Water-Soluble Phosphorus in Fertilizer

J. R. ARCHER and R. P. THOMAS
International Minerals & Chemical Co., East Point, Ga., and Chicago, Ill.

The importance of the water solubility of phosphorus in fertilizers has been questioned, although agronomists have shown that approximately 50% water solubility is sufficient. In the investigation reported, about 250 fertilizer samples, which represent several grades, many plants, and various formulations and times of sampling, were analyzed. The wide variation in results indicates that many factors in fertilizer production could influence the water-soluble phosphorus content. As water solubility is not controlled during production of the fertilizer, no one factor can be singled out as most important. Data indicate that fertilizer can be produced with almost any desired degree of water solubility.

Means of measuring the availability or crop response of phosphate fertilizer has long been a controversial issue. Although the reliability of the present AOAC citrate method has been substantiated by thousands of pot and field tests in this country, there are many advocates of other means of measurement. With the development of the tagged ion technique, better evaluation of proposed methods is now possible. Many soil and agronomy workers are using this new technique, especially to determine the need for water-soluble phosphorus in fertilizer. So far, few results have been published. Most of the workers, and especially Olson (3), Smith (4), and Webb (5), have shown that only 40 to 50% of the phosphorus must be water-soluble. Fertilizers containing a higher proportion of water-soluble phosphorus stimulated earlier growth but did not increase yields. The ideal water-soluble phosphorus content should be just enough for good growth and maximum yield without requiring a price premium.

Previous Analyses

Formerly, the water-soluble phosphorus content of fertilizers and materials was determined by state fertilizer control chemists. Because no such determinations are now available, other agencies or individual companies must supply these data. Clark and Hoffman (2) determined the water-soluble phosphorus content of a large number of fertilizer samples which were obtained from state control chemists. These two U. S. Department of Agriculture workers reported the average water-soluble phosphorus as ranging from 48.4 to 84.5%, depending on materials and fertilizer mixtures. The extremes of these percentages—2.8 to 99.7—indicated that fertilizers could be made with a wide range of water-soluble phosphorus con-

Table I. Water-Soluble Phosphorus Content of Superphosphate Used in Different Plants

Plant Designation	Grade	Materials Added	Moisture Content, %	Water-Soluble Phosphorus Content, %
K	0-18-0	Sand	5.36	89.9
S	0-18-0	Sand	3.40	91.7
C	0-20-0	...	5.93	90.6
C	0-20-0	...	6.34	88.6
I	0-20-0	Limestone	2.30	82.6
J	0-20-0	Vermiculite	4.88	79.3
O	0-20-0	...	4.80	87.0
		...	4.02	90.8
		...	6.01	92.5
		...	4.80	91.5
G	0-47-0	...	1.87	90.0
C	0-50-0	...	3.83	87.5
		...	2.90	84.3
O	0-50-0	...	3.84	84.6
		...	0.87	82.8
		...	1.85	82.6
Z	0-50-0	...	4.03	88.6
		...	2.25	85.7
		...	1.20	84.9
			Av. 3.91	87.1

Table II. Water-Soluble Phosphorus Content of Alkaline Fertilizer Grades
(Manufactured at several plants by various formulations)

Plant Designation	Grade	Materials Added[a]: Triple super	Materials Added[a]: Lime material	Materials Added[a]: Other material	Moisture Content, %	Water-Soluble Phosphorus, %
U	0-10-20	...	Limestone[b]	...	2.60	74.7
D	0-10-30	0-47-0	Hydrated	...	3.40	68.3
J	0-12-12	...	...	...	3.02	77.0
V	0-12-12	...	Limestone[b]	...	3.67	77.2
N	0-14-7	...	...	Sand	7.96	56.5
		...	...	Sand	7.95	56.8
J	0-14-14	...	Granite	...	4.16	62.8
P	0-14-14	...	Limestone	Borax	4.55	85.6
R	0-14-14	...	Hydrated	...	4.47	53.6
Z	0-15-30	0-50-0	Hydrated	...	2.60	56.1
W	0-20-20	0-47-0	...	...	2.70	80.0
C	0-20-20	0-50-0	Hydrated	...	3.60	58.8
T	0-20-20	0-47-0	Hydrated	...	1.90	59.7
					Av. 4.17	66.7

[a] In addition to run of pile superphosphate and potassium chloride (muriate).
[b] Kemidol, commercial limestone, containing magnesium.

tent, and suggested that the recommendations of agronomic research workers could be met.

Procedure

As it is now necessary for each fertilizer company to make its own check on the water solubility of its phosphorus products, about 250 check or control samples were selected for study. The data on water solubility, available phosphorus, and moisture content which appear in the tables were determined by methods recommended by the Association of Official Agricultural Chemists (*1*). The water-soluble phosphorus in the tables is expressed as percentage of available phosphorus. The data obtained are grouped according to grade, materials, and plants. Some formula variations, as well as changes in materials, are included.

Superphosphate

As superphosphate is the foundation for mixed fertilizer, the water-soluble phosphorus content of many superphosphates was determined and is reported in Table I. These results, which show from 79.3 to 92.5% of the phosphorus as water-soluble, are in agreement with many other published results on superphosphates. There is very little difference between the normal and concentrated superphosphate. The average of 87.1% is good, according to the survey of Clark and Hoffman. Although the number of samples compared is small, the data in Table I indicate that the addition of almost anything to superphosphate reduces the water solubility of the available phosphorus. These data suggest also that high moisture content is helpful in maintaining high solubility. Duplicate samples from the same plant check reasonably closely, an indication that the analytical method is satisfactory and that the samples are fairly representative.

Alkaline Grades Superphosphates (including those presented in Table I) were mixed with potash materials and made into alkaline grades of fertilizer. The water solubility of the phosphorus in these fertilizers is presented in Table II. The data indicate that the addition of potassium salts to superphosphate reduces the percentage of water-soluble phosphorus, except when borax is also added, and that high moisture content gives a lower amount of water-soluble phosphorus. The large variation in water-soluble phosphorus at the different plants suggests that factors other than formulation may be important.

Ammoniated Superphosphate In fertilizer plants, it is often desirable to ammoniate portions of the superphosphates to be used

Table III. Effect of Formulation and Plant Variation on Water-Soluble Phosphorus Content of Ammoniated Superphosphate

Plant Designation	Grade	Materials Added[a]: Sulfuric acid	Triple super	Lime	Moisture Content, %	Water-Soluble Phosphorus, %
O	4-16-0	−	−	+	5.34	47.8
K	5-16-0	−	−	−	6.10	61.0
K	5-16-0	−	−	−	6.60	64.7
K	5-16-0	−	−	−	5.90	61.4
H	5-16-0	−	−	+	6.70	67.8
H	5-16-0	−	−	+	6.73	69.1
H	5-16-0	−	−	+	6.65	68.8
H	5-16-0	−	−	+	6.85	66.3
H	5-17-0	−	−	+	7.05	56.4
H	5-17-0	−	−	+	7.18	56.0
Z	5-17-0	−	−	−	6.20	65.9
O	6-24-0	+	+	−	3.55	69.8
O	8-32-0	+	+	−	3.63	69.9
O	8-32-0	+	+	−	3.50	69.9
O	10-20-0	+	+	−	2.10	68.9
O	10-20-0	+	+	−	3.92	68.1
O	10-20-0	+	+	−	2.11	67.7
I[b]	15-15-0	−	+	−	1.20	61.2
	15-15-0	−	+	−	3.07	49.2
	16-20-0	+	+	−	3.68	51.7
					Av. 4.93	63.1

[a] In addition to normal superphosphate and nitrogen carrier.
[b] Ammoniated with urea solution.

Table IV. Effect of Formulation and Plant Variation on Water-Soluble Phosphorus Content of 3-9-6 and 3-12-12 Grades

Plant Designation	Materials Added[a]: NH_3	NH_4NO_3	Urea	Organics	H_2SO_4	Lime	Moisture Content, %	Water-Soluble Phosphorus, %
				3-9-6				
K	+	+	+	+	−	+	3.65	37.9
	+	−	+	+	−	+	3.48	53.2
	+	+	+	+	−	+	2.53	23.9
	+	−	+	+	−	+	3.40	55.1
	+	−	+	+	−	+	4.01	55.5
	+	−	+	+	−	+	3.40	56.4
J	+	+	−	−	−	+	3.40	27.5
X	+	+	+	+	−	+	4.75	64.0
	+	+	+	+	−	+	4.41	57.2
Y	+	−	+	+	−	+	3.98	55.3
							Av. 3.10	48.6
				3-12-12				
B	−	+	−	−	−	+	4.47	40.9
	−	+	−	−	−	+	4.68	45.9
	+	+	−	−	−	+	3.96	46.6
C	+	−	−	−	+	−	2.55	37.5
	+	−	−	−	+	−	3.97	43.4
	+	−	−	−	+	−	2.65	47.0
	+	−	−	−	+	−	2.30	49.5
	+	−	−	+	+	−	3.37	50.7
D	+	−	−	−	+	+	1.75	55.0
	+	+	−	−	−	+	1.53	49.8
	+	+	−	−	−	+	3.57	48.9
J	−	+	−	−	−	+	3.52	59.3
K	+	+	−	−	−	+	4.30	46.2
	+	+	−	−	−	+	4.70	42.7
N	+	+	−	−	+	+	2.40	34.3
	+	−	+	−	+	+	2.34	62.3
	+	−	+	−	+	+	2.42	62.5
O	+	+	−	−	−	+	1.65	34.9
S	+	+	−	−	−	+	5.83	53.9
	+	+	−	−	−	+	4.33	44.9
T	+	+	−	−	−	+	3.62	32.7
	+	+	−	−	−	+	3.32	27.9
	+	+	−	−	−	+	3.34	44.6
	+	+	−	−	−	+	3.46	29.3
	+	+	−	−	−	+	3.78	44.8
	+	+	−	−	−	+	3.19	31.8
							Av. 3.35	44.9

[a] In addition to normal superphosphate and potassium chloride.

Table V. Effect of Formulation and Plant Variation on Water-Soluble Phosphorus Content of 5-10-5 Fertilizer

Plant Designations	Materials Added[a] $(NH_4)_2SO_4$	H_2SO_4	Lime	Moisture Content, %	Water-Soluble Phosphorus, %
C	−	+	−	3.85	36.6
	−	+	−	4.56	38.0
	−	+	−	3.91	60.5
	−	+	−	4.59	40.1
C	−	+	−	4.07	38.2
	−	+	−	3.69	53.1
	−	+	−	3.76	38.0
	−	+	−	4.60	50.1
I	−	+	+	1.39	70.4
	−	−	+	1.74	57.9
	−	+	−	2.48	60.9
	−	+	−	1.12	58.4
	−	−	+	1.45	60.1
J	+	−	+	4.34	22.3
	+	−	+	2.79	12.8
K	+	−	+	3.00	56.9
	+	−	+	3.50	30.1
S	+	−	+	3.55	28.7
	+	−	+	3.22	34.3
U	−	−	+	3.13	27.9
	−	+	+	2.70	29.4
	−	−	+	2.75	28.4
	−	−	+	3.28	41.3
W	+	−	+	3.52	39.2
	+	−	+	3.54	35.5
	+	−	+	3.64	43.1
Y	+	−	+	3.40	43.4
Z	+	−	+	4.58	57.3
	−	+	+	4.76	36.8
				Av. 3.35	42.4

[a] In addition to ammonia and ammonium nitrate solution.

Table VI. Effect of Formulation and Plant Variation on Water-Soluble Phosphorus Content of 10-10-10 Fertilizer

Plant Designation	Materials Added[a] $(NH_4)_2SO_4$	H_2SO_4	Lime	Moisture Content, %	Water-Soluble Phosphorus, %
C	+	+	−	1.00	68.0
	+	+	−	1.77	63.6
	+	+	−	1.07	69.1
	+	+	−	1.22	66.9
C	+	+	−	1.79	60.0
	+	+	−	1.93	57.4
	+	+	−	1.04	68.3
	+	+	−	2.05	57.7
D	+	+	−	1.85	52.5
	+	+	−	1.06	58.4
I	−	+	−	0.72	70.4
N[b]	−	+	+	0.66	35.4
	−	+	+	1.10	32.9
	+	+	−	0.46	69.6
	−	+	−	0.72	70.4
O	+	+	−	0.65	63.6
	+	+	−	0.58	55.4
	+	+	−	0.41	62.5
	+	+	−	0.33	60.0
	+	+	−	1.30	50.7
T	+	−	−	3.08	44.5
	+	−	−	2.45	44.4
Z	+	+	+	2.03	49.8
	+	+	+	2.98	51.6
	+	+	+	1.78	48.5
	+	+	+	1.67	52.3
	+	+	+	1.75	49.0
	+	+	+	1.60	51.1
				Av. 1.46	56.3

[a] In addition to ammonia and ammonium nitrate solution.
[b] Urea solution in place of ammonium solution.

in basing for various fertilizer grades. Table III shows the water-soluble phosphorus content of several ammoniated superphosphates, and gives some factors in the formulation which might influence their solubility. In general, ammoniation of the superphosphate reduces the water-soluble phosphorus content. There are indications that the addition of lime and urea may reduce water solubility. Many other factors, such as heat, rate of ammoniation, time of cooling, and drying which the average fertilizer plant makes little effort to control, may be more important in reducing the percentage of water-soluble phosphorus than the factors shown in this table.

3-9-6 and 3-12-12 Grades In order to compare the influence of different fertilizer grades and methods of formulation, samples of many of the more important grades were selected at random. Two grades selected were the popular 3-9-6 (from southern plants) and 3-12-12 (from all sections of the country). The data given in Table IV indicate that in the 3-9-6 grades, even the use of organics and inert fillers did not prevent a reduction in water-soluble phosphorus. Samples with relatively high moisture content and a lime filler seemed to have low water-soluble phosphorus, regardless of the grade or plant. The reason for the wide variation in the amount of water-soluble phosphorus in a grade manufactured at different plants is not clear. Even within an individual plant it varied with both formula and time of sampling. This indicates that perhaps there are controlling factors other than formulation.

5-10-5 Grades One of the most popular grades in the country as a whole is the 5-10-5 fertilizer. The water-soluble phosphorus content, as well as some formulation variations that might influence it are given in Table V. Again the percentage of available water-soluble phosphorus varies widely. In some instances, a grade made by the same formula but at a different time in a plant varied widely in its percentage of water-soluble phosphorus. Although all the samples of very low moisture were high in soluble phosphorus, the high-moisture samples were not necessarily low in soluble phosphorus. The large variation between individual plants indicates that plant operation may be more of a controlling factor in water-soluble phosphorus than formulation.

10-10-10 Grades Water-soluble phosphorus does not seem to be depressed by the nitrogen carriers in high nitrogen grades. Table VI gives the water-soluble phosphorus in 10-10-10 grades made in different plants using varying formulations. The presence of sulfuric acid appears to promote high phosphorus solubility although this advantage is less in the presence of lime. It is evidently possible to maintain a high percentage of water-soluble phosphorus in high-nitrogen and concentrated fertilizer grades even in a conventional fertilizer plant. A number of analyses in this table show a low percentage of water solubility. Probably careful control of physical factors such as temperature and moisture during both the blending and storage of the mixtures is important.

Dry Mix Grades Because many of the fertilizer plants over the country are dry mixing plants, one such plant was selected to observe the effect of dry mixing upon the water-soluble phosphorus content. The results of these observations are given in Table VII. 4-10-7 and 6-8-4 grades were formulated largely from a previously ammoniated superphosphate, 5-17-0. It would seem that the dry mixing of a previously ammoniated superphosphate, and even the addition of lime, have little effect on the water-soluble phosphorus content.

Table VII. Water-Soluble Phosphorus Content of Miscellaneous Grades, Formulated at One Plant from Previously Manufactured Ammoniated Superphosphate

Grade	Additions to Ammoniated Superphosphate: $(NH_4)_2SO_4$	KCl	Lime	Moisture Content, %	Water-Soluble Phosphorus %
4-10-7	+	+	+	3.63	53.1
	+	+	+	3.20	54.1
	+	+	+	3.61	56.9
	+	+	+	3.01	58.1
5-17-0	..	..	..	7.18	56.0
	..	..	..	7.05	56.4
6-8-4	+	+	+	2.20	56.0
	+	+	+	2.04	55.1
	+	+	+	2.01	55.3
				Av. 2.81	55.5

Random Grades It was thought that a better picture of the water-soluble phosphorus content of a fertilizer might be obtained if random samples were selected from a number of fertilizer grades in several plants. Table VIII gives an indication of some of the materials used in formulation, as well as the water-soluble phosphorus and moisture content. The data are arranged in ascending nitrogen content of the grades. There are very few duplicate samples from the same plant, but there are samples of the same grade from different plants. The data in this table indicate that the higher the concentration of nutrient, the greater the water-soluble phosphorus content. This soluble phosphorus may be associated with salt concentration, although other factors in manufacturing

Table VIII. Water-Soluble Phosphorus Content of Miscellaneous Grades Formulated at Several Plants

Plant Designation	Grade	Materials Added[a]: $(NH_4)_2SO_4$	Organic nitrogen	H_2SO_4	Lime	Moisture Content, %	Water-Soluble Phosphorus, %
T	2-12-6	−	−	−	+	3.60	39.9
V	3-9-9	−	+	−	+	4.62	40.8
U	3-9-18	+	−	−	+	1.85	36.6
B	4-8-6	+	−	−	+	1.60	22.6
V	4-8-6	+	+	−	−	3.05	27.6
Q	4-8-8	−	+	−	−	3.67	47.7
X	4-10-6	−	−	−	+	4.36	37.1
K	4-10-6	+	−	−	+	3.10	35.7
A	4-10-8	−	+	−	+	3.90	53.8
A	4-12-12	−	+	−	−	5.50	55.6
D	4-16-16	−	−	−	−	4.00	19.9
M	5-7-5	+	+	−	−	1.70	28.9
Z	5-8-7	+	+	−	+	3.43	37.8
Z	5-8-7	+	+	−	+	3.41	37.1
C	5-10-10	−	−	+	−	3.90	42.5
C	5-20-20	−	−	−	−	3.41	55.8
M	6-6-6	−	+	−	−	2.90	46.3
H	6-8-4	−	−	−	+	4.15	36.7
T	6-8-6	+	−	−	+	1.72	24.9
G	6-8-6	+	−	−	+	2.35	30.7
W	6-8-8	+	−	−	+	2.76	36.0
H	6-8-8	+	−	−	+	2.95	42.9
L	6-9-12	+	−	−	+	3.87	20.9
W	6-12-12	+	+	−	−	2.70	59.5
U	7-14-7	−	−	+	−	3.55	50.6
L	8-12-12	+	−	−	+	3.65	38.6
C	8-16-16	+	−	+	−	1.40	62.5
C	10-20-10	+	−	+	−	2.30	57.2
I	10-20-10	−	−	+	−	1.15	69.7
U	12-12-12	+	−	+	−	1.95	57.2
						Av. 3.05	41.8

[a] In addition to ammonium nitrate solution.

Table IX. Water-Soluble Phosphorus of a Wide Range of Grades at a Central Plant

Grade	Materials Added[a]: Nitrogen	H_2SO_4	Lime	Moisture Content, %	Water-Soluble Phosphorus, %
0-14-7	−	−	−	7.96	56.5
	−	−	−	7.95	56.8
2-12-6	NO_3	−	−	5.11	51.9
		−	−	4.22	51.8
3-12-12	Urea	+	+	2.34	62.3
		+	+	2.42	62.5
4-12-8	Urea	+	+	4.10	71.9
		+	+	3.88	72.5
		+	+	4.01	47.4
		+	+	4.05	47.5
4-16-16	Urea	+	−	5.30	74.5
		+	−	4.80	73.0
5-10-10	NO_3	+	+	1.17	73.9
		+	+	1.05	75.4
5-20-20	Urea	−	−	3.21	63.3
		−	−	3.10	63.1
6-8-6	Urea	+	+	2.67	49.4
		+	+	2.62	49.3
6-6-18	Urea	+	−	2.06	56.8
		+	−	2.05	56.9
6-12-12	Urea	+	−	1.40	66.8
		+	−	1.35	66.9
8-16-16	Urea	+	−	2.51	44.5
		+	−	2.35	42.7
10-10-10	Urea	+	−	0.46	69.6
		+	−	0.72	70.4
				Av. 3.19	60.7

[a] In addition to superphosphate and potassium chloride.

Table X. Water-Soluble Phosphorus Content of Several Grades Formulated at a Southern Plant

Grade	Materials Added[a] $(NH_4)_2SO_4$	$NaNO_3$	Organic nitrogen	Lime	Moisture Content, %	Water-Soluble Phosphorus, %
3-9-6	−	+	+	+	3.65	37.9
	−	+	+	+	2.53	23.9
	+	−	+	+	3.48	53.2
	+	−	+	+	3.40	55.1
3-9-9	−	+	+	+	3.62	57.9
4-8-8	+	−	−	+	2.06	38.3
4-8-12	−	+	+	−	2.99	47.4
	−	+	+	−	2.65	47.7
4-10-6	+	−	−	+	3.74	33.3
	+	−	+	+	3.10	35.7
4-12-12	−	−	−	+	4.15	36.3
	−	−	−	+	3.90	36.2
5-10-5	+	−	−	+	3.30	56.2
	+	−	−	+	3.50	30.1
5-10-10	−	+	−	+	2.38	37.8
6-8-6	+	−	−	+	2.95	43.3
8-8-8	+	−	−	+	2.70	35.6
					Av. 3.18	41.5

[a] In addition to ammonia and ammonium nitrate solution.

may be important. Lime may have a depressing effect on the water-soluble phosphorus content of fertilizer.

Plant Results

Central Plant A large number of grades from one plant were selected to study the effect of grade changes on the water-soluble phosphorus content, as it was thought there should be less variation in mechanical treatments. Table IX presents the data for a central plant. With few exceptions, the method of manufacture in this plant appears to be favorable for the production of fertilizers high in water-soluble phosphorus. Sometimes lime appears to depress the phosphate solubility; in other cases it does not. In this plant urea solutions were used to produce a fertilizer mixture with high water-soluble phosphorus content. This plant has good facilities for controlling manufacturing factors such as temperature, time, moisture, drying, and cooling. This may explain why the plant's fertilizer mixtures are rather high in water-soluble phosphorus.

Southeastern Plant Several grades manufactured at a southeastern plant were selected for test. Table X gives a strong indication that lime may depress the solubility of the phosphorus in these fertilizers. The concentrated fertilizers—those with the most units of plant food—were practically as low in water-soluble phosphorus as the low nutrient grades. The wide variations and generally low results indicate that the manufacturing methods used in this plant may be responsible for the somewhat lower water-soluble phosphorus. This plant does not have a dryer or cooler. The moisture content of the fertilizer, the slow cooling, and the long time allowed for reacting in the pile may be responsible for the low water-soluble phosphorus content.

Midwestern Plant One of the midwestern plants was selected for study of random analysis. The data in Table XI indicate that lime may be responsible for low water-soluble phosphorus content, although other factors, such as low ammoniation and lack of sulfuric acid, may also play a part. The use of sulfuric acid to help retain the nitrogen seems to be favorable to high water-soluble phosphorus content. The fact that this plant has facilities for rapid drying and cooling of the fertilizer mixture may be partially responsible for the favorable water-soluble phosphorus data. The data indicate that in this plant the more concentrated the fertilizer the higher is the water-soluble phosphorus content.

Southwestern Plant Grades were selected at random at one southwestern plant to observe the effect of grades and formulation on the water-soluble phosphorus content (Table XII). The high water-soluble phosphorus content of the fertilizer mixtures produced in this plant, which has rapid drying and cooling facilities, indicates that the manufacturing processes used may be the desirable ones for maintaining this phosphorus solubility. These favorable results were obtained by different nitrogen solutions with and without the use of sulfuric acid. Another striking thing indicated in this table is that the dry samples, or those

Table XI. Water-Soluble Phosphorus of Several Fertilizer Grades Manufactured at One Middle West Plant

Grade	Materials Added[a] $(NH_4)_2SO_4$	H_2SO_4	Lime	Moisture Content, %	Water-Soluble Phosphorus, %
0-20-0	. .	. .	. .	4.80	87.0
	. .	. .	. .	6.01	92.5
3-9-18	−	−	+	3.25	33.2
3-12-12	−	−	+	1.65	34.9
4-16-16	−	−	−	2.27	54.8
	−	−	−	2.72	59.1
5-20-20	−	+	−	1.15	53.8
6-24-0	−	+	−	3.55	69.8
8-32-0	−	+	−	3.50	69.9
10-10-10	+	+	−	0.58	55.4
10-20-10	+	+	−	1.90	71.0
	−	+	−	2.11	67.7
12-12-12	+	+	−	0.70	57.5
				Av. 2.63	62.0

[a] In addition to ammonium nitrate solution.

Table XII. Water-Soluble Phosphorus Content of Several Grades Manufactured at Southwestern Plant

Grade	Materials Used in Formulation: Nitrogen solution	H_2SO_4	Lime	Moisture Content, %	Water-Soluble Phosphorus, %
5-10-5	NO_3	−	+	1.45	60.1
7-14-7	NO_3	+	−	3.55	70.0
8-24-8	NO_3	+	−	3.17	59.8
		+	−	3.12	60.1
10-10-10	NO_3	+	−	2.52	61.6
10-20-10	NO_3	+	−	1.57	71.3
15-15-0	Urea	+	−	3.07	49.2
		+	−	1.20	61.2
				Av. 2.46	61.7

with low moisture content, usually have a higher content of water-soluble phosphorus.

Conclusions

In this study not enough samples represented any given set of chemical, mechanical, and physical conditions to prove any point. However, trends in results did suggest some factors or group of factors which influenced the water solubility of phosphorus in these fertilizers. Any addition to superphosphate (except sulfuric acid and borax) reduced the percentage of water-soluble phosphorus. High moisture in mixed goods usually reduced the content of water-soluble phosphorus, unless the superphosphate had been previously based down as ammoniated superphosphate. Rapid drying and cooling to decrease the moisture content generally maintained a high percentage of water-soluble phosphorus. Mechanical steps in plant operation could be an important factor to watch in maintaining high water-soluble phosphorus.

The average water-soluble phosphorus value for about 250 samples was 48.4%, well within the limits of 40 to 50% proposed by research agronomists. Less than 23% of the samples failed to reach the minimum value of 40%. These lower values were mostly from the southeastern part of the country, where the need for a high water-soluble phosphorus is less, as most soils have been fertilized for a long time and are higher in available phosphorus, and from the older and less modern plants. As the more modern plants manufacture fertilizer of consistently higher values, it seems that fertilizer of 60 to 65% water-soluble phosphorus content can be made in a regular fertilizer plant with the usual fertilizer ingredients, if continued agronomic study suggests that this is desirable.

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ATMOSPHERIC POLLUTION

Spanish Moss and Filter Paper Exposures for Detection of Air-Borne Fluorides

W. H. MacINTIRE,[1] MARY A. HARDISON, and DELLA R. McKENZIE

The University of Tennessee Agricultural Experiment Station, Knoxville, Tenn.

Intensities of fluorine emissions to the atmosphere in certain eastern and central Tennessee locales were determined by month-long covered field-exposures of Spanish moss in cotton (cord), nylon, and dacron bags and of 12.5-cm. limed filter papers. Fixations in covered cord and nylon bags were similar to and greater than fixations in the less porous dacron bags, and were greater in the outer zones than in the cores of the moss. Drying the moss decreased its capacity to fix air-borne fluorides. Fixations by the moss in the protected cord and nylon bags and by protected limed filter papers were consistently concordant in spotting high and low occurrences of fluorine in the atmosphere.

The washdown of fluorides and their fixation by Spanish moss have served to indicate atmospheric emissions deemed responsible for abnormal incidence of fluorine in nearby field crops (*6*) and a resultant economic problem in livestock farming (*5*). The quantities of fluorine carried by single rainfalls at six locations in 1948, 1949, and 1950 were reported in 1952 (*8*) and, in 1951, atmospheric occurrences were determined also through the quantities fixed in month-long exposures of Spanish moss at multiple locations in relation to industrial emissions in three Tennessee counties (*7*).

No fluorine contamination occurred in the vegetation grown in pot cultures at Knoxville, but fluorine content increased during further growth outdoors at the Middle Tennessee Station, although not in the transported vegetation grown in the fluorine-free atmosphere of an adjacent chamber (*7*). Thus the transported plants acquired fluorine from both soil and air during their 21 days' growth at Columbia, whereas the plants in the chamber derived fluorine solely from the soil.

The atmosphere near Knoxville was examined frequently through exposures of sodium carbonate and hydrated lime, and hydrofluoric acid was identified as the chief fluoric contaminant at the university's Blount County Farm, some 6 miles from the manufacture of aluminum in a large operation (*6*). Hydrofluoric acid was identified also as the chief fluoric emission in the thermal conversion in the defluorination of Tennessee brown rock phosphate into "fused tricalcium phosphate" (*4*), whereas hydrofluosilicic acid and silicon tetrafluoride are emitted in the nodulization of charges of rock phosphate for the electric reduction furnace and in acidulations of rock phosphate. At one time all three processes were in operation in Maury County.

The findings reported here were from further studies of the fixation of atmospheric fluorides by Spanish moss, variously bagged, and by exposures of limed filter papers at multiple locations in Blount and Maury Counties.

Source and Composition of Moss

Several 100-pound supplies of moss were obtained at intervals from the same

[1] Present address, 4201 Twenty-eighth Ave., No., St. Petersburg, Fla.