferred to a large Inconel crucible, and 1 gram of lime (fluorine free) was added to every 50 grams of green material. Sufficient water was added to completely cover the material. Phenolthalein was added in sufficient amount to develop a definite pink color. The mixture was then evaporated to dryness, taking care that the mixture remained alkaline during the entire evaporation.
>
> The Inconel crucible containing the dry material was slowly introduced into a muffle so that the contents would not burst into flame. The ignition was continued at 550° C until the ash was white or grey. Fluorine analysis was made on an aliquot of this weighed ash.
>
> The plant samples were analyzed for fluorine by modifications of the Willard and Winter method (Willard and Winter, 1933) as contained in the Stanford Research Institute, Private Communication.
>
> Soils: A soil sample was prepared by first air drying the entire sample. The soil sample was then passed through a pulverizer and thoroughly mixed. Moisture samples were calculated on a few samples but since this was quite low it was decided to run all the fluorine analyses on the air dry soils. A 20 gram representative sample was taken from the sieved pulverized soil and fluorine analysis was made from a portion of this sample.

FIELD STUDIES

Procedure

Soil sampling, Utah County, 1951 and 1938. The initial phase of this investigation was to determine the concentric distribution of fluorine from a reference point in Utah County.

This reference point is located geographically at the southeast corner of Section 8, Township 6 South, Range 2 East, to facilitate soil sample locations. From this point radii were drawn 36° apart, dividing the area surrounding the above reference point into 10 equal 36° quadrants. Using the radius line running directly north of the reference point, and proceeding clockwise to each radii successively, each quadrant between adjacent radii is numbered numerically, with the first quadrant being designated quadrant 0 (from 0° - 36°); from the 36° radius to the 72° radius designated quadrant 1; quadrant 2 from 72° - 108°; up to 360°, with the quadrant between 324° - 360° being 9. In order to give direction and distance to any location, concentric circles were drawn at intervals from the reference point. For a distance of 2 miles out from the reference point, concentric circles were drawn every one-half mile; after these four circles, four more circles were drawn a mile apart out to a total distance of 6 miles. From 6 miles distance out from the reference point, concentric circles were drawn every 2 miles to the greatest distance south of the reference point of 20 miles. The distance from the reference point is expressed as the number of half-miles from it in any given direction to the outer boundary of each segment. With the quadrant designation indicating direction, the half-mile designation indicates relative distance from the reference point. The two put together indicate a specific area at a certain relative direction and distance (in half miles) from the reference point and was designated sector to express them together. For example, a sample located in sector 418 would be in an approximate southeast direction from the reference point (between 144^0 - 180^o) with the fartherest distance being 9 miles from the reference point (18 half miles). Figure 1 shows this detailed arrangement of sampling and figures 2 and 3 show the location of the 1938 and 1951 field samples respectively. This same method was used in locating plant survey samples.

In order to sample directionally from the reference point and to still keep the number of samples within bounds for fluorine analysis, only every other quadrant was sampled starting with quadrant "0" and proceeding clockwise to 2, 4, 6, and 8, respectively. As many different series were sampled as possible, and soils were sampled at 40 different soil profile locations. Each profile was sampled at the profile intervals of 0 to 3 inches, 3 to 6 inches, 6 to 12 inches, and 12 to 24 inches. At each profile location field notes were made as to location, texture, color, and degree of calcareousness as measured by evolution of CO_2 with dilute acid.

In order to estimate the naturally occurring fluorides in soils, soils were sampled at 13 different locations in Cache County, Utah, approximately 120 miles north of this reference point described above. Cache Valley is essentially free from atmospheric pollution by fluorine from industrial sources.

The dried soil samples were prepared for analysis by passing them through a Braun pulverizer and screening out the larger rocks and foreign material. Fluorine analysis of soils was made by the direct

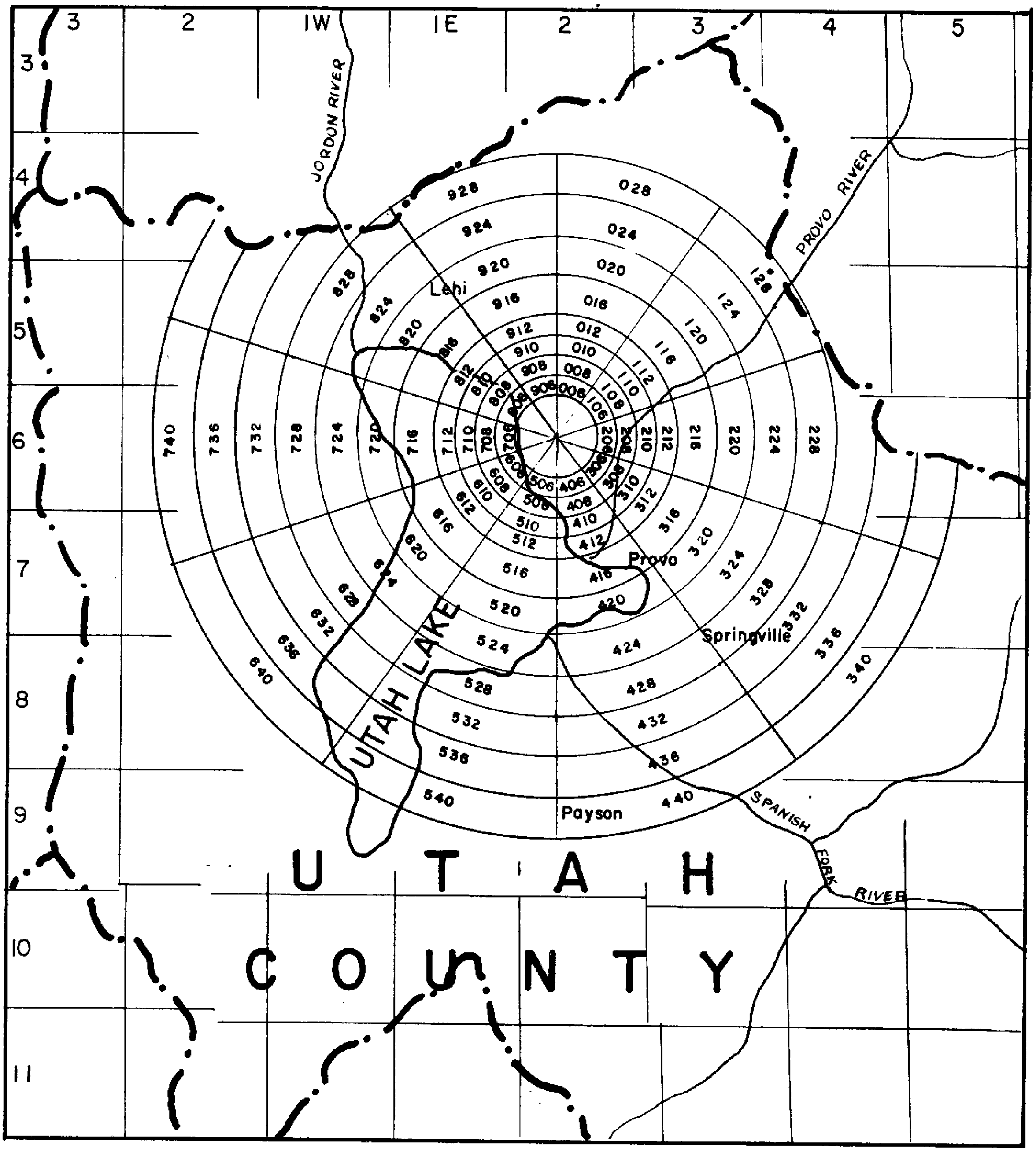

FIGURE I Sector Diagram, showing distances and direction from reference point (S.E. corner Sec. 8, T 6 S R 2 E) in Utah County.

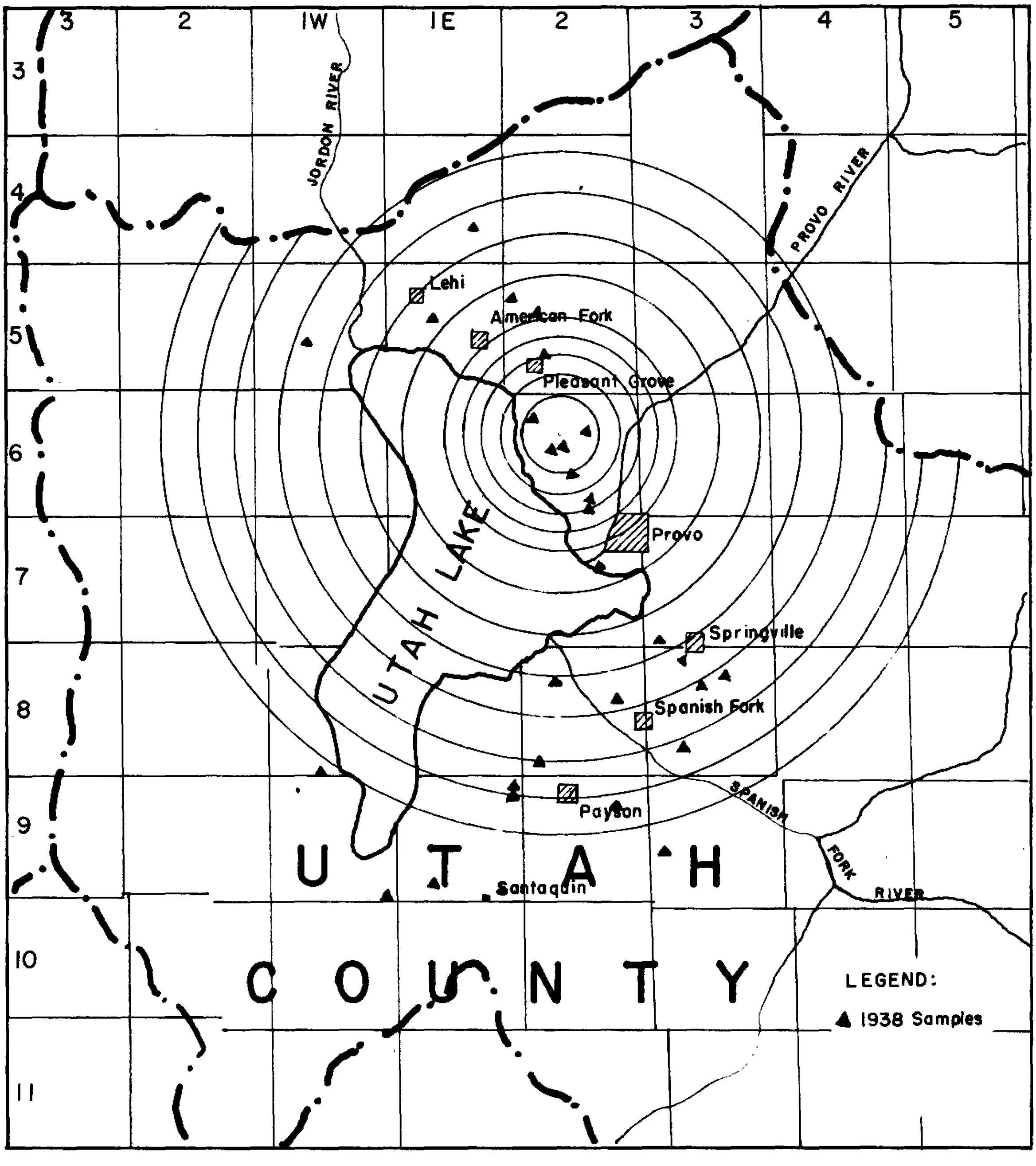

FIGURE 2 Soil Sample locations for 1938 soil profiles

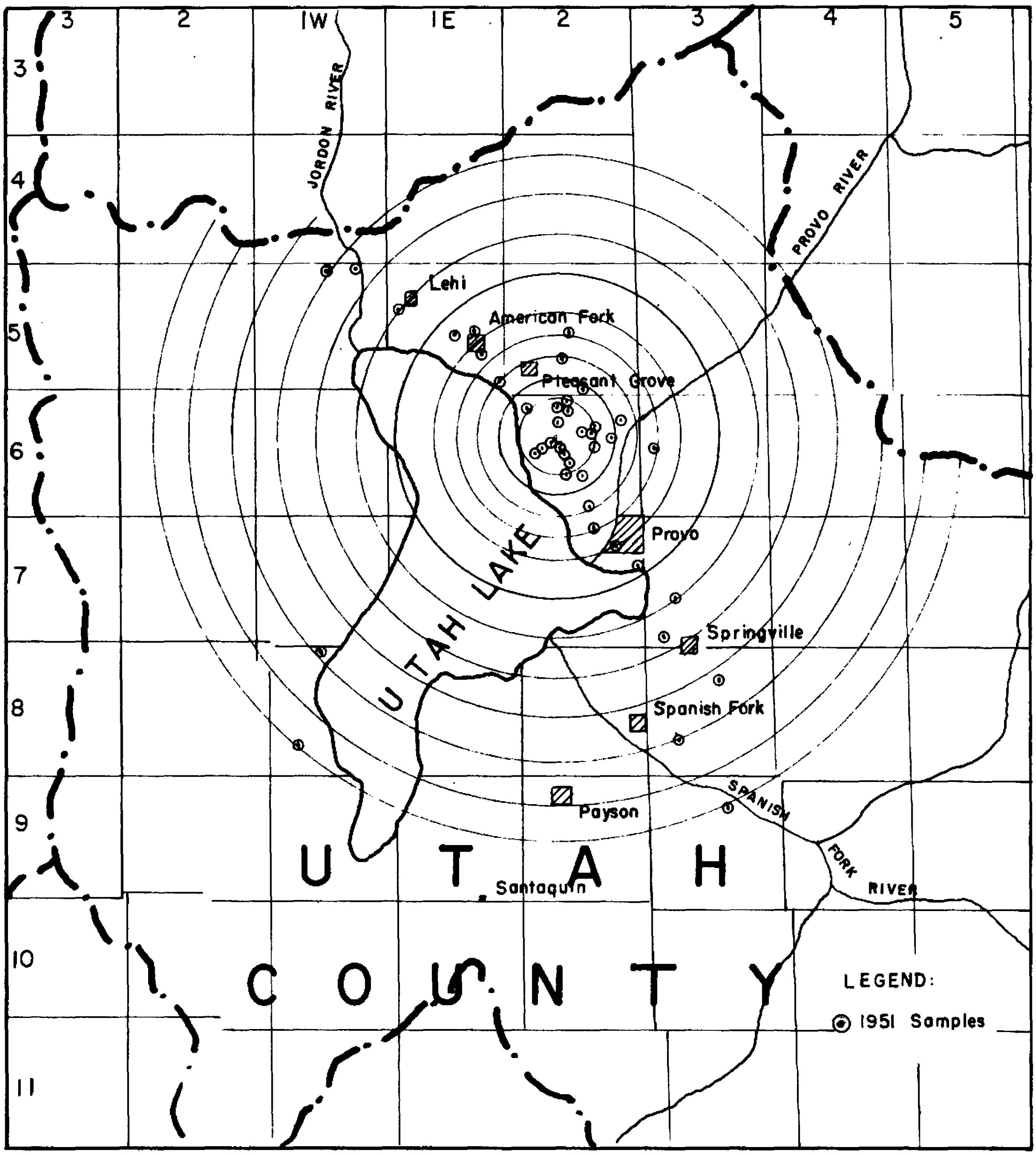

FIGURE 3 Soil Sample locations for 1951 soil profiles

double-distillation method developed by MacIntire, Hardin, and Jones (1951). The pH (paste) values were determined with a Beckman pH meter. Titrateable lime (%$CaCO_3$) was determined for each soil. The CO_2-soluble phosphrous was also determined using the stannous-chloride method.

Since lime ($CaCO_3$) tends to fix the fluorine in soils as CaF_2, some correlation would be expected between fluorine and lime in soils. Since fluorine is often closely associated with phosphorus, some relationship might exist between fluorine content and phosphorus content of the soil.

Results

Table 7 gives the summary of the analytical results on the soils sampled in Utah County in 1951.

Table 8 gives the summary of the analytical results on the soils sampled in Cache County.

Table 9 gives the fluorine contents and other analytical results on the soils sampled in 1938. In figure 4 is illustrated the average differences in p.p.m. fluorine between compared area samples of 1938 and 1951 at various distances from the reference point in Utah County.

Eighteen different soil series profiles are represented in the 1938 sampling. Thirteen of the same profiles are represented in the 1951 samplings plus three profiles not previously sampled in 1938. The range of soil textures in both samplings varies from loamy sands to clay loams. The per cent $CaCO_3$ varies from essentially non-calcareous to highly calcareous. It will be noted from both tables 7 and 9 that the fluorine content of the 1938 and 1951 soil samples varies from a low of 142 p.p.m. to a high of 1160 p.p.m. in the topsoil (0-6 inches) and from a low of 116 p.p.m. to a high of 1520 p.p.m. in the subsoil (6 inches, plus).

The field soils data indicate that as the lime content increases

Table 7. Description, location, pH, lime, phosphorus, and fluorine contents of Utah County soils, sampled in 1951

Soil type	Field soil number	Sector	Depth	Texture	pH	$CaCO_3$	P	F
			inches			per cent	p.p.m.	p.p.m.
Orem loamy sand	5	001	0-3	Coarse L. S.	8.2	1.50	2	195
			3-6	"	8.3	1.50	2	142
			6-12	"	8.2	2.26	2	227
			12-24	Medium L. S.	8.2	6.05	3	197
Orem loamy sand	6	002	0-3	Coarse L. S.	7.4	3.05	3	172
			3-6	"	7.9	2.00	2	159
			6-12	"	8.0	3.03	1	149
			12-24	Coarse sand	8.1	2.34	1	194
Bingham gravelly loamy sand	7	003	0-3	Gravelly L. S.	7.1	1.90	3	334
			3-6	"	6.9	2.72	2	274
			6-12	"	7.0	2.28	2	345
			12-24	"	7.6	3.43	2	390
Bingham sandy loam	8	004	0-3	S. L.	7.5	1.23	3	346
			3-6	S. L.	7.5	0.92	1	275
			6-12	L. S.	7.6	1.08	2	280
			12-24	L. S.	7.4	0.86	2	500
Welby loam	9	006	0-3	Loam	7.6	2.52	20	888
			3-6	"	7.5	2.30	8	842
			6-12	C. L.	7.9	4.00	2	995
			12-24	C. L.	7.7	18.52	1	1110

Table 7. Description, location, pH, lime, phosphorus, and fluorine contents of Utah County soils, sampled in 1951 (Continued)

Soil type	Field soil number	Sector	Depth	Texture	pH	$CaCO_3$	P	F
			inches			per cent	p.p.m.	p.p.m.
Pleasant Grove gravelly loam	10	008	0-3	Light clay loam	7.5	17.90	2	780
			3-6	" " "	7.6	14.30	4	840
			6-12	C. L.	7.6	16.00	3	845
			12-24	Gravelly C. L.	7.8	19.00	2	1030
Kirkham silty clay loam	11	010	0-3	Si C.L.	7.6	12.00	5	795
			3-6	"	7.5	11.70	2	818
			6-12	"	7.4	11.90	1	753
			12-24	"	7.5	10.30	1	850
Orem loamy sand	12	201	0-3	Medium sand	8.0	0.86	1	218
			3-6	"	8.1	0.78	1	142
			6-12	"	8.3	0.54	1	116
			12-24	"	8.0	0.44	1	159
Bingham gravelly sandy loam	13	202	0-3	Gravelly S. L.	7.5	1.23	1	385
			3-6	"	7.7	1.23	1	404
			6-12	"	7.7	1.11	1	346
			12-24	Gravelly v.f.s.l.	7.5	1.08	-	360
Bingham sandy loam	14	203	0-3	S. L.	7.2	1.08	1	284
			3-6	S. L.	7.3	0.86	1	305
			6-12	S. L.	7.3	0.93	1	305
			12-24	S. L.	7.2	0.98	1	303

Table 7. Description, location, pH, lime, phosphorus, and fluorine contents of Utah County soils, sampled in 1951 (Continued)

Soil type	Field soil number	Sector	Depth	Texture	pH	$CaCO_3$	P	F
			inches			per cent	p.p.m.	p.p.m.
Bingham gravelly sandy loam	15	204	0-3	Gravelly L. S.	7.4	0.88	2	327
			3-6	"	7.4	0.93	2	294
			6-12	"	7.7	0.86	1	266
			12-24	Stoney L. S.	7.5	0.78	2	344
Bingham gravelly loam	16	206	0-3	Gravelly loam	7.0	2.00	3	425
			3-6	"	7.1	1.40	3	316
			6-12	"	7.1	1.40	1	403
			12 +	Not sampled				
Bingham stoney loam	17	208	0-3	Stoney loam	7.5	1.50	3	490
			3-6	"	7.5	1.38	3	480
			6-12	"	7.6	1.50	2	589
			12-24	Not sampled				
Kirkham loam	18	210	0-3	Loam	7.5	16.4	5	895
			3-6	"	7.6	16.0	3	795
			6-12	"	7.7	17.3	2	960
			12-24	Light C. L.	7.5	17.8	2	980
Taylorsville sandy loam	19	401	0-3	S. L.	8.0	3.90	2	371
			3-6	S. L.	8.0	3.26	2	338
			6-12	S. L.	8.7	2.44	1	360
			12-24	L. S.	8.6	1.58	1	403

Table 7. Description, location, pH, lime, phosphorus, and fluorine contents of Utah County soils, sampled in 1951 (Continued)

Soil type	Field soil number	Sector	Depth	Texture	pH	$CaCO_3$	P	F
			inches			per cent	p.p.m.	p.p.m.
Taylorsville loam	20	402	0-3	Loam	8.7	3.29	1	686
			3-6	F.S.L.	8.0	3.56	3	524
			6-12	Light C. L.	8.3	13.57	9	600
			12-24	"	8.0	3.51	2	502
Orem loamy sand	21	403	0-3	L. S.	7.6	1.72	50	316
			3-6	L. S.	7.4	1.67	23	294
			6-12	Fine sand	7.7	1.85	54	360
			12-24	"	8.2	3.70	5	327
Taylorsville loam	22	404	0-3	Loam	7.9	8.11	8	457
			3-6	"	8.0	7.17	14	425
			6-12	"	8.0	5.09	2	436
			12-24	S. L.	7.9	19.60	5	479
Welby loamy sand	23	406	0-3	L. S.	7.7	1.70	4	392
			3-6	L. S.	7.6	1.40	7	305
			6-12	L. S.	7.7	1.16	6	338
			12-24	Fine sand	7.6	1.08	3	314
Welby silt loam	24	408	0-3	Silt loam	7.8	14.90	5	632
			3-6	"	7.7	13.20	3	579
			6-12	"	7.8	14.70	2	665
			12-24	"	7.9	23.80	1	535

Table 17. Description, location, pH, lime, phosphorus, and fluorine contents of Utah County soils, sampled in 1951 (Continued)

Soil type	Field soil number	Sector	Depth	Texture	pH	$CaCO_3$	P	F
			inches			per cent	p.p.m.	p.p.m.
Hardy loam	25	410	0-3	Silt loam	8.2	14.70	4	624
			3-6	"	8.5	14.90	3	567
			6-12	Loam	8.2	18.90	1	556
			12-24	V. F. S. L.	8.4	18.90	1	501
Provo silt loam	26	412	0-3	Silt loam	7.7	15.90	3	643
			3-6	"	7.7	14.20	1	579
			6-12	"	7.7	13.90	2	556
			12-24	Loam	7.7	15.40	3	590
McBeth fine sandy loam (poorly drained)	27	416	0-3	F. S. L.	8.0	10.50	13	665
			3-6	F. S. L.	8.0	11.50	36	524
			6-12	Loam	8.2	10.00	2	612
			12-24	F. S. L.	7.8	7.40	3	589
Welby sandy loam (imperfectly drained)	28	420	0-3	S. L.	7.9	2.27	4	370
			3-6	S. L.	8.2	2.80	5	316
			6-12	L. S.	8.0	2.57	2	306
			12-24	Medium sand	8.1	2.61	2	393
McBeth silt loam	29	424	0-3	Silt loam	7.7	14.20	14	556
			3-6	"	7.8	13.80	6	480
			6-12	"	7.9	12.60	2	535
			12-24	H. silt loam	7.8	10.50	1	567

Table 7. Description, location, pH, lime, phosphorus, and fluorine contents of Utah County soils, sampled in 1951 (Continued)

Soil type	Field soil number	Sector	Depth	Texture	pH	$CaCO_3$	P	F
			inches			per cent	p.p.m.	p.p.m.
Timpanogas fine sandy loam	30	428	0-3	F. S. L.	7.6	10.10	20	404
			3-6	F. S. L.	7.8	10.20	23	349
			6-12	F. S. L.	7.8	10.50	30	371
			12-24	L. S.	7.7	3.50	12	348
Welby clay loam	31	432	0-3	C. L.	7.5	17.70	7	786
			3-6	C. L.	7.6	17.90	23	754
			6-12	C. L.	7.6	11.30	4	710
			12-24	C. L.	7.6	14.40	1	590
Welby sandy loam	32	436	0-3	S. L.	7.7	6.40	2	415
			3-6	S. L.	7.7	6.40	3	425
			6-12	S. L.	7.8	6.15	1	425
			12-24	L. S.	7.9	11.10	2	393
Genola loam	33	640	0-3	Silt loam	7.9	19.40	18	960
			3-6	"	7.7	19.30	13	755
			6-12	"	7.6	19.10	3	796
			12-24	"	7.6	21.90	4	840
Genola fine sandy loam	34	632	0-3	F. S. L.	7.8	25.10	18	830
			3-6	F. S. L.	7.9	24.90	15	698
			6-12	Silt loam	8.0	24.70	17	764
			12-24	"	8.1	21.10	13	743

Table 7 Description, location, pH, lime, phosphorus, and fluorine contents of Utah County soils, sampled in 1951 (Continued)

Soil type	Field soil number	Sector	Depth	Texture	pH	$CaCO_3$	P	F
			inches			per cent	p.p.m.	p.p.m.
Hardy loam	35	602	0-3	Loam	7.7	48.60	5	1160
			3-6	"	7.7	50.00	16	1120
			6-12	"	7.8	48.50	9	1230
			12-24	"	7.7	52.80	3	1520
American Fork loam	36	603	0-3	Loam	7.8	7.22	21	415
			3-6	"	7.9	7.91	12	469
			6-12	"	7.8	7.17	8	502
			12-24	Light C. L.	7.7	14.60	2	436
Taylorsville loamy sand	37	604	0-3	L. S.	7.7	2.86	34	349
			3-6	L. S.	7.7	3.23	36	317
			6-12	S. L.	7.9	3.11	23	338
			12-24	L. S.	7.7	1.23	12	295
Payson fine sandy loam	38	806	0-3	F. S. L.	7.7	2.94	13	480
			3-6	F. S. L.	7.8	2.62	12	457
			6-12	F. S. L.	7.8	3.01	19	447
			12-24	Loam	7.9	3.15	2	512
McBeth heavy silt loam	39	808	0-3	H. Si L.	7.6	34.50	8	1100
			3-6	"	7.6	40.80	5	1049
			6-12	Si C. L.	7.7	46.50	1	1130
			12-24	Silt loam	7.9	48.50	2	875

Table 7 Description, location, pH, lime phosphorus, and fluorine contents of Utah County soils, sampled in 1951 (Concluded)

Soil type	Field soil number	Sector	Depth	Texture	pH	$CaCO_3$	P	F
			inches			per cent	p.p.m.	p.p.m.
McBeth silty clay loam	40	810	0-3	Si C. L.	7.5	42.80	71	862
			3-6	"	7.6	42.20	60	874
			6-12	"	7.7	43.00	50	840
			12-24	"	7.7	47.20	10	862
McBeth fine sandy loam	41	812	0-3	F. S. L.	7.6	12.50	11	742
			3-6	F. S. L.	7.8	12.50	16	720
			6-12	Loam	8.0	12.40	3	730
			12-24	F. S. L.	7.8	35.50	8	676
Logan silty clay loam	42	816	0-3	C. L.	7.6	52.20	3	1060
			3-6	C. L.	7.7	45.40	2	1080
			6-12	C. L.	7.8	50.9	2	993
			12-24	H. Si L.	7.8	52.9	2	970
Red Rock fine sandy loam	43	820	0-3	F. S. L.	7.7	7.07	49	731
			3-6	F. S. L.	7.8	7.51	8	743
			6-12	Loam	7.9	6.92	23	720
			12-24	F. S. L.	8.0	6.97	3	885
Taylorsville silt loam	44	824	0-3	Si L.	7.9	8.71	21	787
			3-6	"	7.8	8.63	5	810
			6-12	"	8.1	7.69	5	830
			12-24	C. L.	7.7	16.70	3	787
Red Rock loam	45	828	0-3	Si L.	7.4	2.45	10	731
			3-6	"	7.6	2.51	7	700
			6-12	"	7.6	3.90	2	743
			12-24	"	7.7	5.72	1	720

Table 8. Description, location, pH, lime, phosphorus, and fluorine contents of Cache County soils, sampled in 1951

Soil type	Soil profile number	Location	Depth	pH	$CaCO_3$	P	F
			inches		per cent	p.p.m.	p.p.m.
Millville loam	46	SE of buildings at Greenville farm, Logan, Utah	0-3	7.8	12.4	5	830
			3-6	7.8	12.4	3	896
			6-12	7.8	12.5	3	906
			12-24	7.9	25.3	1	862
Trenton clay	47	(Solonetz structure) One mile west of airport on Benson road	0-3	8.1	25.3	10	666
			3-6	8.1	8.9	28	590
			6-12	8.4	10.7	18	744
			12-24	8.8	12.1	5	734
Benson fine sandy loam	48	1320' SW of NE corner of Sec. 14 T12N R1W	0-3	7.8	2.0	4	372
			3-6	7.9	1.8	13	392
			6-12	8.0	1.5	5	449
			12-24	7.8	-	5	514
Trenton silty clay loam	49	NE corner of Sec. 17 T12N R1W in dry land wheat field	0-3	7.8	2.3	17	753
			3-6	7.9	2.7	18	764
			6-12	8.1	2.4	12	785
			12-24	8.3	12.2	1	940
Salt Lake silty clay loam	50	One-fourth mile east of Clarkston. South side of road	0-3	7.4	5.5	73	590
			3-6	7.5	4.9	42	611
			6-12	7.3	3.9	35	687
			12-24	7.5	3.8	15	800

Table 8. Description, location, pH, lime, phosphorus, and fluorine contents of Cache County soils, sampled in 1951 (concluded)

Soil type	Soil profile number	Location	Depth	pH	$CaCO_3$	P	F
			inches		per cent	p.p.m.	p.p.m.
Mendon silt loam	51	1500' west of Newton	0-3	7.4	3.3	10	754
			3-6	7.4	3.1	7	785
			6-12	7.3	2.8	5	765
			12-24	7.4	3.0	0	850
Mendon clay loam	52	One-fourth mile north of the S/4 corner Sec. 29 T12N R1W	0-3	8.0	6.3	2	730
			3-6	8.0	7.0	1	785
			6-12	8.0	8.1	1	765
			12-24	8.0	9.0	2	810
Mendon loam	53	1.2 miles SE of Mendon on Mendon-Wellsville road	0-3	7.1	1.9	30	535
			3-6	7.1	1.5	42	545
			6-12	7.1	1.4	28	555
			12-24	7.1	1.3	12	600
Hyrum gravelly loam	54	1000' NE of W/4 corner Sec. 14 T10N R1W	0-3	6.7	1.8	2	305
			3-6	6.7	1.8	0	316
			6-12	6.7	1.2	1	305
			12-24	6.8	1.5	0	327
Sterling loam	55	On Hyrum-Paradise road 1320' north of SW corner Sec. 3 T10N R1E	0-3	7.4	1.9	13	447
			3-6	7.4	1.9	38	500
			6-12	7.3	1.8	23	480
			12-24	7.5	6.6	23	590

Table 9. Description, location, pH, lime, phosphorus, and fluorine content of Utah County soils sampled in 1938. (Analyses made in 1951)

Field profile number	Soil type	Sector	Depth	pH	$CaCO_3$	P	F
			inches		per cent	p.p.m.	p.p.m.
026	Genola loamy sand	640	0-4	8.2	21.2	15	556
			4-12	7.8	25.8	6	600
			13-20	7.5	37.6	3	885
			20-26	7.7	23.4	3	1120
			26-72	7.7	32.2	2	1060
048	Genola loam	544	0-7	7.8	23.3	6	787
			7-13	8.1	20.1	3	1020
			13-22	7.9	31.0	2	1023
47L	Hardy loamy sand	536	0-12	8.0	54.7	0	895
			12-21	7.9	59.4	9	1015
9	Red Rock loamy sand	420	0-2	7.5	22.4	70	500
			2-26	7.6	28.7	1	665
			26-72	8.1	24.1	0	350
240	Red Rock loam	428	0-5	8.0	20.0	0	556
			5-10	7.7	17.6	9	480
			10-32	8.0	24.1	6	480
13H	Welby loam	432	0-8	7.7	18.7	2	327
			8-17	7.7	11.9	0	600
			17-23	7.8	14.7	0	580
			23-62	7.9	35.6	0	665
			62-72	8.3	22.4	0	436

Table 9. Description, location, pH, lime, phosphorus, and fluorine content of Utah County soils sampled in 1938. (Analyses made in 1951) (Continued)

Field profile number	Soil type	Sector	Depth	pH	$CaCO_3$	P	F
			inches		per cent	p.p.m.	p.p.m.
130	Santaquin loamy sand	428	0-16	7.9	0.7	3	207
			16-44	8.0	0.4	3	197
6	Leland silt loam	828	0-6	8.0	2.6	33	643
			6-17	8.3	6.4	21	712
			17-25	8.6	47.1	13	785
37	Red Rock clay loam (gritty)	820	0-10	8.1	6.9	2	885
			10-21	7.8	7.5	1	815
			21-46	6.8	2.9	0	860
			46-72	8.2	1.2	0	382
2	Orem loamy sand	403	0-9	8.0	0.4	17	227
			9-21	7.8	0.6	6	160
			21-72	8.8	2.2	8	205
16L	Welby loamy sand	103	0-11	7.8	1.5	8	240
			11-23	7.7	0.7	6	286
			23-38	7.9	0.6	6	262
			38-43	8.0	15.9	3	272
			43-60	8.3	5.4	3	240
42	Welby silt loam	916	0-8	7.6	8.6	2	730
			8-15	7.6	16.8	1	730
			15-30	7.8	31.7	0	632

Table 9. Description, location, pH, lime, phosphorus, and fluorine content of Utah County soils sampled in 1938. (Analyses made in 1951) (Continued)

Field profile number	Soil type	Sector	Depth	pH	$CaCO_3$	P	F
			inches		per cent	p.p.m.	p.p.m.
44	Taylorsville silt clay loam	912	0-9	7.7	15.6	5	664
			9-26	7.8	12.7	0	830
			26-35	7.9	30.3	0	765
			35-60	8.0	36.0	0	1000
	Battle Creek silty clay loam	924	0-4	7.6	5.0	2	785
			4-9	7.6	9.0	0	850
			9-16	7.7	30.4	0	752
			16-25	7.8	41.2	1	775
49	Hardy clay loam	408	0-6	8.5	14.3	17	470
			6-18	8.1	27.9	4	590
			18-29	-	-	-	-
			29-60	8.2	45.6	2	490
14X	Welby sandy loam	408	0-13	7.8	7.6	4	447
			13-21	8.0	18.4	1	404
			21-31	8.3	24.7	1	360
			31-72	8.3	20.8	1	567
14	Payson sandy loam	806	0-10	8.0	2.5	22	447
			10-16	8.3	1.3	18	371
			16-21	8.0	3.5	46	458
			21-33	8.3	25.0	24	447
			33-72	8.9	22.0	2	700

Table 9. Description, location, pH, lime, phosphorus, and fluorine content of Utah County soils sampled in 1938. (Analyses made in 1951) (Continued)

Field profile number	Soil type	Sector	Depth	pH	$CaCO_3$	P	F
			inches		per cent	p.p.m.	p.p.m.
13	Timpanogas fine sandy loam	428	0-9	7.6	2.9	5	425
			9-14	7.4	1.6	3	393
			14-20	7.6	1.0	5	316
			20-30	7.6	1.5	5	404
			30-50	7.8	14.8	5	325
55X	Benjamin silty clay	532	0-5	7.7	23.1	32	1025
			5-10	7.9	24.6	2	1385
			10-21	7.9	28.4	1	895
35	Ironton clay loam	536	0-5	8.3	38.8	11	730
			5-20	8.0	46.1	1	644
			20-28	-	-	-	-
			28-43	8.0	52.3	0	1025
15X	McBeth silty clay loam	424	0-11	8.3	10.6	13	250
35X	McBeth loam	424	0-9	7.6	7.3	26	468
			9-13	7.9	11.6	0	468
			13-33	7.8	10.1	0	273
			33-72	7.8	8.8	0	295
440	Logan silt loam	524	0-5	7.8	23.6	0	916
			5-22	7.9	14.4	0	1050

Table 5. Description, location, pH, lime, phosphorus, and fluorine content of Utah County soils sampled in 1938. (Analyses made in 1951) (Concluded)

Field profile number	Soil type	Sector	Depth	pH	$CaCO_3$	P	F
			inches		per cent	p.p.m.	p.p.m.
43	Pleasant Grove loam	440	0-9	6.9	0.6	9	382
			9-17	6.9	11.7	0	404
			17-30	6.9	10.9	0	730
02	Welby fine sandy loam	436	0-8	7.7	2.3	23	426
			8-27	7.9	5.4	13	382
4	Taylorsville fine sandy loam	201	0-16	8.0	2.0	14	393
			16-20	-	-	-	-
			20-28	8.1	25.6	15	250
			28-72	8.0	31.0	2	840
450	Logan silt loam	008	0-6	7.7	51.7	38	700
			6-22	-	-	-	-
			22-72	7.8	59.8	0	720
11L	McBeth silty clay loam	416	0-5	7.5	35.2	28	700
			5-12	7.6	33.4	4	960
4X	Welby fine sandy loam	502	0-9	8.0	5.1	9	380
013	Bingham gravelly loam	328	0-11	7.8	4.8	8	610
23G	Welby fine sandy loam	544	0-2	7.8	4.1	15	620
			2-22	7.9	5.4	2	620
			22-38	8.0	6.3	1	645

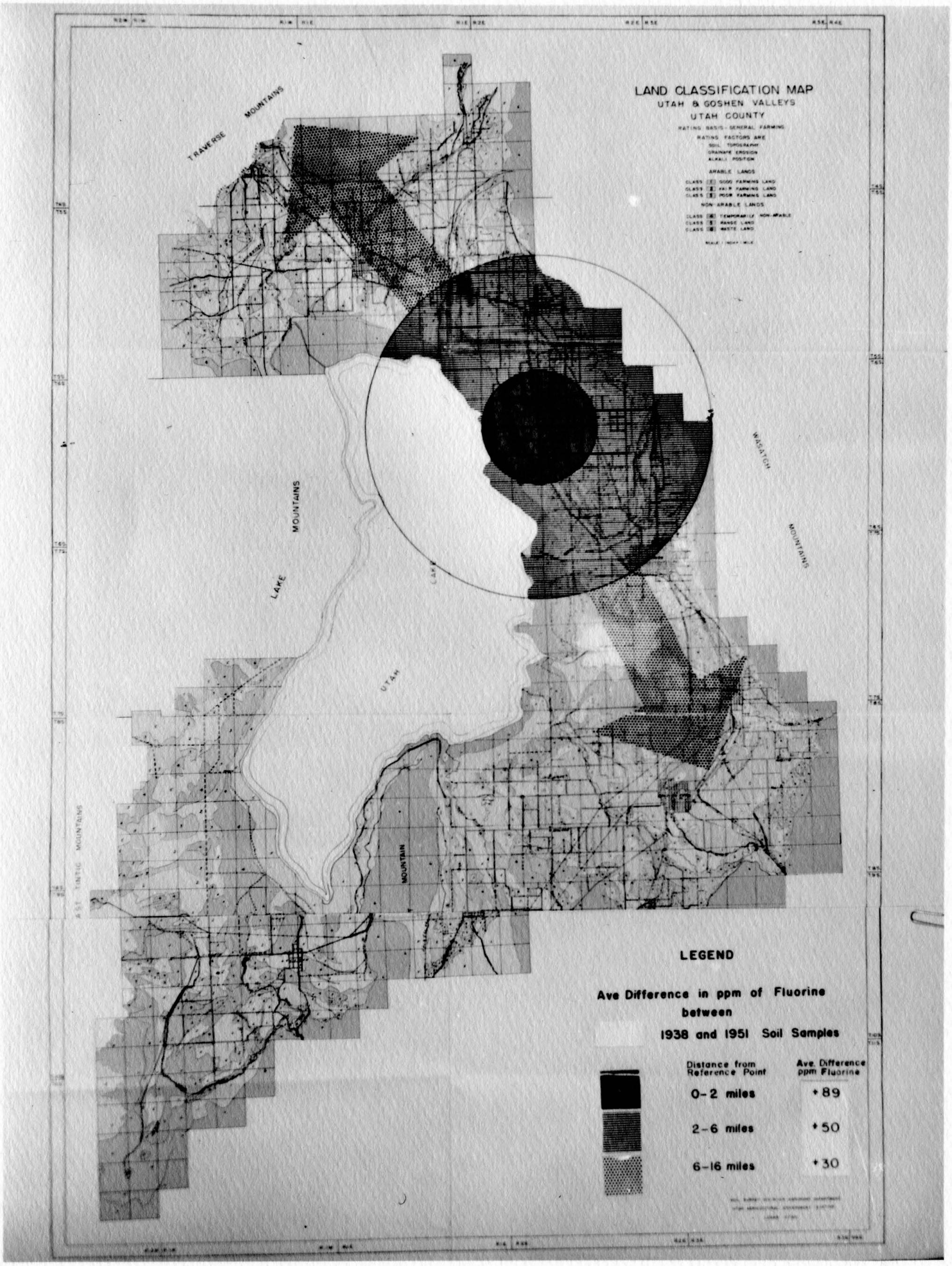

Figure 4. Average differences in parts per million fluorine between 1938 and 1951 soil profiles, in three areas progressively distant from the reference point located at the southeast corner of Section 8, Township 6 North, Range 2 East.

in the profile the fluorine content increases, but there are exceptions. These exceptions can possibly be explained in differences in mode of deposition of fluorine carrying constituents in the soil and differences in natural occurring fluorine from the original parent material. Fluorine content bears no relationship to the soluble phosphorus content of the soil. Sandy soils have less fluorine than heavier textured soils.

In table 8, with the exception of the Trenton clay, there is usually an increase of fluorine content with the depth of profile, with the lowest fluorine content being in the surface three inches. It should be noted, however, that only ten profiles were sampled in Cache County. In 32 out of 40 profiles sampled in Utah County in 1951 there was an average increase of 64 parts per million of fluorine in the first three inches over the 3 to 6 inch depth. In normal profiles free from atmospheric pollution from industrial sources, there is a gradual increase of fluorine content with depth in the profile from the surface. In calcareous western soils this would be expected to occur inasmuch as leaching of soluble fluorides would be carried downward through the profile.

In order to appraise a relative measure of the concentric distribution of fluorine in the Utah County soils at successively greater intervals from the reference point at the southeast corner of Section 8, T6S, R2E, the following calculations were made. The fluorine content was averaged for the 0 to 24 inch depths for each profile for each of the three respective areas of 0 to 2 miles, 2 to 6 miles, and 6 to 16 miles from the above point. These averages were calculated for 1951 for the profile portion of 0 to 24 inches. For the 1938 samples, the average was calculated for the nearest profile intervals to 0 to 24 inches. This was necessary inasmuch as the soil samples for 1938 were taken at odd intervals in profile sampling, but the differences are only slight in most cases. In table 10 are the results of these average comparisons for the three areas. The differences are expressed in average differences in parts per million fluorine for each of three areas, progressively distant from the above reference point.

Table 10. Average differences of profile samples (0-24") sampled in 1938 and 1951 in Utah County

Area	Distance from reference point	Average fluorine content 0-24" 1938 samples	Average fluorine content 0-24" 1951 samples	Average difference greater than 1938 samples
	miles	p.p.m.	p.p.m.	p.p.m.
1	0-2	307	396	+ 89
2	2-6	565	615	+ 50
3	6-16	634	664	+ 30

The results in the above table indicate a slight increase in fluorine content with increased proximity to the above reference point. Conversely, in succeedingly farther intervals from the reference point, the average increase in fluorine content of the soils is less. These data must be interpreted with caution, however, because of undoubtedly interacting differences of fluorine contents of soil parent materials and differences in patterns of distribution of fluorine atmospheric contaminants. Changes in direction and velocity of wind and time of directional air movement will account over a long period of time for a rather complex distribution pattern of fluorine in soil from the atmosphere.

GREENHOUSE EXPERIMENTS ON FLUORINE UPTAKE

Uptake studies by turnips grown on soils treated with NaF, experiments 1 and 2

The first experiment on fluorine uptake employed four different soils, each treated with 0, 200, 400, 800, and 1600 p.p.m. fluorine added as NaF. Table 11 gives the chemical and physical characteristics of all the soil types used in this and the succeeding experiments; and table 12 tabulates location, soil type, and naturally occurring fluorine content of all soils used. Soil samples 1 and 3 were non-calcareous soils from different soil series. Soil samples 2 and 4 were calcareous soils, each from different series. Soil 1 is an Orem loamy sand, and Soil sample 2 is from Ironton loam. These are both soils from Utah County; the Orem soil, non-calcareous, is located 800 feet south of the center of Section 9, T6S, R2E; and the Ironton soil, highly calcareous, is located 500 feet west of the northeast corner of Section 21, T6S, R2E. Soil sample 3, a non-calcareous soil of moderate clay-colloid content, is from a Cache County soil type, designated Mendon silt loam. It is located one-fourth mile west of Newton, Cache County, Utah. Soil 4, a moderately calcareous soil, designated Petersboro silt loam[1] (although not typical because of the high phosphorus content) was taken from the U. S. A. C. alfalfa fertilizer experimental plots at Petersboro on the west side of Cache County.

Each air-dry soil was put through a 1 cm. screen, thoroughly mixed,

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[1] This soil was originally mapped in 1913 as of the Mendon series, but it is not typically Mendon because it is calcareous throughout the profile. Therefore this local name is applied.

Table 11. Chemical analyses of soils used in greenhouse experiments

Observations	Soil Type				
	Orem loamy sand (Utah County) non calcareous	Ironton loam (Utah County) highly calcareous	Mendon silt loam (Cache County) non calcareous	Petersboro silt loam (Cache County) calcareous	Taylorsville fine sandy loam (Utah County) calcareous
Soil number	1	2	3	4	5
Depth of profile used	0-6"	0-12"	0-7"	0-6"	0-12"
pH - paste	8.0	8.5	7.4	7.4	7.8
pH - 1:5	8.7	8.9	8.2	7.9	8.3
Total soluble salts per cent	.02	.24	.05	.11	.05
Organic matter per cent	1.2	11.3	4.0	5.5	4.5
$CaCO_3$ (lime) per cent	0.36	52.0	0.30	10.5	21.0
Avail. PO_4 p.p.m.	14	11	12	56	17
Avail. K p.p.m.	21	275	121	270	160
Per cent clay colloid 0.002 mm.	11	20	24	18	25
Per cent moisture (air dry)	0.82	3.70	4.55	3.51	6.39
$ECx10^3$ saturated extract conductance	-	6.0	-	-	1.6
$ECx10^3$ 1:1 extract conductance	0.5	3.2	0.9	1.1	0.6
Exchangeable Na, m.e./100 gms.	0.1	3.5	1.7	-	0.8
Exchangeable sodium per cent	0.30	10.0	5.8	-	4.0
Base Exchange Capacity	2.88	34.80	29.21	14.75	6.96
ppm F	248	874	810.	368	490.

Table 12. Notes on soils used in greenhouse experiments

Soil type	Depth	Location	Naturally occurring F before greenhouse treatments
			p.p.m.
Orem loamy sand (non-calcareous)	0-6"	Utah County. In apricot orchard. 800' south of the center of Sec. 9, T6S. R2E.	248
Ironton loam (highly calcareous)	0-12"	Utah County. Lewis Clegg farm. 500' west of the northeast corner of Sec. 21, T6S. R2E.	874
Mendon silt loam (non-calcareous)	0-7"	Cache County, Utah. 1/4 mile west of Newton-Clarkston highway.	810
Petersboro silt loam (calcareous)	0-6"	Cache County, Utah. U.S.A.C. alfalfa fertilizer plots, west side of valley.	368
Taylorsville fine sandy loam (calcareous)	0-12"	Utah County. Lewis Clegg farm. In field 100' south of hay barn.	490

and weighed into 2-gallon, glazed pots in the amount of 6 kg. per pot, oven dry basis. The five treatments were replicated four times. The NaF was mixed with the dry soil in a Patterson-Kelley twin-shell blender so that the added NaF was mixed uniformly throughout the soil. The soils were then moistened and left 48 hours for the added NaF to come to equilibrium with the soil chemical constituents. When the soil was sufficiently dried, 16-20-0 ammonium phosphate fertilizer was added to all pots at the rate of 600 lbs. per acre. This fertilizer was stirred into the soil in the top 3-4 inches, and about 25 White Globe turnip seeds were planted. The first planting was made on August 7, 1951. Because of a poor stand resulting from damping off of the seedlings, they were replanted August 20, 1951. At the same time, extra seeds were planted in a greenhouse flat to grow extra plants for transplanting. On September 4, 15 plants were transplanted into control pot #16, replicate 1, that had been missed in planting.

The following notes were made on the growth of the turnip crop on September 13, just prior to thinning each pot to 10 plants each:

Soil #1

(a) On the 0, 200, and 400 p.p.m. F treatments, the growth and stand were good.

(b) 800 p.p.m. treatment - growth was retarded, but the stand was good.

(c) 1600 p.p.m. treatment - all but one or two spindly plants had died. The surface of the soil had already a black crust typical of black alkali.

Soil #2

(a) Stand was good for nearly all treatments. Growth was uniform except that growth of the turnip seedlings was slightly retarded for the 800 p.p.m. and 1600 p.p.m. treatments.

Soil #3

(a) Plants were quite uniform for all treatments except the 1600 p.p.m., which showed slightly retarded growth for the turnip seedlings.

Soil #4

(a) Plants were quite uniform with the exception of the 800 and 1600 p.p.m. treatments in which turnip seedlings seemed slightly retarded.

The turnip seedlings in all the 1600 p.p.m. F treatment pots had died from toxicity to the NaF on Soil 1, so on September 15 these were all replanted with transplants of turnip seedlings. These transplanted seedlings, too, succumbed to the lethal effects of the excessive NaF within a week in the 1600 p.p.m. treatments of Soil 1.

The turnip crop was two months and five days old at the time of harvest on October 26 and 27, 1951. The top growth was lush and green and some small roots were formed.

The turnips were pulled and the tops cut off about one-half inch above the tuber. The tops were weighed and then washed in tap water containing Vel, rinsed in tap water and finally rinsed in distilled water. The leaves were allowed to dry on paper towels. Drying was facilitated by use of an electric fan. As soon as the leaves were dry they were cut up (whole leaf and petiole) into 1/2" to 1" pieces and weighed into a pint plastic container containing a 2-gram portion of CaO. This was to neutralize any fluorine that might be liberated from the cellular or intercellular tissues at any time after the maceration of the tissue by cutting. At the same time a similar sample was taken to determine the percentage of moisture. Duplicate samples were taken of plants from each pot for fluorine analysis. The samples were then stored in cold storage lockers until the fluorine analyses were run. Yield data were also calculated.

Experiment 2 was similar to experiment 1, except that Na_2SiF_6 was used for soil treatment instead of NaF. The soils used this time were Soil 1, the Orem loamy sand, and Soil 4, the Petersboro silt loam. After Na_2SiF_6 was mixed into the soil in each pot, they were watered and left as in experiment 1 for 48 hours for the sodium fluosilicate to come to equilibrium with the chemical constituents in each soil. The fertilizer was added in the amount and by the same method as before. About 25 White Globe turnip seeds were planted in each pot on September 11, 1951. Two weeks later the seedlings were thinned to 10 plants per pot. Stands at thinning time were much better than with the NaF on the same two soils, and the problem of damping off of seedlings was less critical. Seedlings, although slightly retarded in growth, grew better on the 800 and 1600 p.p.m. treatments for Soil 1 than where NaF was used as the fluorine source. However, stand was reduced to three plants in two pots at the 1600 p.p.m. treatment. After getting past the seedling stage, the turnip plants grew vigorously until they were harvested on November 17, 1951, in the same manner as before. Where there was sufficient plant sample, duplicate samples were harvested from each pot. The cut-up green plant material, after washing, was dried and weighed as before into sealed plastic containers containing 2 grams of fluorine-free CaO. These turnip plants were about two months and seven days old at the time of harvest, and a few small enlarged roots had set on some, but not all, plants. Some roots were harvested and analyzed. Amounts of fluorine in vegetative and root portions of the turnip plants were compared. There was about 1.9 times as much fluorine in tops than in the roots. Yield data were also calculated.

The uptake studies on the turnips were preliminary to the uptake studies with Ranger alfalfa.

Results

The addition of fluorine from the NaF and Na_2SiF_6 sources to each of the soils in this and succeeding experiments represents increments that might be added artificially from the atmosphere by industrial operations over a long period of time. The highest amount added, 1600 p.p.m., is an amount that may be purely theoretical and not possible to reach over many years of accumulation in the soil. Nevertheless it must be borne in mind that the addition of fluorine would increase in the soils surrounding industrial operations that evolve fluorine as an atmospheric contaminant unless steps are taken to absorb the fluorine bearing gases. These uptake studies have been pursued with the thought of the extent to which plants would be able to absorb fluorine from soil (exclusive of contamination by fluorine of plant tissue from the atmosphere) in which fluorine levels would be progressively increased. The above chemicals have been used only as a source of fluorine, and not because there is no good evidence that fluorine from certain industrial operations released fluorine in this form in sublimed dusts from the stacks. More likely the form is that of droplets of HF and H_2SiF_6.

Yield values for the turnip petioles and leaves from the NaF and Na_2SiF_6 soil treatments are tabulated in table 13. When yield values are compared with uptake values in table 14, they are found to decrease as the uptake values increase. The yields were affected to the greatest extent on the Orem loamy sand. In fact, the high level treatment of 1600 p.p.m. was lethal to all the turnip plants. The yield was reduced

Table 13. Summary of yields of turnip leaves and petioles grown on four soils (1, 2, 3 and 4) treated with five rates of NaF, experiment 1; and yields of turnip leaves and petioles grown on two soils (1 and 4) treated with five rates of Na_2SiF_6, experiment 2

(Average dry plant weights in grams per pot)*

Date of harvest	Soil number	Soil type	0	200	400	800	1600	Mean yield for each soil, all treatments
			Fluorine added to soil (p.p.m. as NaF)					
10/26/51	1	Orem loamy sand	11.4	11.8	8.1	2.4	0.0	6.7
10/26/51	2	Ironton loam	19.2	18.0	12.4	13.6	7.8	10.4
10/26/51	3	Mendon silt loam	17.6	14.2	12.7	13.4	11.8	10.5
10/26/51	4	Petersboro silt loam	27.1	23.0	19.2	15.8	13.9	15.8 ? ?
			Fluorine added to soil (p.p.m. as Na_2SiF_6)					
11/17/51	1	Orem loamy sand	5.5	6.9	8.5	8.8	2.9	6.5
11/17/51	4	Petersboro silt loam	19.7	12.2	24.8	12.5	12.1	16.3

*Mean of four replications for each treatment for each soil

Table 14. Summary of average fluorine content (parts per million*) of a crop of White Globe turnip leaves and petioles grown on four soils (1, 2, 3 and 4) treated with five rates of NaF; and average fluorine content of White Globe turnip leaves and petioles grown on two soils (1 and 4) treated with five rates of Na_2SiF_6

Date of harvest	Soil number	Soil type	0	200	400	800	1600
			Fluorine added to soil (p.p.m. as NaF)				
10/26/51	1	Orem loamy sand	27.5	39.5	172.3	197.5	lethal
10/26/51	2	Ironton loam	14.5	28.2	27.3	37.0	283.5
10/26/51	3	Mendon silt loam	25.0	19.5	37.0	70.2	132.0
10/26/51	4	Petersboro silt loam	14.3	29.8	28.5	42.0	61.5
		Treatment means*	17.9	25.8	30.9	49.7	159.0
			Fluorine added to soil (p.p.m. as Na_2SiF_6)				
11/17/51	1	Orem loamy sand	43.8	56.5	75.0	75.5	234.0
11/17/51	4	Petersboro silt loam	43.3	66.2	39.2	95.2	95.5
		Treatment means*	43.5	61.3	57.1	85.3	164.7

*Mean of four replications for each treatment for each soil on the 800 p.p.m. treatment with NaF to an average of 2.4 grams (dry weight). Although average yield was lower on the Na_2SiF_6 treated Orem soil, growth occurred on every treatment. Yields were greater on the calcareous than on the non-calcareous soils. Among non-calcareous soils, Yields were much higher on the Mendon silt loam for all treatments than on the Orem loamy sand. The contrast is greatest at the highest treatment rates. ~~Both soils are non-calcareous~~. The rate of decline in yields from lowest to highest treatments was less on the calcareous than on the non-calcareous soils. In comparing the yields from the two calcareous soils, the Petersboro soil maintained greater yields for all fluorine treatments than did the Ironton loam.

The lowest fluorine content was in the turnip tops grown on untreated Ironton loam and untreated Petersboro silt loam, 14.5 and 14.3 p.p.m. respectively. However, for the high treatment the Ironton loam produced dry weight foliage of 283.5 p.p.m. compared to the 61.5 p.p.m. foliage produced from the Petersboro soil. The fluorine content in the foliage from the control pots of the non-calcareous soils is greater by 11-13 p.p.m. The highest treatment, lethal to the turnip plants on the Orem loamy sand, produced vegetation from the Mendon silt loam of 132 p.p.m. The Mendon silt loam induced less fluorine content at the high level than did the Ironton loam. The plants growing on the Petersboro soil had the lowest content of fluorine for all treatments, the highest value being 61.5 p.p.m. (see table 14).

For some unexplainable reason, the fluorine contents induced from the soils for the Na_2SiF_6 treatments from the Orem loamy sand and the Petersboro silt loam were nearly three times that of the same soils with NaF treatments. The fluorine contents of the turnip tops for the highest level treatment (1600 p.p.m. F) for the Orem loamy sand exceeded the fluorine content of the turnip tops grown on the Petersboro soil by two and a half times.

It is advisable to examine the difference in uptake values for the two calcareous soils, Ironton loam and Petersboro silt loam. If per cent of $CaCO_3$ is any deterrent to uptake of fluorine by plants in proportion to its presence in the soil, the Ironton loam would take up less fluorine at the highest treatment level, but we find it takes up nearly five times as much. An examination of table 11 reveals that the Ironton soil has five times as much $CaCO_3$ as the Petersboro. In the section on discussion we will see why content of $CaCO_3$ in the soil is not necessarily a factor for repressing uptake of fluorine by plants. The differences in fluorine content of the turnip tops from the two non-calcareous soils is also of significance. Since both soils are non-calcareous soils (only 0.3 per cent $CaCO_3$) we would expect fluorine contents of the turnip tops to be nearly the same. However, table 11 shows differences that explain the apparent ability of the turnip roots to extract less fluorine from Mendon silt loam than from Orem loamy sand. The Orem loamy sand has less than half the colloidal capacity to absorb fluorine and fix it against uptake absorption by plant roots. The Mendon silt loam has a higher base exchange capacity than the Petersboro soil. The importance of both lime and colloidal content of the greenhouse soils is important in explaining the comparison of growth made in figures 5 to 10. Figure 5 indicates that Orem loamy sand (Soil 1) has less ability than the other soils to fix fluorine. Growth drops off sharply in treatment four and to no growth in treatment five. In comparing the growth of turnip tops on the non-calcareous Mendon silt loam in figure 7, it will be noted that the growth is not much less from the lower to the higher treatments with NaF. The best growth through all five treatments is with NaF,

Figure 5. White Globe turnips grown on Orem loamy sand treated with 0, 200, 400, 800, and 1600 p.p.m. of fluorine added as NaF

Figure 6. White Globe turnips grown on Ironton loam treated with 0, 200, 400, 800, and 1600 p.p.m. of fluorine added as NaF

Figure 7. White Globe turnips grown on Mendon silt loam treated with 0, 200 400, 800, and 1600 p.p.m. fluorine added as NaF

Figure 8. White Globe turnips grown on Petersboro silt loam treated with 0, 200, 400, 800, and 1600 p.p.m. fluorine added as NaF

Figure 9. White Globe turnips grown on Orem loamy sand treated with 0, 200, 400, 800, and 1600 p.p.m. fluorine added as Na_2SiF_6

Figure 10. White Globe turnips grown on Petersboro silt loam treated with 0, 200, 400, 800, and 1600 p.p.m. fluorine added as Na_2SiF_6

illustrated in figure 8 for the Petersboro silt loam. The growth on the other calcareous soil, Ironton loam, illustrated in figure 6, is also fairly uniform for all five treatments, but the growth of the turnip tops is not as rank nor luxuriant as that obtained on the Petersboro silt loam.

The differences in growth obtained from Orem loamy sand and Petersboro silt loam treated with Na_2SiF_6 are illustrated in figures 9 and 10. Nearly uniform growth is evidenced by the turnips grown on the Petersboro soil, but the turnips grown on the Orem loamy sand show a sharp decline in growth on treatment 4 and only the growth of two or three spindly plants on treatment 5.

Table 15 presents the analysis of variance for fluorine contents of turnip tops grown on Ironton loam, Mendon silt loam, and Petersboro silt loam soils treated with NaF. Although the level of uptake of fluorine is significantly greater for the Orem loamy sand, it is not included in the analysis because there were no harvested crops for treatment 5; there were one or two missing values for the 800 p.p.m. soil treatment; and because of inconsistently high uptake values. The breakdown of treatments between soils is shown to be significant and the uptake of fluorine relative to chemical treatment levels is significant. The interaction between soils and rates of chemical treatments is highly significant for uptake of fluorine with NaF as the source of fluorine.

Much the same points are borne out in the statistical analysis in table 16 for fluorine contents of turnip tops grown on Orem loamy sand and Petersboro silt loam soils treated with Na_2SiF_6. Differences between soils are significant. The fluorine content changes between chemical treatment levels are highly significant. Interaction of

Table 15. Analysis of variance of fluorine content of White Globe turnips grown on three soils (2, 3 and 4) treated with five rates of NaF. Experiment 1

Source of variation	Degree of freedom		Mean squares
Replications	3		5,377
Treatments	14		19,180**
Between soils		2	9,210*
Between chemical treatments		4	40,604*
Soils x treatments		8	10,960**
Error	42		2,025
Total	59		

** Significant beyond the 1 per cent level

* Significant at the 5 per cent level

Table 16. Analysis of variance of the fluorine content of White Globe turnips grown on three soils (2, 3 and 4) treated with five rates of NaF. Experiment 2

Source of variation	Degrees of freedom		Mean squares
Replications	3		4,371
Treatments	9		13,088**
Between soils		1	9,263*
Between chemical treatments		4	18,975**
Soils x treatments		5	6,526*
Error	27		2,058
Total	39		

** Significant beyond the 1 per cent level
* Significant at the 5 per cent level

soils x treatment rates is also significant. This first power interaction in the cases of both NaF and Na_2SiF_6 treatments indicates that the treatment levels react differently with the different soils. This is what we would expect with differing amounts of $CaCO_3$ and colloidal content in each soil to neutralize the effects of the added fluorine.

Uptake studies by first crop Ranger alfalfa, experiment 3a

On November 27, 1951, ten days after all the turnips were harvested, all the soils used in experiments 1 and 2 were planted to Ranger alfalfa. To assure a balanced nutrition in this and succeeding crops, fertilizer was added to all soils at the rate of 300 pounds per acre. The pots were all randomized in four blocks as before. Germination was better in most cases than with the turnips. However, the high level of 1600 p.p.m. fluorine with the NaF as the source was also lethal for Soil 1, Orem loamy sand. Small alfalfa seedlings were transplanted from a flat, but they would not take root and develop in this soil at this high-level treatment.

Moisture for the alfalfa, as for the turnips, was maintained as near as possible to the field optimum for each soil. Soil 1 had a low moisture capacity and required more frequent irrigation. Soil 2, containing a high amount of organic matter, had a high water holding capacity and held water moderately well for crop use. Soil 3 had an even higher water holding capacity and dried out comparatively slowly. Soil 4 stored water well and did not dry out rapidly. The soils were watered by "feel"; that is, the relative degree of dryness or moistness of the soil was felt with the fingers before water was applied. Then enough was applied only to bring the moisture up to an optimum growing level. Sufficient moisture was supplied so that lack of moisture at no time in the growing of the crop would be a limiting factor. The water used was Logan City water. This water is comparatively fluorine free, averaging only about 0.15 p.p.m.

The first crop of alfalfa was harvested March 15, 1952, at about the one-half bloom stage. The entire alfalfa plants were harvested from each pot, and the green weights taken.

Samples of the Ranger alfalfa were washed, dried, cut up, and prepared for storage in air-tight plastic containers similar to the procedure used for turnip tops in experiment 1. Fluorine analysis was made of whole alfalfa plants.

Uptake studies on the second crop of Ranger alfalfa, experiment 3b

The first crop of alfalfa was grown during the winter months when the daylight hours were short and the intensity of sunlight during the day was less than during a normal growing period, so a second crop was started after the first harvest was clipped off. Pots were put in randomized blocks as before. No fertilizer nor additional soluble fluorides were added. The stage of maturity at harvest was between 1/10 and 1/2 bloom stage. The second crop of alfalfa was harvested May 10, 1952. Procedures were the same as for the first crop.

Uptake studies from first crop Ranger alfalfa from two soils with Na_2SiF_6 as fluorine source, experiment 4a

Additional information was sought on uptake of Na_2SiF_6 on a calcareous and non-calcareous soil, so pots were prepared as before with 6 kg. (oven dry basis) of soil weighed into each 2-gallon glazed pot. Each treatment, 0, 200, 400, 800, and 1600 p.p.m. of F with Na_2SiF_6, was replicated four times and the pots watered and planted as before. Supplemental fertilizer (16-20-0) was added at the rate of 300 pounds per acre. Soils used were Soil 3, the non-calcareous Mendon silt loam, and Soil 5, a calcareous soil not previously used. In the late fall of

1951, more Soil 2 was needed for the greenhouse experiments, so an attempt was made to secure more from the field. However, the snow cover prevented securing the same soil, so the soil this time was obtained 100 yards east of the original sampling. The soil is of a different series, Taylorsville, with slightly different texture--less organic matter, less sodium, and nearly one-half less field fluorine content. Reference is made again to table 11 for the chemical and physical characteristics of the soils used in the greenhouse experiments.

Ranger alfalfa was planted January 15, 1952. The stand was good in almost all pots, but was slightly retarded with the 800 p.p.m. and 1600 p.p.m. fluorine levels on both sides.

Plants were harvested April 12, 1952, at one-half full bloom stage.

Uptake studies from second crop Ranger alfalfa from two soils with Na_2SiF_6 as fluorine source, experiment 4b

After the first crop was harvested in 4a above, the alfalfa was allowed to grow again and the second crop was harvested May 31, 1952, at a stage of maturity between 1/10 and 1/2 bloom.

Samples were duplicated the same as in the first crop, and washing, drying, and storage techniques were the same except that lime was not added to the sample until fluorine analysis was begun after taking the samples from storage. Chemical analysis for fluorine was made on the plant tissue after a period of storage in a freezing compartment.

Uptake studies of third crop Ranger alfalfa from composited replicates covering all treatments from all soils in experiments 4a and 4b, experiment 5

After the harvest of the second crop alfalfa in 4a, April 12, 1952, the alfalfa was kept growing by watering regularly and the immature alfalfa cut off, until the second crop of alfalfa in 4 b was harvested May 31, 1952. At this time the pots of both 4a and 4b experiments were randomized into four replicates (blocks) of five treatments, including both NaF and Na_2SiF_6 fluorine sources, and all five soils that had been used in all previous experiments. This made 160 pots in all, randomized in four replicates of 40 pots each. The soils were watered and the alfalfa was allowed to mature into a third crop. On July 10, 1952, this crop was harvested and prepared for fluorine analysis. Total yield dry weight basis was calculated per replicate. However, statistical analysis was not applied on this third crop because replicates of each treatment for each soil were harvested together and one fluorine analysis was run for each composite sample of whole alfalfa.

The balance of the summer the alfalfa was kept cut off and the pots watered to keep the alfalfa growing.

Uptake study of fourth crop Ranger alfalfa from all treatments, both chemicals (NaF and Na_2SiF_6) and all soils used in previous uptake studies

After the heat of the summer and fall had subsided and a more normal temperature was maintainable, it was decided to crop a last and fourth crop of alfalfa. Pots were re-randomized into an overall randomized block design of all the previous used pots and chemical treatments (160 pots--40 pots per replication or block). After all plants had been evenly clipped, the alfalfa was allowed to grow a fourth crop. This began October 7, 1952. On October 23, artificial lights were turned on at 5:00 p.m. and left on until about 3:00 a.m., adding sufficient light for a total of 18 hours per day. Over each bench of alfalfa pots the total output of three reflector type lights was 1500 watts. The latter part of November the lights were turned down to a total of 14 hours of combined artificial light and sunlight per day. Lights were not turned on during the day, even though there were numerous cloudy days.

Harvest took place on December 31, 1952. Vegetative samples included the whole alfalfa as before. The vegetative harvest stage was that of 1/10 bloom. Samples were prepared for storage in much the same way as before, except that no lime was mixed with the samples before storage in the cold storage locker.

Results

The important consideration of the greenhouse studies was to ascertain the extent of uptake of fluorine by absorption of plant roots from a soil media supplied with various rates of fluorine treatment from soluble fluorides. The soil in the control pot, obviously, would represent the soil before any atmospheric contamination was present; while the 1600 p.p.m. level of fluorine added would represent a maximum that could conceivably be deposited on and abosrbed by the soil at a reasonable future interval of time.

Effect of the soluble fluorides, NaF and Na_2SiF_6, on the growth of Ranger alfalfa is reflected in table 17. When these yield data are compared with the summary of fluorine contents in table 18, the same vegetative correlation is apparent that was also evident for the turnips--as the yield decreases the fluorine content increases. The Petersboro soil has the capacity to yield better than the other soils, with a mean yield for four crops of 11.37 grams dry weight. Mendon silt loam was next in ability to produce alfalfa over all levels of soluble fluoride treatments. The Ironton loam, although a highly calcareous soil, ranks third in yield capacity for four crops; and the Orem loamy sand ranks fourth. For the fluosilicate treatments the yields range in the same order as with the fluoride treatments. The mean yields on the various soils in decreasing order were 11.62 grams for Petersboro; 10.22 grams for Mendon silt loam; 9.02 grams for

Table 17. Summary of alfalfa yields, dry weight in grams* for four crops of Ranger alfalfa grown on four soils treated with five rates of NaF; and four crops grown on soils treated with five rates of Na_2SiF_6

Date of harvest	Soil number	Soil type ppm F	Crop	0	200	400	800	1600	Yield for each soil, all treatments
				Fluorine added to soil (p.p.m. as NaF)					
3/15/52	1	Orem loamy sand 248	1	9.4	8.5	8.8	4.8	0.0	6.3
5/10/52			2	13.5	14.9	13.3	7.1	0.0	9.8
7/10/52			3**	7.3	8.4	10.2	4.3	0.0	7.5
12/13/52			4	5.3	9.0	8.2	7.9	0.0	6.1
				8.88	9.98	10.13	6.03	0.0	
					Mean for four crops				7.42
3/15/52	2	Ironton loam 874	1	10.2	9.4	8.7	8.0	5.2	8.3
5/10/52			2	12.1	15.5	12.6	11.8	8.9	12.2
7/10/52			3**	7.1	9.8	8.0	8.1	8.2	8.2
12/13/52			4	9.1	11.3	9.5	9.3	7.7	9.4
				9.63	11.50	9.70	9.30	7.50	
					Mean for four crops				9.52
3/15/52	3	Mendon silt loam 810	1	8.9	11.1	11.9	13.1	7.6	10.5
5/10/52			2	14.1	13.1	18.8	16.6	12.1	14.9
7/10/52			3**	11.2	10.7	12.0	11.0	7.7	10.5
12/13/52			4	8.2	8.6	9.5	8.6	6.3	8.2
				10.60	10.88	13.05	12.33	8.43	
					Mean for four crops				10.97
3/15/52	4	Petersboro silt loam 368	1	16.2	11.9	11.9	13.1	7.6	12.1
5/10/52			2	16.4	15.1	14.8	16.6	12.1	15.0
7/10/52			3**	10.1	10.4	11.6	10.0	9.0	10.2
12/13/52			4	7.5	9.6	8.9	8.9	6.1	8.2
				12.55	11.75	11.80	12.15	8.70	
					Mean for four crops				11.37

Table 17. (Concluded)

Date of harvest	Soil number	Soil type	Crop	0	200	400	800	1600	Yield for each soil, all treatments
				Fluorine added to soil (p.p.m. as Na_2SiF_6)					
3/15/52	1	Orem loamy sand	1	9.0	6.8	9.1	6.8	4.8	7.3
5/10/52			2	14.0	12.9	9.0	11.8	5.2	10.6
7/10/52			3**	7.3	6.4	7.8	7.0	3.4	6.4
12/13/52			4	6.4	7.3	7.1	7.4	5.5	6.7
				9.18	8.35	8.25	8.25	4.73	
						Mean for four crops			7.67
3/15/52	4	Petersboro silt loam	1	12.9	10.3	12.2	12.7	12.8	12.2
5/10/52			2	16.3	15.8	17.4	15.6	14.9	16.0
7/10/52			3**	10.1	9.8	9.4	11.1	6.9	9.5
12/13/52			4	6.9	9.6	9.0	9.1	8.7	8.8
				11.55	11.38	12.00	12.13	10.83	
						Mean for four crops			11.62
4/12/52	3	Mendon silt loam	1	12.5	13.2	11.3	14.1	16.9	13.6
5/31/52			2	11.5	14.9	12.8	14.6	10.0	12.8
7/10/52			3**	7.2	7.1	7.6	6.3	6.3	6.9
12/13/52			4	6.6	7.7	7.4	8.6	7.6	7.6
				9.45	10.73	9.78	10.90	10.20	
						Mean for four crops			10.22
4/12/52	5	Taylorsville fine	1	11.4	11.7	11.8	11.9	11.6	11.7
5/31/52		sandy loam 490	2	10.3	10.9	10.4	11.4	10.1	10.6
7/10/52			3**	3.4	7.4	7.5	7.1	7.0	6.5
12/13/52			4	6.8	8.3	8.0	7.5	5.9	7.3
				7.98	9.58	9.43	9.48	8.65	
						Mean for four crops			9.02

*Mean of four replications for each treatment for each soil.

**Replicates were composited and harvested together. Yield values are average per treatment per replicate.

Table 18. Summary of average* fluorine content (p.p.m.) of four crops of Ranger alfalfa grown on four soils treated with five rates of NaF; and average fluorine content of four crops of Ranger alfalfa grown on four soils treated with five rates of Na_2SiF_6

Date of harvest	Soil number	Soil type	Crop	0	200	400	800	1600	Mean fluorine content - all treatments
				Fluorine added to soil (p.p.m. as NaF)					
3/15/52	1	Orem loamy sand	1	30.2	54.2	79.0	89.0	-	
5/10/52			2	15.5	30.3	46.0	111.0	-	
7/10/52			3**	9.0	38.0	103.0	250.0	-	
12/13/52			4	9.7	14.7	19.2	23.2	-	
		Mean		16.1	34.3	61.8	98.3	-	52.6
3/15/52	2	Ironton loam	1	25.5	24.0	25.7	35.2	103.2	
5/10/52			2	13.7	11.2	17.7	29.2	76.0	
7/10/52			3**	10.0	28.0	23.0	14.0	152.0	
12/13/52			4	8.5	6.2	8.5	15.0	24.0	
		Mean		14.4	17.3	18.7	23.3	88.8	32.5
3/15/52	3	Mendon silt loam	1	25.0	27.7	27.7	51.0	65.0	
5/10/52			2	14.2	15.5	26.5	24.2	79.5	
7/10/52			3**	7.0	11.0	23.0	44.0	63.0	
12/13/52			4	7.7	8.5	11.5	12.5	29.0	
		Mean		13.5	15.7	22.2	32.9	59.1	28.7
3/15/52	4	Petersboro silt loam	1	15.0	50.0	25.7	33.0	53.0	
5/10/52			2	13.0	22.5	26.0	43.2	61.2	
7/10/52			3**	8.0	19.0	25.0	40.0	96.0	
12/13/52			4	7.7	7.5	11.5	17.5	60.7	
		Mean		10.9	24.7	22.0	33.4	67.7	31.7

Table 18. (Concluded)

Date of harvest	Soil number	Soil type	Crop	0	200	400	800	1600	Mean fluorine content - all treatments
				Fluorine added to soil (p.p.m. as Na_2SiF_6)					
3/15/52	1	Orem loamy sand	1	26.0	108.0	71.7	135.2	91.5	
5/10/52			2	13.5	51.0	53.0	74.7	160.1	
7/10/52			3**	9.0	86.0	76.0	70.0	40.0	
12/13/52			4	9.7	12.0	23.0	24.7	49.5	
		Mean		14.5	64.2	55.9	76.1	85.2	59.2
3/15/52	4	Petersboro silt loam	1	38.2	42.0	45.2	41.2	43.0	
5/10/52			2	15.0	27.5	28.7	37.0	43.0	
7/10/52			3**	8.0	21.0	35.0	33.0	40.0	
12/13/52			4	14.0	11.2	10.0	14.0	17.2	
		Mean		18.8	25.4	29.7	31.3	~~25.8~~ 35.7	~~28.2~~
4/12/52	3	Mendon silt loam	1	14.5	26.7	35.0	53.7	87.2	
5/31/52			2	11.3	16.5	30.3	59.0	173.7	
7/10/52			3**	7.0	16.0	29.0	53.0	120.0	
12/13/52			4	9.2	9.7	11.7	25.2	23.0	
		Mean		10.5	17.2	26.5	47.7	103.5	41.1
4/12/52	5	Taylorsville fine sandy loam	1	27.5	37.0	36.2	37.0	70.7	
5/31/52			2	12.3	16.3	18.5	33.5	112.0	
7/10/52			3**	5.0	5.0	20.0	35.0	155.0	
12/13/52			4	10.0	9.5	10.0	14.5	20.5	
		Mean		13.7	16.9	21.2	30.0	89.5	34.3

*Mean of four replications for each treatment for each soil.

**Replicates were composited and harvested together. Values are of composited samples.

Taylorsville fine sandy loam; and 7.67 grams for Orem loamy sand.

For all crops, with the exception of the crops grown on Mendon silt loam and Taylorsville fine sandy loam treated with Na_2SiF_6, the largest crop was the second crop. This was perhaps because the growing conditions were more of an optimum for normal light and temperature to encourage vegetative growth. The main reason for a drop in yield for the third crop was possible because of the high temperature level of the greenhouse during most of the growing period. General decrease in yield for the fourth crop was probably lack of normal light periods for photosynthesis, even though supplemental artificial light was provided. The general tendency was for the yields to decrease with the number of crops grown.

Whereas yields of dry matter decrease with treatment rates applied to soils, fluorine content of Ranger alfalfa increases with treatment rates. In comparing the mean fluorine content of Ranger alfalfa grown for all NaF treatments, the Mendon silt loam and Petersboro silt loam compare closely in their capacity for minimizing the uptake of fluorine. Ranger alfalfa grown in Ironton loam absorbs more fluorine, and the most fluorine of all is absorbed from the Orem loamy sand and the NaF treatments.

Ranger alfalfa grown on Petersboro soil treated with Na_2SiF_6, as influenced by the soil, takes up the least mean fluorine content, 28.2 p.p.m., for four crops. Taylorsville fine sandy loam induces slightly more, 34.3 p.p.m.; Mendon silt loam induces a fluorine content of 41.1 p.p.m., and Orem loamy sand induces the most fluorine content in Ranger alfalfa (59.2 p.p.m.) as measured by mean fluorine content of all crops and all treatments.

Some inconsistencies are noted in the uptake values influenced by some soils where a soil with a lower treatment produces vegetation with more fluorine content than a soil with a higher treatment. This can be usually explained by the experimental error involved in sample preparation for analysis or in the fluorine analysis itself. In spite of precautions exerted to minimize carry-over in the stills from previously run samples by acid washing of the stills before a new analysis was made, some sporadically high samples were found. These were all checked by a rerun when sufficient ash of plant sample was left for a determination.

Analysis of variance for fluorine content for the first, second, and fourth crops of Ranger alfalfa is tabulated in tables 19, 20, and 21. The difference in uptake as related to the five treatment levels is highly significant except in the first crop on soils 3 and 5 (table 21), and here it is significant at the 5 per cent point. This indicates, then, that for these soils we could expect increases in uptake of fluorine for increases in amounts of soluble fluorides added, under the conditions for the greenhouse experiments.

In the analysis of variance (table 20) of the fluorine content of three crops of Ranger alfalfa grown on Soils 1 (Orem loamy sand) and 4 (Petersboro silt loam) with five rates of NaF and Na_2SiF_6 as fluorine sources, some interesting uptake questions are answered. The source of variation between soils is highly significant, indicating that for these soils (calcareous and non-calcareous) there is a chance of 99:1 that the difference is real in ability of Ranger alfalfa to extract more fluorine from the non-calcareous soil than from the calcareous soil. In the first and second crops the first order interaction of treatment rates x soils indicates that the soils do not react the same with all treatment levels. The second order interaction (table 20) for treatment rates x chemicals x soils is significant for all three crops. This confirms our expectation that two soils of differing colloidal content and activity and lime content would react differently in

Table 19. Analysis of variance of the fluorine content of three crops of Ranger alfalfa grown on three different soils (2, 3 and 4) with five treatment rates of NaF

Source of variation	Degrees of freedom		Mean squares for crops		
			1st	2nd	4th
Replications	3		1103	72	50
Treatments	14		2029**	2089**	789**
Between soils		2	2740*	68	420**
Between chemical rates		4	5061*	6816**	812**
Soils x chemical rates		8	335	230*	871*
Error	42		770	104	80
Total	59				

** Significant beyond the 1 per cent level

* Significant at the 5 per cent level

Table 20. Analysis of variance of the fluorine content of three crops of Ranger alfalfa grown on two different soils (1 and 4) with five treatment rates of each of two chemicals, NaF and Na_2SiF_6

Source of variation	Degrees of freedom	Mean squares for crops		
		1st	2nd	4th
Replications	3	5757**	274	196*
Treatment rates	3	6515**	7523**	322**
Chemicals	1	4323**	22	25
Soils	1	22952**	8509**	518**
Treatment rates x soils	3	3617**	1906**	121
Treatment rates x chemicals	3	417	806**	14
Chemicals x soils	1	518	34	0
Treatment rates x chemicals x soils	3	6277**	3135*	191*
Error	45***	553	132	49
Total	63***			

*** Degree of freedom for error and total is reduced one each in the analysis (44 and 62, respectively) because of one calculated missing value.

** Significant beyond the 1 per cent level

* Significant at the 5 per cent level

Table 21. Analysis of variance of the fluorine content of three crops of Ranger alfalfa grown on two different soils (3 and 5) treated with five different rates of Na_2SiF_6

Source of variation	Degrees of freedom	Mean squares for crops 1st	2nd	4th
Replications	3	390	8721*	217
Chemical rates	4	3926*	23752**	472**
Soils	1	31	3861	240
Soils x chemical rates	9	169	594	33
Error	22	1136	2593	102
Total	39			

** Significant beyond the 1 per cent level

* Significant at the 5 per cent level

inducing uptake of fluorine in plants with different treatment levels of fluorine added to the soils.

Figures 11 to 18 inclusive illustrate the differences in growth of the first crop of Ranger alfalfa. With the NaF soil treatments for Soil 1 the growth was reduced in the fourth treatment, and no growth was secured on the high level. Relatively even growth was secured on the Ironton soil, although there was a noticeably reduced growth at the high level treatment. Growth was quite uniform for the alfalfa grown on the Mendon silt loam, as was the growth on the Petersboro silt loam.

For the Na_2SiF_6 soil treatments, growth for the Orem sandy loam decreased at the higher level but did not fail entirely as did the alfalfa and turnips both for the high level NaF treatment. On Soil 3 (Mendon silt loam, figure 17) growth seemed to be stimulated at the higher levels, which was borne out in the average yields for the first crop of Ranger alfalfa grown on the Mendon silt loam. The growth of alfalfa on the Petersboro soil treated with Na_2SiF_6 was quite uniform for all treatments.

Figure 19 summarizes the trend in uptake for the turnip crop and the four alfalfa crops for the five treatment rates for the NaF used on all the soils. Figure 20 similarly summarizes the trend in uptake ~~for the turnip crop.~~ of F from Na_2SiF_6

The differences that exist in pH and conductivity for the soils used in the greenhouse experiments after one crop of turnips and the first three crops of alfalfa were harvested are given in table 22. For both the NaF and the Na_2SiF_6 treatments, the pH was generally raised with increased additions of fluorine from the fluorine sources--with the exception of Soil 3, where the pH was reduced to 6.8 for the high level Na_2SiF_6 treatment. A similar tendency was noted for conductance

Figure 11. First crop Ranger alfalfa grown on Orem loamy sand treated with 0, 200, 400, 800, and 1600 p.p.m. fluorine added as NaF

Figure 12. First crop Ranger alfalfa grown on Ironton loam treated with 0, 200, 400, 800, and 1600 p.p.m. fluorine added as NaF

Figure 13. First crop Ranger alfalfa grown on Mendon silt loam treated with 0, 200, 400, 800, and 1600 p.p.m. fluorine added as NaF

Figure 14. First crop Ranger alfalfa grown on Petersboro silt loam treated with 0, 200, 400, 800, and 1600 p.p.m. fluorine added as NaF

Figure 15. First crop Ranger alfalfa grown on Orem loamy sand treated with 0, 200, 400, 800, and 1600 p.p.m. fluorine added as Na_2SiF_6

Figure 16. First crop Ranger alfalfa grown on Petersboro silt loam treated with 0, 200, 400, 800, and 1600 p.p.m. fluorine added as Na_2SiF_6

Figure 17. First crop Ranger alfalfa grown on Mendon silt loam treated with 0, 200, 400, 800, and 1600 p.p.m. fluorine added as Na_2SiF_6

Figure 18. First crop Ranger alfalfa grown on Taylorsville fine sandy loam treated with 0, 200, 400, 800, and 1600 p.p.m. fluorine added as Na_2SiF_6

of 1:1 soil extracts to increase with increased additions of the fluoride and the fluosilicate. The pH did not attain an excessively high value except for Soil 1 in which no growth was obtained for any crop at the 1600 p.p.m. rate. This value averaged 8.8 with individual potted soil values ranging as high as 9.1. This soil at the 1600 p.p.m. level had a typical black alkali surface crust, making it a definitely high alkaline soil. Highest conductivity value was noted for the high level treatment for the Ironton loam soil (No. 2), where the conductivity of the 1:1 extract was found to be 4.12 millimhos. The saturated extract would range considerably higher than this, definitely making this soil at this high level treatment a saline-alkali soil. This may explain in part the decidedly lower yields at this treatment level and the higher average fluorine contents when compared to the normal Petersboro and Taylorsville soils.

Table 22. Chemical analyses on greenhouse soils after one crop of White Globe turnips and three crops of Ranger alfalfa

Soil	Chemical added to soil	pH of soil before greenhouse experiments	Treatment levels compared			EC x 10^3 conductivity before greenhouse experiments	Treatment levels compared		
			0	800	1600	1:1 extract	0	800	1600
			*pH after third crop of alfalfa				EC x 10^3, 1:1 extract after third crop of alfalfa		
1	NaF	8.0	7.9	8.6	8.8**	0.50	0.60***	0.89	1.87**
2	NaF	8.5	8.5	8.3	8.6	3.20	2.72	2.49	4.12
3	NaF	7.4	7.4	7.4	7.8	0.90	1.14	1.41	1.51
4	NaF	7.4	7.9	8.0	8.1	0.60	1.05	1.65	2.49
1	Na_2SiF_6	7.9	7.9	7.9	8.1	0.50	0.69	0.95	1.16
3	Na_2SiF_6	7.4	7.6	7.0	6.8	0.90	0.63	0.63	0.65
4	Na_2SiF_6	7.4	7.7	7.9	7.9	0.60	1.01	1.12	1.47
5	Na_2SiF_6	7.8	8.1	8.0	8.2	0.60	0.68	0.68	0.73

*pH (paste)

**pH determinations and millimohos per centimeter—conductivity are means of four replications. It is of interest to note that the paste pH of the 1600 treatment ranged from 8.5 to 9.1. These soils had typically black alkali surface, which is also characterized by a high pH.

***Conductivity measurement of the controls is made after the addition of (16-20-0) fertilizers and the many irrigation treatments for growing the crops.

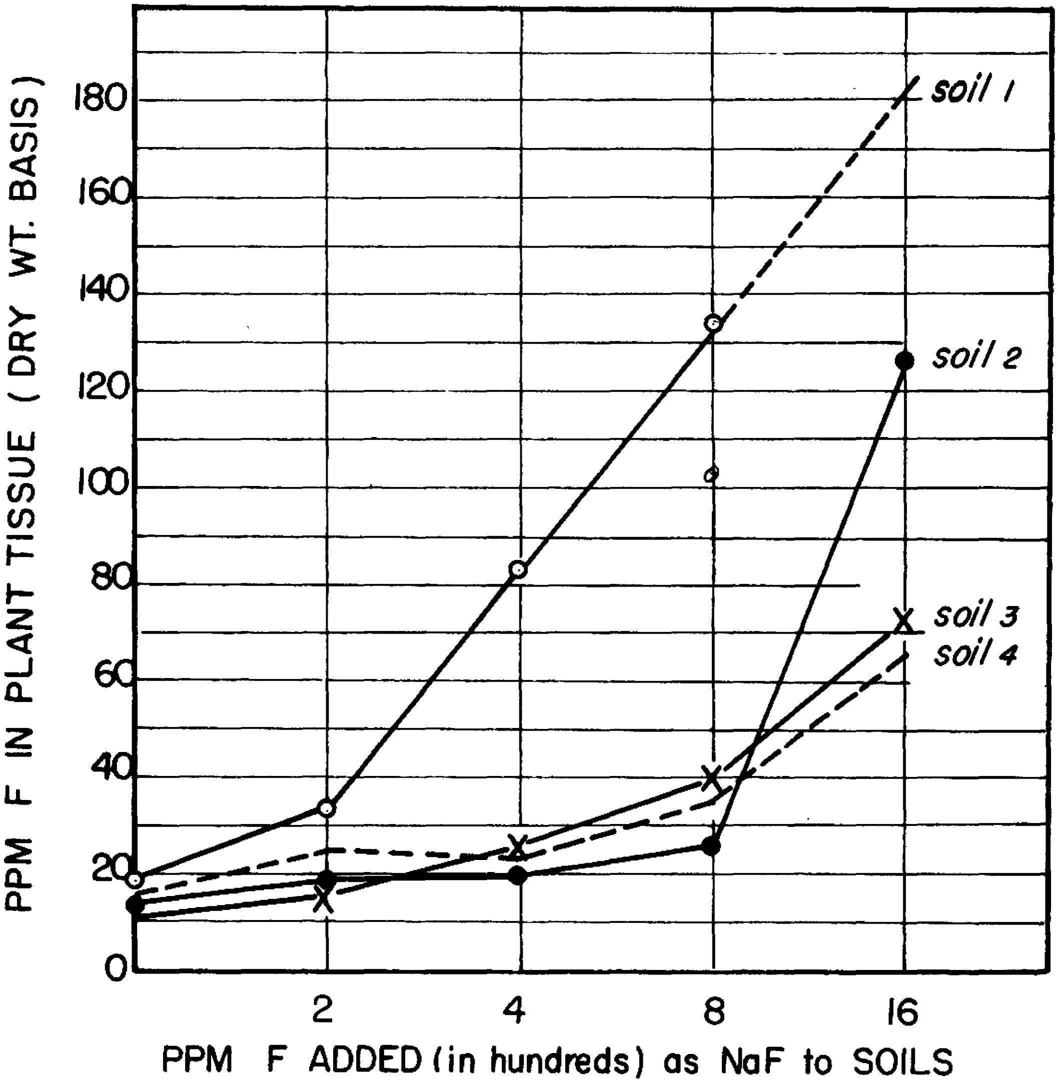

Figure 19. Summary of fluorine content of one crop of turnip tops and four crops of alfalfa on soils treated with four rates of NaF.

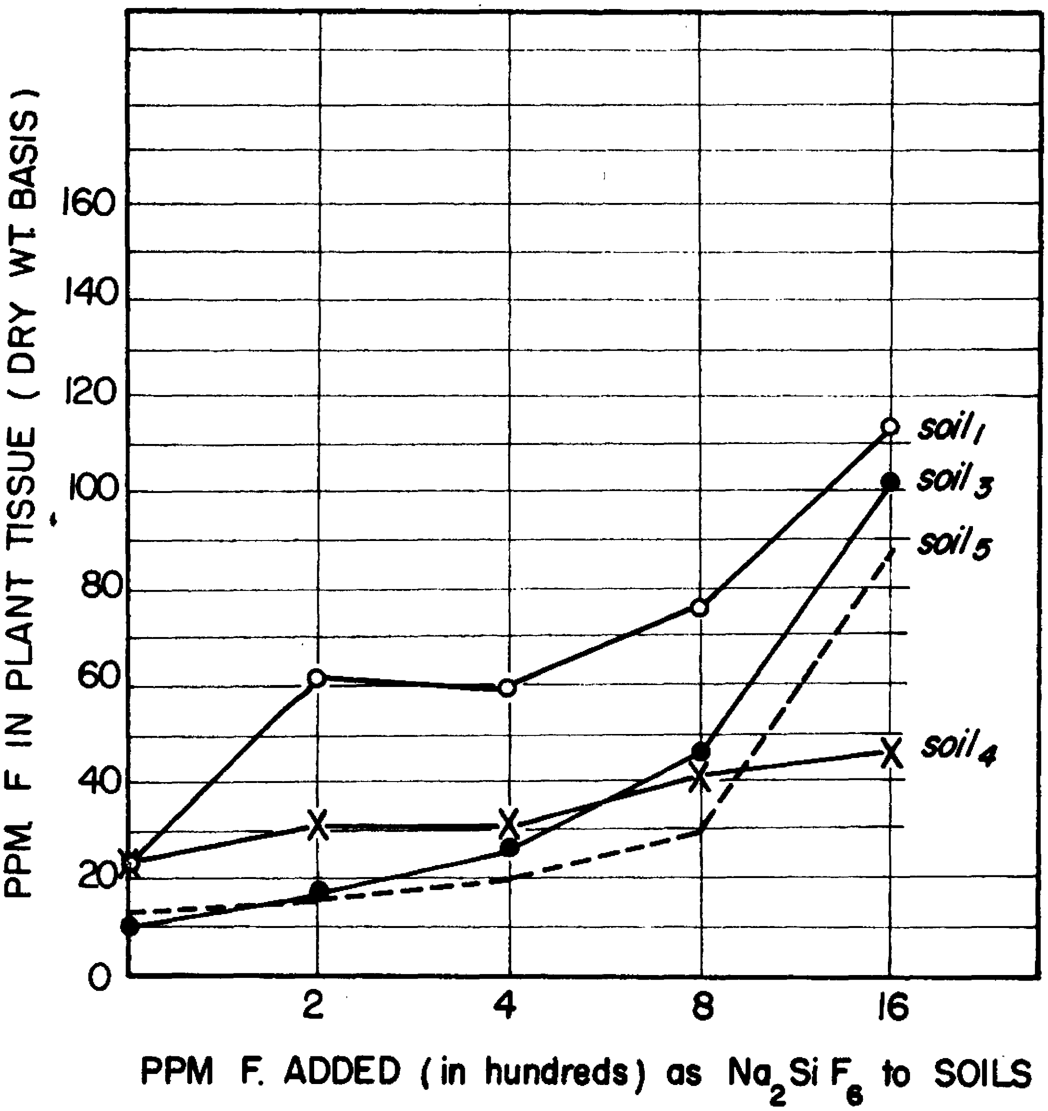

Figure 20. Summary of fluorine content of one crop of turnip tops and four crops of alfalfa grown on soils treated with four rates of Na_2SiF_6 .

DISCUSSION

Most investigators who have been working with the problem of fluorine uptake by plants from soils have assumed that plants absorb more fluorine from soluble fluorine-treated non-calcareous soils than from similarly treated calcareous soils. Furthermore, they have assumed that the main reason for this difference results from the $CaCO_3$ fixing soluble fluorine as insoluble CaF_2. Results obtained in this study indicate that there are non-calcareous soils of sufficiently high colloidal content that are able, under the conditions of these experiments, to be more effective in repressing the uptake of fluorine by plants than a calcareous soil. This soil was a Mendon silt loam, which is discussed in more detail below. We must necessarily, therefore, consider also the ability of the colloidal fraction of the soil to fix fluorine in soils.

Although there is a tendency for calcareous soils to reduce markedly the movement of fluorine ions into foliage from root absorption, this does not prevent plants from absorbing significant amounts at higher treatment levels. The Petersboro silt loam and the Ironton loam used in this study make good comparisons since they are both calcareous soils. The colloid content of the soils is comparably the same. The Petersboro has a moderate $CaCO_3$ content of 10.5 per cent, while the Ironton has a high $CaCO_3$ content of 52.0 per cent. On the basis of lime content alone, we might expect the Ironton to be capable of fixing more fluorine than the Petersboro. But this is not the case, because the Ironton soil induces a higher fluorine content in vegetation at the higher treatment levels than does the Petersboro soil. Other differences between the two soils are responsible for the greater induced fluorine content. The difference in pH of the two soils suggests that a difference in solubility of $CaCO_3$ in furnishing calcium ions may be a factor. The pH of 7.4 for the Petersboro would promote greater availability of calcium ions than the higher pH of 8.5 for the Ironton loam. Another item between the two soils which may be important is the difference in available phosphorus. The Petersboro soil furnishes an unusually large amount of soluble phosphorus. With added fluorine we have the proper combination for the formation of greater amounts of insoluble CaF_2 and apatite, $3Ca_3(PO_4)_2CaF_2$, in the soil. In final effect this would make less fluorine available to plants. An examination of other items in table 11 reveals differences in organic matter and soluble salts. These in combination with the others above, and separately, may influence the greater uptake from the Ironton loam than from the Petersboro silt loam. From the evidence available it is difficult to establish the real reason or reasons for the differences in these two calcareous soils.

Also of value is the comparison of the Mendon silt loam and the Ironton loam, the former a non-calcareous soil and the latter a highly calcareous soil. The Mendon silt loam ranks between the Ironton loam and the Petersboro silt loam for inherent ability in inducing least fluorine content in vegetation when these soils are treated with NaF. The Mendon silt loam, while having only slightly higher clay more colloidal content, may contain more active colloid as evidenced by the relatively high base exchange capacity. The nature of clay colloid may be different. The Ironton may have less exchangeable Ca than the Mendon soil where the exchangeable calcium may be relatively high. This needs to be ascertained from further study, because these factors may be the important ones in rating the Mendon silt loam to be more effective in fixing fluorine than the Ironton soil.

This discussion serves to point out that those factors that have had to be considered together in these present studies could well be used in future studies as single limiting factors. For example, the availability of fluorine in soils could be studied in calcareous soils as influenced by pH in the range encountered here from 7.4 up to 8.5 or above, with other factors that have been different in these studies being the same. Another study that would be of value would be to make the only limiting factor affecting availability of fluorine that of the influence of different amounts of soluble salts added to the soil, inasmuch as this may be one of the differences apparent between western soils and those of higher rainfall areas. Further study could also be made using the factor of colloidal content being the only variable in studying the availability of fluorine both in combination with and without the competing influence of lime. Further study would also be worthwhile in studying the exchangeable calcium-exchangeable sodium ratio on the exchange complex and ascertain the effect on the uptake of fluorine by plants.

Likewise we may ask the question as to why the inherent differences between eastern soils that have been limed and normally calcareous western soils. There are differences in their abilities to influence the fluorine content of vegetation grown on them. This is illustrated when levels in these experiments with the moderately calcareous Petersboro silt loam are compared with the limed eastern soils of Tennessee and elsewhere. The uptake level of fluorine is apparently greater from the western soils, but the reason for the difference is not clearly apparent. Data from these experiments are not able to answer the question fully. Perhaps the best we can do is to point out differences that may be somewhat responsible. The differences of higher pH in western than eastern soils would hardly account for the difference because higher pH values would promote less availability of soluble fluorides than for the more acid conditions of eastern soils. Soluble salts of sodium and potassium in western soils, not usually present in soils of the high rainfall areas of the east, may be influencing factors capable of inducing higher levels of fluorine content in plants grown on them.

Recent work by MacIntire, Winterberg, et al (1947); Hurd-Karrer, (1951); MacIntire, et al (1951); and the author in this thesis definitely show that fluorine content of plants from soil absorption is materially greater when the source of soil fluorine is from treatments with soluble forms such as NaF, Na_2SiF_6, KF, or HF rather than CaF_2 or phosphatic slags, even though considerable soil lime may be present.

The Mendon silt loam, a non-calcareous soil having a higher colloidal fraction than any of the other soils used in these studies, demonstrates the importance of the colloidal fraction of a soil also being responsible for absorption and fixation of fluorine in soils. Compared with the Orem loamy sand it had over twice the colloid content. At the higher levels of treatment with NaF and Na_2SiF_6 it produced higher yields of vegetation which absorbed less fluorine from the soil than the Orem loamy sand. A similar parallel is noted in comparing the nearly tenfold difference between the base exchange capacities of the two soils.

In the work of the author, the turnip plants were able to absorb more fluorine from soils than were the Ranger alfalfa plants. Some analyses showed that turnips could absorb as high as 500 p.p.m. without showing evidence of tissue injury. Alfalfa was more sensitive to large amounts of added fluorine in the soil, and under the different temperature-moisture-light relationships of the four crops may possibly account for different extents of necrotic leaf tissue at the outer perimeter of the leaves. No correlation was apparent, however, between injury and uptake values or treatment.

Turnip roots analyzed in the work for this thesis contained nearly one-half as much fluorine as the tops above ground. The theory of Daines, Leone, and Brennan (1952) that soil fluorine causes high leaf content and even higher root content does not hold here. Alfalfa roots, although not analyzed in this study, may present a different aspect, however.

In the field studies it was observed that in general the fluorine content in a soil profile increases with depth and is usually greater in heavier textured soils than sandy or light textured soils. However, soils adjacent to a source of heavy atmospheric contamination have a larger amount in several inches of topsoil than that portion of the profile immediately below. Heavier textured subsoil zones of lime accumulation increase fluorine content. Leaching action of water removes more fluorine from sandy soils than from the heavier textured soils equally distant from a source of atmospheric contamination.

Soils located where there is little or no influence from atmospheric contaminants derive most of their fluorine from the parent materials. This was apparent in the Cache County soils. However, with a major source of atmospheric contamination from industry close at hand, the total soil fluorine is a combined result of parent material and that absorbed from the atmosphere. The soil fluorine contributed by the parent material is largely fixed and not appreciably available, but the soluble fluorides from atmospheric effluents that find their way to the soil are available for immediate uptake by plants until the time that they are leached out of the soil by downward percolating waters or until they are fixed by the soil lime or partially fixed by soil colloids.

It will be noted from table 19 that the fluorine content of Ranger alfalfa decreases, generally, from the first to the fourth crops. This may indicate that time is a factor in the fixing of fluorine more completely by the calcium carbonate and the colloidal fraction of soil. A future examination of these soils in examining the difference between readily soluble fluorides and "fixed" forms of fluorine would prove helpful in answering the question of the influence of time on the availability of the fluorine ion. This may be significant because the plants in this present study have extracted in four crops only a very small fractional part of the original fluorine input.

It should be borne in mind that the conditions of these greenhouse experiments cannot be exactly duplicated in the field. Conditions of normal drainage of the soil profile in the field are not maintained in potted greenhouse soils. Under irrigation, the leaching out of soluble fluorides may be appreciable, especially with extremely sandy soils such as the Orem loamy sand. Another factor which must be taken into account is the quality of the water used in irrigation. In most cases water from the Wasatch front used for irrigation in Utah County carries several equivalent parts per million of calcium. This would furnish available calcium in addition to that made available in calcareous soils from the solubility of $CaCO_3$ (16 p.p.m.) to react with the fluoride ion to form insoluble CaF_2. In a non-calcareous soil the dissolved calcium carried by the water coupled with the leaching action may be sufficient in limiting more soluble fluorides from uptake by root absorption than the author was able to show from the greenhouse experiments. With a more normal pattern of root distribution in the field soils, especially for a deep-rooted plant such as alfalfa, the question naturally arises as to what effect this would have upon the fluorine uptake from the whole soil profile. Uptake studies under field conditions could give us more tangible evidence.

SUMMARY AND CONCLUSIONS

1. In a series of greenhouse experiments, five different soils were treated with five different rates of NaF and Na_2SiF_6. Fluorine analyses were made of White Globe turnip tops and the whole foliage of Ranger alfalfa to ascertain the fluorine content of the vegetation as influenced by the treatment of the soil. The results indicate that:

(a) Higher average fluorine contents of both turnip tops and alfalfa were obtained from the non-calcareous than from the calcareous soils by root absorption from the soils.

(b) As yields decreased as a result of higher treatment levels, content of fluorine in the plant tissue of the turnips and alfalfa increased.

(c) Mendon silt loam, a non-calcareous soil of higher colloidal content than any of the other calcareous or non-calcareous soils used in the greenhouse studies, produced higher yields of vegetation containing less fluorine than vegetation produced on the other non-calcareous soil, Orem loamy sand.

(d) Yields and plant fluorine contents for the same soil treatments varied for the three different calcareous soils.

(e) An average uptake of fluorine for four soils treated with the highest rate of NaF indicates the following decreasing order of ability for the soils to induce the largest content of fluorine in vegetation: Orem loamy sand (non-calcareous), Ironton loam (highly calcareous), Mendon silt loam (non-calcareous), and Petersboro silt loam (moderately calcareous)

(f) Average uptake of fluorine for four soils treated with the highest rate of Na_2SiF_6 indicates the following decreasing order of ability for the soils to induce the largest content of fluorine in vegetation: Orem loamy sand; Mendon silt loam; Taylorsville fine sandy loam (calcareous), and Petersboro silt loam.

(g) Plants differ in their abilities to absorb fluorine. Turnip tops had a higher fluorine content than alfalfa crops that followed on the same treated soils.

(h) The results of the greenhouse studies require considerable care in interpreting with respect to field conditions. Normal profile drainage, natural plant rooting habitat, differences in quality of irrigation water, depth and changes in soil profile, and other differences in the field may have inducing or inhibiting effects on fluorine uptake by plants. Field observations of fluorine uptake by plants should follow these greenhouse studies to more adequately appraise reaction of field soils to soluble fluorides or fluosilicates.

2. Samples of field soils obtained in 1938 and 1951 were used to study the fluorine content of the soils with respect to distance from a reference point in Utah County. Cache County, Utah, soils were sampled in order to estimate the naturally occurring fluorine in soils.

The data on these soils bring out the following relationships:

(a) Fluorine in soil does not always increase with depth. Proximity to industrial sources of fluorine may cause the upper few inches to contain more than the portion of the profile immediately below.

(b) Cache County soils, in general, increase in fluorine content with depth.

(c) The heavier textured soils from both Cache County and Utah County contained more fluorine than light textured or sandy soils.

(d) There is an apparent decrease in average fluorine content in the top 24 inches of the soils of Utah County when correlated with distance concentrically from the reference point at the southeast corner of Section 8, Township 6 South, Range 2 East.

LITERATURE CITED

Bartholomew, R. P. Fluorine, its effect on plant growth and its relation to the availability to plants of phosphorus in phosphate rocks. Soil Sci. 40:203-217. 1935.

Churchill, H. V., Rowley, R. J., and Martin, L. N. Fluorine content of certain vegetation in a Western Pennsylvania area. Anal. Chem. 20:69-71. 1948.

Clark, F. W. and Washington, H. S. The composition of the earth's crust. U. S. Geol. Survey Prof. Paper 127. 1924.

Daines, Robert H., Leone, Ida, and Brennan, Eileen. The effect of fluorine on plants as determined by soil nutrition and fumigation studies. Proc. U. S. Tech. Conf. on Air Pollution (pp. 97-105). New York: McGraw-Hill Book Co., Inc., 1952.

Dean, L. A. and Rubins, E. J. Anion exchange in soils; exchangeable phosphorus and the anion-exchange capacity. Soil Sci. 63:377-387. 1947.

Dickman, S. R. and Bray, R. H. Replacement of abosrbed phosphate from kaolinite by fluoride. Soil Sci. 52:263-273. 1941.

Greenwood, D. A. Fluoride intoxication (review). Physiol. Reviews 20:582-616. 1940.

Hardin, L. J. Determination of fluorine content of soils. A.O.A.C. Collaborative Report. 1951.

Hart, E. B., Phillips, P. H., and Bohstedt, G. The relation of soil fertilization with superphosphate and rock phosphate to fluorine content of plants and drainage waters. Am. Jour. Pub. Health 24:936-940. 1934.

Hurd-Karrer, Annie M. Comparative fluorine uptakes by plants in limed and unlimed soils. Soil Sci. 70:153-159. 1950.

Jeffries, C. D. Occurrence of fluorine in limestones and dolomites. Soil Sci. 71:287-289. 1951.

Leone, I. A., Brennan, E. G., Daines, R. H., and Robbins, W. R. Some effects of fluorine on peach, tomato, and buckwheat when absorbed through the roots. Soil Sci. 66:259-266. 1948.

MacIntire, W. H. Soil content of fluorine and its determination. Soil Sci. 59:105-109. 1945.

________ Air versus soil as channels for fluoric contamination of vegetation in two Tennessee locales. Proc. U. S. Tech. Conf. on Air Pollution (pp. 55-58). New York: McGraw-Hill Book Co., Inc., 1952.

________ and associates. Effects of fluorine on Tennessee soils and crops. Ind. and Eng. Chem. 41:2466-2475. 1949.

________ Hardin, L. J., and Jones, L. S. The direct double-distillation procedure for the determination of fluorine content of soils. Jour. of the Assoc. of Official Agric. Chemists. 34:597-603. 1951.

________ Hardin, L. J., Oldham, F. D., and Hammond, J. W. Development of phosphorous pentoxide insolubility in phosphatic mixtures. The formation of fluorapatite and its cause. Ind. and Eng. Chem. 29:758-766. 1937.

________ Jones, L. S., and Hardin, L. J. Fluorine losses in the calcination of analytical charges of fluoride-enriched soils. Jour. of Assoc. of Official Agric. Chem. 33:654-663. 1950.

________ Shaw, W. M., Robinson, B., and Sterges, A. J. Disparity in the leachability of fluorine from incorporations in phosphated and slagged soils. Soil Sci. 65:321-339. 1948.

________ and Winterberg, S. H. Pot method for soil cultures. Soil Sci. 62:33-41. 1946.

________ Winterberg, S. H., Clements, L. B., and Durham, W. H. The effects of calcium fluoride incorporations on plant growth, fluorine and phosphorus uptake and soil pH. Soil Sci. 63:195-207. 1947.

________ Winterberg, S. H., Clements, L. B., Hardin, L. J., and Jones, L. S. Crop and soil reactions to applications of hydrofluoric acid. Ind. and Eng. Chem. 43:1800-1803. 1951.

________ Winterberg, S. H., Clements, L. B., Jones, L. S., et al. Effect of fluorine carriers on crops and drainage waters. Ind. and Eng. Chem. 43:1797-1799. 1951.

________ Winterberg, S. H., Thompson, J. G., and Hatcher, B. W. Fluorine content of plants fertilized with phosphates and slags carrying fluorides. Ind. and Eng. Chem. 34:1469-1479. 1942.

Marshall, E. Edmund. The colloid chemistry of the silicate minerals. New York: Academic Press, Inc., 1949.

McClure, F. J. Availability of fluorine in sodium fluoride vs. sodium fluosilicate. Public Health Reports 65:1175-1186. 1950.

_______ Mineral metabolism (Fluorine and other trace elements). Ann. Rev. Biochem. 18:335-354. 1949.

McHargue, J. S. and Hodgkiss, H. H. Report on less common elements in soils. Fluorine in soil and other materials related to agriculture. Jour. Assoc. Off. Agr. Chem. 22:249-251. 1939.

Milton, R. F. Titrimetric estimation of fluorine. Analyst 74:54. 1949.

Mitchell, H. H. and Edman, Marjorie. Fluorine in soils, plants, and animals. Soil Sci. 60:81-90. 1945.

Nelson, J. W. and Eckman, E. C. Soil survey of the Cache Valley area, Utah. Field operations of the Bureau of Soils. U. S. Department of Agriculture (pp. 2099-2164). 1913.

Prince, A. L., Bear, F. E., Brennan, E. G., Leone, I. A., and Daines, R. H. Fluorine: its toxicity to plants and its control in soils. Soil Sci. 67:269-277. 1949.

Robinson, W. O. and Edgington, Glen. Fluorine in soils. Soil Sci. 61:341-353. 1946.

Rogers, Austin Flint. Study of minerals and rocks. New York: McGraw-Hill Book Co., 1921.

Roholm, K. Fluorine intoxication. H. K. Lewis and Co., Ltd., 1937.

Stanford Research Institute Analytical Section, Stanford, California, Methods. Preparation of various materials for fluorine analysis. A.S.M. 1402. April 25, 1951. (mimeo)

Stanford Research Institute, Stanford, California. Fusion of plant samples with sodium hydroxide. Private communication.

Steinkoenig, L. A. Relation of fluorine in soils, plants, and animals. Jour. Ind. and Eng. Chem. 11:463-465. 1919.

Vinogradov, A. P. and Danilova, V. V. Dorklady Akad Nauk. S.S.S.R. 59:1317-1319. (C.A. 42:7473). (Originial work not available)

Willard, H. H. and Winter, O. B. Volumetric method for determination of fluorine. Ind. and Eng. Chem. (Anal. Ed.) 5:7. 1953.

Wilson, LeMoyne, Johnson, Kale, Hugie, Vern K., and Bartholomew, O. F. Soil Survey of the Utah Goshen Valley area. (typewritten, unpublished report)