

1924

Physical properties of fertilizer materials

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<https://doi.org/10.7275/6871354>

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PHYSICAL PROPERTIES OF FERTILIZER MATERIALS

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PHYSICAL PROPERTIES OF FERTILIZER MATERIALS.

Raymond Alson Mooney

Thesis submitted for the
Degree of Master of Science

Massachusetts Agricultural College

Amherst

June, 1924.

Contents.

I.	Statement of purpose and general introduction.	Page 1
II.	Limitations of the investigation.	5
III.	Review of literature.	7
IV.	Survey of the problem.	12
V.	Treatment of the problems involved.	13
VI.	Results of the investigation:	
	A. Materials under different conditions of storage.	22
	B. Analysis of the materials used.	27
	C. Data for materials exposed to varying conditions of humidity.	29
	D. General summary of data.	48
VII.	Discussion of data.	56
VIII.	Summary.	60
IX.	Bibliography.	62
X.	Acknowledgments.	64

PHYSICAL PROPERTIES OF FERTILIZER MATERIALS.

A statement common to most text-books dealing with fertilizer materials is that such salts as sodium nitrate, muriate of potash and others of a similar nature are decidedly hygroscopic or even deliquescent when exposed to an atmosphere of high relative humidity. In spite of the importance of hygroscopicity and its possible resultant caking, there is a paucity of definite information regarding these important physical properties of fertilizer materials and the conditions under which they prevail. That the factors involved are important is admitted, though they may concern not so much the manufacturer who has facilities for the handling and storing of fertilizers as the small dealer and farmer. Not infrequently, fertilizers that are stored for a few weeks under poor conditions may become physically unfit for use unless reground or otherwise restored. With such conditions it is reasonable to believe that other changes may take place that are detrimental to the value of the fertilizer.

There is also a further possibility that some materials, not usually considered hygroscopic may absorb

water in quite large amounts when exposed to an atmosphere of more than average humidity; and in case of mixtures, this moisture may later be reabsorbed by the more hygroscopic materials. Van Harreveld-Lako⁽¹⁰⁾ found that urea would withdraw moisture from ammonium sulphate at certain humidities. Regardless of the significance of these statements, the fact that such fertilizers do absorb from 15% to 25% moisture under average conditions of humidity seems of sufficient importance to be considered.

It should be remembered that our knowledge regarding the properties and use of fertilizers is still undeveloped; we need but review a few of the publications of the agricultural experiment stations to verify this. Furthermore, this same literature suggests that we are entering an era of new fertilizers. Air-nitrogen products, double salts of ammonia and phosphoric acid and other highly concentrated materials are now or soon will be on the market. Ideas are being changed, conclusions revised, conceptions broadened; and investigators, in general, are searching with a larger application of the problem.

Purpose.

The purpose of this investigation is first, to study the hygroscopicity of fertilizer materials under known conditions of humidity and temperature; and second, to determine the amount of caking resulting from such exposures. A consideration of the problem suggested the following questions:

1. Is not definite information of these physical properties desirable for those handling fertilizer materials, be they manufacturer, dealer or farmer?
2. Is the absorption of moisture by fertilizers during periods of high humidity of an amount sufficient to affect their value?
3. Will the usefulness of some of the new materials be impaired because of their hygroscopicity?
4. Is the hardness of caking correlated with the humidity to which the fertilizers have been exposed?
5. Under average conditions of humidity does sodium nitrate, muriate of potash and similar salts carry as high content of moisture as their appearance would indicate?
6. Can the advisability of storing fertilizers in cellars or other enclosed spaces be determined from a knowledge of the average humidities of such places?
7. Is the lack of literature and information concerning this subject a proper criterion for determining the value of such an investigation?

It will be shown by experimental data that those fertilizer materials not considered hygroscopic will under average conditions of humidity have a very high moisture content, and that some materials mentioned as hygroscopic have a much lower water content than is generally believed. It will also be shown that with most materials the absorption of moisture in excessive amounts takes place only at times of high humidity, and that in a closed cellar or room fertilizers could be stored without cakiness or absorption of moisture if the humidity be maintained but very little below average.

In this thesis hygroscopicity is construed to mean the taking in of moisture by both adsorption and absorption, for which the word sorption has been suggested but which has not come into general use. In the case of finely divided organic materials adsorption is the dominant factor in hygroscopicity whereas with inorganic substances absorption becomes dominant at certain humidities.

Theoretically, hygroscopicity and deliquescence of inorganic materials are dependent upon the solubility of the material. Since the rate of solubility, and in most cases solubility varies with the temperature it would seem that hygroscopicity must be correlated with temperature. On the other hand, hygroscopicity is a result of the difference in vapor pressures between that

of the atmosphere and the solution formed by the dissolving material. If this relative differences/ in vapor pressures does not change with temperature, then it would follow that temperature does not affect hygroscopicity. That this may be true for some salts at certain humidities and within limits of temperature is indicated by the following data: using the vapor pressures of saturated salt solutions as found by Edgar and Swan⁽²⁾ and computing the ratio between the vapor pressure of a saturated solution of muriate of potash and that of the atmosphere at 78% humidity we find it to be 1 : 0.9047 at 68 F, and 1 : 0.9046 at 75 F, or practically the same; with a saturated solution of sodium nitrate at the same humidity this ratio is 1 : 1.037 at 68 F, and 1 : 1.039 at 78.8 F.

Particular attention will be given to the condition and behavior of the materials under the various treatments and also to data which may suggest other phases of the problem worthy of further investigation.

Limits of the Investigation.

The conclusions reported in this study are subject to some limitations. In work of this nature where days or weeks must elapse before getting single determinations, time is necessarily a limiting factor in the

scope of the problem. The preliminary investigation to ascertain the best methods for conducting the study became much more involved than was anticipated. More than 400 determinations were made before a procedure could be adopted that best suited the conditions of the problem. The amounts of fertilizer to use, the length of time for exposing the samples, the method of drying, and the number of samples necessary for significant results, were all factors that had to be determined by experiment.

Considerable difficulty was experienced in drying the samples at the temperature called for by the official method. There were losses that could not be explained until samples were dried over concentrated sulphuric acid or in the oven at a low heat before finally finishing at the required temperature. (10) Van Harreveld-Lako in his work on the hygroscopicity of fertilizers dried the samples over calcium oxide before exposing them. This method was tried and it was found to give a large experimental error. For example, sodium nitrate was set over sulphuric acid with a specific gravity of 1.205 giving a relative humidity of 78%. The ten samples that were oven-dried before exposing gave a probable error of the mean of ± 0.974 ; the ten samples that were not oven-dried until after exposure gave a probable error of the mean of ± 0.108 . Uniform fineness of material was another important factor in

affecting the probable error of the mean of samples subjected to the same humidity. Sodium nitrate was set at the same humidity with different degrees of fineness; that which passed a 1mm but not through a 0.5mm sieve, and that which passed the 5mm sieve. The average results for the coarser material was 35.39% moisture with a probable error of the mean of ± 0.276 , for the finer material 33.01% moisture and a probable error of the mean of ± 0.526 . The time of the exposure was 163.5 hours at a temperature of 20 degrees. A slight difference in the character of the supports in the humidors was another cause of serious error.

Review of Literature.

The literature contains but very little information on the physical properties of fertilizers and the writer was able to obtain but two references dealing with the subject.

(10)

Van Harreveld-Lako at Pasoerean, Java, studied certain nitrogenous fertilizers with the purpose of determining whether their hygroscopicity would prevent their usefulness to the sugar growers on the Island. Since many of the materials used were pure salts and not fertilizers the value of the results for purpose of comparison is considerably discounted.

The relative humidities used in the trials were based on five year (1913 - 1917) averages for January,

This article was borrowed from the U. S. D. A. Library, Washington, D. C., and was translated by Mr. Henry Louwsma.

February and August at Assembagoes, Rogodjampi, Pasoerean, Pekalongan and Batavia, all places on Java. The required humidities were obtained by diluting sulphuric acid according to data given in the physical tables of Landolt, (5) Bornstein and Roth .

The samples of fertilizers were dried over calcium oxide before exposing and again dried to constant weight over the same material after exposure. About 40 to 50 grams of fertilizer were used for each sample. The samples were weighed and the acid renewed frequently during the time of exposure.

Results at 75.5 % humidity:

Sodium nitrate (p), urea (p), ammonium chloride, ammonium sulphate (p), potassium nitrate (p), and ammonium phosphate (p) remained constant in weight during the time exposed. Ammonium sulphate nitrate gained 4.6 % moisture in six days and was moist. At the end of 35 days it was nearly in complete solution with 22% moisture. The ammonium nitrate absorbed 8.6 % moisture in six days, 48.2 % in 35 days and was completely dissolved. The urea (f) gained 12.3 % moisture in 2 1/2 months and was still absorbing water when the test was discontinued.

Results at 82.9 % humidity:

The potassium nitrate remained constant in weight. Sodium nitrate took up water rapidly and after 28 days it contained 13.5 % moisture and was partially dissolved.

Ammonium chloride (f) absorbed 20.4 % moisture in three months and showed no evidence of liquefaction. Urea (p) in 2 1/2 months took up 32.4 % moisture and but few crystals were left. The urea (f) absorbed 38.6 % water in the same time and was nearly dissolved. The ammonium phosphate (p) had taken up 0.8 % moisture in 17 days when the experiment was discontinued.

The fact that ammonium nitrate had become partially liquefied when it had taken up 13.5 % water and the ammonium chloride showed no evidence of liquefaction with 20.4 % moisture was attributed to the greater solubility of ammonium nitrate in water.

Results at 87.2 % humidity:
(p)

Potassium nitrate was the only material that did not absorb moisture at this humidity.

Results at 70.4 % humidity:

Urea (f) lost 1% moisture in 9 days while sodium nitrate (f) gained 0.6 % in the same time. It was believed that a very slight decrease in the humidity would prevent the sodium nitrate from absorbing water.

Ammonium sulphate saltpeter was a mixture of ammonium sulphate and ammonium nitrate.

(p) means chemically pure.

(f) means average fertilizer material without regard to purity.

Comparative results between sodium nitrate (f) and urea (f).

Strength of acid.	Relative humidity.	% moisture urea (f).	% moisture sodium nitrate (!)
31.55 %	72.9	0.4	3.6
30.00	75.5	1.9	5.4
28.50	77.8	3.0	6.5
27.00	79.7	4.4	7.6

General conclusions:

Ammonium sulphate nitrate, sodium nitrate (f), urea (f), ammonium chloride and ammonium sulphate decrease in hygroscopicity in the order named. It was concluded that ammonium sulphate nitrate could not be used on Java and that where it is impractical to use sodium nitrate, on account of dampness, it is thought that urea or ammonium chloride may be substituted without any special difficulty.

Where humidities are stated in this review they were computed by the writer from the given vapor pressures. The change was made because humidity is the more familiar term.

(2)

Edgar and Swan determined the vapor pressures of saturated solutions of typical water-soluble solids, not forming crystalline hydrates, at temperatures varying from 20 C to 30 C. The substances worked with were potassium and ammonium nitrates, potassium and ammonium chlorides,

ammonium and dihydrogen orthophosphate, and urea. The selection was made to include materials of various degrees of solubility and of different chemical types. The work was attempted because of the paucity of data and lack of concordance in such data as exist upon the saturated aqueous solutions of the substances in question at low temperatures.

The method of procedure in the investigation was that proposed by Smith and Menzies employing the isoteniscope. Since this method is concerned wholly with a problem in physical chemistry it will not be discussed further.

Results in part follow; Vapor pressure in mm mercury:

Temperature	muriate of potash	sodium nitrate	ammonium nitrate	Urea.
19	13.97	12.34	10.46	13.37
20	14.97	13.06	11.10	14.15
21	15.98	14.02	11.79	14.93
22	17.01	14.87	12.48	15.73
23	18.05	15.76	13.21	16.56
24	19.10	16.70	13.96	17.44
25	20.20	17.83	14.73	18.39
26	21.37	18.72	15.51	19.39

Temperature O C.	Ammonium sulphate	Ammonium sulphate potassium nitrate	Ammonium dihy- drogen phosphate
19	13.30	11.99	15.31
20	14.20	12.73	16.33
21	15.12	13.51	17.41
22	16.09	14.31	18.51
23	17.11	15.15	19.66
24	18.06	16.03	20.82
25	19.26	16.92	22.09
26	20.42	17.82	23.47

Survey of the Problem.

The selection of a satisfactory method for conducting the study necessitated the consideration of a number of minor problems that had a possible bearing on the value of the results to be obtained. Some of these questions were decided by getting experimental evidence; others were arbitrarily determined by the limitations of the problem; a few were largely a matter of choice.

The following were the most important questions considered in working out the general plan:

1. Materials to be used.
2. Temperatures at which to work with and the methods of controlling them.
3. Humidities to be used and the method of obtaining them.
4. Treatment of the material before exposure.
5. Degree of fineness of the material when exposed.
6. Quantity of material necessary for satisfactory results.
7. Containers to be used.

8. Length of time to expose the samples.
9. Method of drying the samples after exposure.
10. Amount of acid and the necessity of changing the acid during exposure.
11. Purity of the samples.

Treatment of the Problems Involved.

1. Materials. For the determination of hygroscopicity, it was decided to use the common commercial materials and as many of the newer fertilizers as could be obtained. The fertilizers used were ammonium nitrate (crystalline), ammonium nitrate (granular), ammonium sulphate nitrate, calcium nitrate, sodium nitrate, ammonium sulphate, urea, calcium cyanamid, dry ground fish, tankage, cottonseed-meal, bone meal, acid phosphate, calcined phosphate, rock phosphate, kainite, muriate of potash, potassium sulphate, 4-8-4 mixtures: (1) sodium nitrate, acid phosphate, and muriate of potash; (2) sodium nitrate, tankage, acid phosphate, and muriate of potash; (3) sodium nitrate, acid phosphate, muriate of potash and peat filler.

2. Temperature. The average of the mean monthly temperatures for June, July and August for the five-year period, 1918-1923 was found to be 68.2 F or 20.1 C. Since a considerable amount of the trouble caused by hygroscopicity

occurs during the warmer months, the temperature of 20.1 C was chosen as the most desirable for our purposes. A solution to the problem of keeping the humidors at this required temperature was found in a small interior 6' by 10' room that was built for photographic work. The temperature was nearly constant at 20 C, in this room, and such slight variations as did occur were corrected by a tank of running water.

3. Humidities. The average of the mean monthly humidities for June, July and August for the same five-year period was found to be 78.0 % and since this was of some significance, a part of the determinations of hygroscopicity were based on this humidity. The highest humidity found was 97.5 % and this was chosen to study the effect of such a high degree of saturation upon some of the materials not thought of as hygroscopic. A humidity of 87.75 %, midway between the average and the highest, and one which commonly occurs, was taken as a third. It was desirable, if possible, to establish the humidities at which the vapor pressures of the saturated solutions of the materials would be in equilibrium with the vapor pressure of the atmosphere and consequently no absorption of moisture. A computation based on the vapor pressures of saturated solutions at 20 C as found
(2)
by Edgar and Swan would establish these equilibria for sodium nitrate, ammonium nitrate, and urea at 75.22 %, for sodium nitrate, ammonium nitrate, and urea at 75.22 %, and urea at 75.22 %.

63.87 %, and 81.49 % humidity, respectively. These computations correspond very closely with the experimental data obtained by Van Harreveld-Lako⁽¹⁰⁾ for the pure materials.

However, the materials used were impure salts and the vapor pressures may be slightly lower than in case of the pure materials. This is indicated by the fact that Van Harreveld-Lako⁽¹⁰⁾ found sodium nitrate (fertilizer) absorbed moisture at a humidity of 70.4 % while sodium nitrate (c.p.) did not gain in weight at a humidity of 75.5 %. The data of Van Harreveld-Lako⁽¹⁰⁾ also suggests that this may not be true in all instances since ammonium nitrate absorbed more moisture at a humidity of 75.5 % than a mixture of ammonium nitrate and ammonium sulphate.

From the above discussion it will be seen that a humidity approaching the desired equilibrium for more than one material could be only approximated, and because of this, humidities of 73 % and 68 % were chosen as possessing the greatest possibilities for the establishment of the degree of atmospheric saturation where no moisture would be absorbed by the fertilizers.

The humidities were obtained by diluting sulphuric acid to such a strength as to give the desired vapor pressure. The dilutions were computed from the tables given by Landolt, Bornstein and Roth.⁽⁵⁾ The dilutions of the acid,

based on a temperature of 20 C, were as follows:

Per cent acid	Specific gravity	Vapor pressure	Relative humidity
3.51	1.023	16.930	97.5 ⁴
<u>17.77</u>	1.126	15.236	87.75
27.98 ^{28.7}	1.205	13.550	78.04
31.55 ^{32.05}	1.234	12.675	73.00 [✓]
34.62 ^{34.67}	1.260 ^{1.2571}	11.807	68.00 [✓]

Six-inch desiccators, provided with coarse wire screen for supporting the boxes, were used for humidors. 200 cc. of acid was used in each humidor for hygroscopicity determinations. The acid was not changed during the time of exposure and was not used a second time without standardizing to the original specific gravity.

4. Treatment of the materials: The fertilizers were kept in glass stoppered bottles and were not dried before using except in case of ammonium nitrate and sodium nitrate which were dried on the bench to facilitate sieving. (10)
 Van Harreveld-Lako in his work on hygroscopicity dried the samples before exposing them, but it was found in the preliminary trials that such a method gave greater variations in the results, probably due to the effect of heat in coagulating colloidal organic materials and thus affecting hygroscopicity, for this reason the method was not used. All of the material was thoroughly mixed before taking the sample in order to insure uniformity.

5. Fineness of material. It is not feasible to work with the materials in the condition in which they came from the bags because it would have required much larger samples, larger humidors and a correspondingly longer time of exposure. Therefore, the fertilizers were sieved in order to meet the conditions under which we were working. In the preliminary trials with samples passing a 1mm but not a 0.5 mm sieve, and that passing the 0.5 mm sieve, the results in the first instance gave a slightly smaller probable error of the mean. However, we did not seem justified in discarding the finer material and the samples were graded to all passing the 1 mm sieve.

6. Quantity of material. In the preliminary trials the amounts of fertilizer were varied from 20 to 50 grams and it was found that these quantities were too large for the humidors and the volume of the acid. Obviously, if 250 grams of material were subjected to the effects of 200 cc of acid in a six-inch humidor the withdrawal of water from the acid by such a volume of fertilizer would appreciably affect the specific gravity of the acid and would correspondingly change the humidity. Because of these reasons, the samples were taken in an amount that would cover the bottom of the container at a uniform depth of about 0.6 cm. The same volume was used in all of the determinations even though the weight varied slightly with the different fertilizers. It was also found by trial that this method gave

more uniform results in the time that could be allowed for exposure.

7. Containers. The fertilizers were exposed in two-inch aluminum boxes that were provided with closely fitting covers. The containers were covered at all times except during exposure and drying and any change in weight due to evaporation while handling and weighing was reduced to a minimum. The containers were washed, oven-dried and weighed each time they were used.

8. Time of exposure. The question of the length of time for exposing the fertilizers resolved itself into two possibilities; exposing the materials until they no longer absorbed moisture, or limiting the exposure to a definite time. An objection to the first procedure was that in case of the salts which are deliquescent the vapor pressures of the acid and the salt solution may require a long time to reach an equilibrium. In fact, during the preliminary trials, sodium nitrate, in 53 days, absorbed moisture until the container was filled without becoming constant in weight. Furthermore, if it were desirable to obtain the total absorption of any salt at a given vapor pressure it could be done by other methods much more quickly. Also, if the materials were exposed at different lengths of time, the results being on a different basis would have no comparative values.

In the preliminary trials samples were set at lengths of time varying from 7 to 53 days. It was found that with the volume of acid and material as stated, seven days gave the most satisfactory results and the hygros-copcity determinations were made at this length of time.

9. Drying the materials. ⁽⁷⁾ The samples were dried according to the official method which states that sodium nitrate, ammonium nitrate, ammonium sulphate and the potash salts should be dried to a constant weight at 130 C, other materials dried at 100 C. Calcium nitrate was dried at the higher temperature. When the samples were very moist, it was necessary to dry them in a desiccator or at a very low heat before subjecting them to the required temperature. The reason for this was that the salts would "crawl", if dried too rapidly, and cause inaccurate results.

10. Necessity of changing the acid during the exposure. Since it requires a little time for the attainment of the desired humidity after the humidors are set, frequent changes seemed undesirable. With only five samples of fertilizer in each humidor and the short time of exposure, it was thought best not to disturb them, or change the acid, until the samples were weighed at the end of seven days. The data indicates that we were justified in this decision. For example, sodium nitrate at 97.5 % humidity absorbed approximately 38% water. The total loss of weight on drying

the samples was 9.7921 grams. Assuming that all of this water was removed from the acid it would cause an increase in the strength of the acid of 0.18% and would change the humidity about 0.1%, a difference inside the limit of experimental error. With acid giving a humidity of 97.5% potassium sulphate in seven days caused a change in the specific gravity of 0.003, a negligible amount.

11. Purity of the samples. The samples were commercial fertilizers and their purity consisted of being free from mixtures with other materials. Qualitative tests were made to confirm the presence of impurities in the various salts.

Cakiness.

Since cakiness in fertilizers is a resultant of exposure to unfavorable moisture conditions it was thought desirable to associate the study of caking with that of hygroscopicity. The problem while stated apart from the declaration of purpose of this work is in no sense separate from it. It is purposed to measure the degree of caking of fertilizer materials resulting from exposures to known humidities, to obtain comparative data for each of the materials studied and to attempt to correlate the degree of caking with the humidity to which the material was subjected. The data cited must necessarily be comparative and subject to some limitations in its application.

Method.

The materials were exposed under the same conditions as for the determination of hygroscopicity except that the amount of acid was increased to 350 cc and the time lengthened to 14 days to correspond with the larger amount of fertilizer used for the samples. After exposure the material was immediately transferred to molds made from 1/2" brass pipe cut to 1 1/4 " lengths and which were greased and lined with paper in order that the caked material might be removed without injury. The fertilizers were allowed to dry in the molds, and, with the exception of muriate of potash and ammonium nitrate which were dried in the oven at 40 C, were all dried on the bench in the room. After drying, the cylinders of caked fertilizer were cut to 1/2 " lengths in which form they were used for the determination of cakingness. The tests were made with a testing machine capable of recording weights from 1 to 200 pounds. The molded material for testing was placed on an iron bar and under an iron stirrup which gave a definite crushing point. The hardness of caking was interpreted in terms of the number of pounds of pressure per square inch required to shatter the cylinder of material. The sources of error and limitations of the investigation will be discussed in the summary.

Moisture Content of Fertilizers under Different Conditions of Storage.

- - - - -

It was desirable to have data on the moisture content of fertilizers that had been in storage; first, for comparison with materials that had been exposed to known humidities, and second, to ascertain whether the per cent of moisture was high enough to affect the value of the fertilizer. For this purpose samples were collected from the fertilizer stock of the Experiment Station, Grounds Department, Pomology Department and Higgins and Company, South Deerfield. The samples were collected September 19th, the exception being those from Higgins which were obtained about October 1st.

The mean monthly humidities for the six months preceding the date of sampling were as follows: April 63.3 %, May 66.9 %, June 70.2 %, July 77.0 %, August 77.0 %, September to 19th 77.6 %, whole month 81.5 %. It will be seen that it was at the end of a period of very low humidity. In fact the mean humidities of 65.3 % and 66.9 % for April and May were the lowest recorded for any month during the five year period. For this reason, the moisture contents are probably lower than they would be after a period of higher humidity.

Experiment Station:

Sodium nitrate, sulphate of potash, muriate of potash, acid phosphate and sulphate of ammonia were obtained from the Station. The materials had been stored since spring on a cement floor in a building used solely for the purpose. The different fertilizers were piled in separate places and were in good condition.

Grounds Department:

The fertilizers were piled together on boards resting on the dirt floor of an under-ground shed. All of the fertilizers had been there since spring and some since the previous year. The materials were in poor physical condition, especially the sodium nitrate, which was caked very hard.

Pomology Department:

The materials were piled together on a cemented portion of a shed floor. They had been stored since spring and even longer and were in poor physical condition.

Higgins and Company:

All of the materials were obtained from the main storage building at the plant. The acid phosphate had been stored in bulk for eight months. The steamed bone was considered an adulterated product and had been stored in bags since the previous spring. The cyanamid had been stored in bags approximately nine months. There were two

lots of ground fish, one of recent purchase and freshly ground and another which had been stored in bulk for three months. The tankage had been stored ⁱⁿ bags for three months; hoof meal, seven months; rape seed meal (coarse), two months; rape seed meal (fine), a longer time. All of the materials were in good physical condition.

Results of the Determination.

<u>Fertilizer</u>	<u>Source</u>	<u>Per cent moisture.#</u>
Sodium nitrate	Experiment Station	0.39
Ammonium sulphate	"	1.61
Acid phosphate	"	14.97
Muriate of potash	"	1.03
Sulphate of potash	"	2.30
Sodium nitrate	Grounds Department	0.53
Ammonium sulphate	"	2.99
Acid phosphate	"	6.09
Sodium nitrate	Pomology Department	1.09
Calcium cyanamid(Impure)	"	16.06
Tankage	"	10.45
Acid phosphate	"	8.33
Calcium cyanamid	Higgins and Company	1.30
Tankage	"	7.00
Ground fish (fresh)	"	9.11
Ground fish (old)	"	8.82
Acid phosphate	"	7.98
Steamed bone	"	6.05
Rape seed meal(coarse)	"	8.62
Rape seed meal (fine)	"	6.13
Castor bean pomace	"	7.45
Hoof meal	"	11.27

#The per cent moisture, in all data cited, is based on the dry weight of material.

Discussion.

The most striking evidence brought out by these data is the low moisture content of the sodium nitrate and muriate of potash as compared with the organic materials. The appearance of both the sodium nitrate and muriate of potash would have suggested a much higher water content than was found. The variation in water content of certain materials obtained from different sources indicates the variability of the humidity prevailing under common storage conditions. The high moisture content of the acid phosphate and the cyanamid is probably due to the water of hydration of the gypsum and lime contained in these materials respectively. There is, on the whole, but little variation in the moisture content of the organic materials.

With the exception of those materials mentioned it will be seen that the moisture content of the fertilizers are in fairly close agreement with the results obtained by experiments carried out at approximately the mean average humidity (77.2 %) of the three months preceding the date of sampling.

Analysis of Fertilizers.

Material	Ammonia	Phosphoric Acid	Potash
Ammonium nitrate ¹	40.07	.....	.....
Ammonium nitrate ²	41.20	.....	.....
Ammonium sulphate nitrate	32.50	.....	.....
Calcium nitrate	15.78	.....	.....
Sodium nitrate	18.21	.....	.....
Ammonium sulphate	24.96	.....	.....
Urea	55.50	.....	.....
Calcium cyanamid	24.28	.....	.....
Dry ground fish	9.00	5.00	.....
Tankage	9.99	4.58	.....
Cottonseed-meal	7.28	3.00	1.00
Bone meal	4.85	24.00	.....
Acid phosphate	.....	16.00	.....
Calcined phosphate	.....	27.00	.....
Rock phosphate	.....	32.00	.....
Kainite	.....	.....	12.00
Muriate of potash	.....	.....	48.00
Potassium sulphate	.....	.....	48.00

Qualitative Tests.

Material	SO ₄	Cl.	NO ₃	Ca.	Mg.	Na.	K.
Ammonium nitrate ¹	-	+	+	+	-	-	-
Ammonium nitrate ²	-	+	+	+	-	-	-
Ammonium sul. nitrate	+	+	+	+	+	+	+
Calcium nitrate	-	-	+	+	+	+	-
Sodium nitrate	+	+	+	+	+	+	+
Ammonium sulphate	+	-	-	-	-	-	-
Urea	-	-	-	-	-	-	-
Kainite	+	+	+	+	+	+	+
Muriate of potash	+	+	+	+	+	+	+
Potassium sulphate.	+	+	+	+	+	+	+

Ammonium Nitrate (1)Hygroscopicity.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	36.54 \pm 0.107 [#]
87.75	8	7	20	27.53 \pm 0.152
78.04	5	7	20	16.99 \pm 0.066

Cakiness.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Crushing force lbs. per sq. in.	Difference.
97.50	8	14	20	266.49 \pm 9.54	195.43 \pm 11.18
87.75	11	14	20	54.44 \pm 3.65	26.62 \pm 6.88
78.04	16	14	20	71.06 \pm 5.83	

Condition.

Humidity

- 97.50 Nearly dissolved, a few crystals remaining.
- 87.75 Partly dissolved.
- 78.04 Very moist and at the point of showing free liquid.

The probable error of the mean in this and all other experiments cited in this article was calculated by means of Peters' approximation formula, given by Mellor (8). The probable error of the mean is $\pm 0.8453 \frac{\sum(+V)}{\sqrt{N-1}}$, in which $\sum(+V)$ is the

sum of the deviations of all the individuals from the mean, without regard to the sign, and N is the number of the individuals. If the difference between the means is 3.8 times its probable error, the chance is 30 to 1 (Wood and Stratton, 1910) that the difference is significant.

Ammonium Nitrate (2)Hygroscopicity.

Humidity per cent.	No. of samples.	Time hours.	Temp. ° C.	Average per cent moisture.	
97.50	5	168	20	29.79 \pm	0.252
87.75	5	168	20	23.56 \pm	0.081
78.04	5	168	20	11.50 \pm	0.113
73.00	5	168	20	8.87 \pm	0.107
68.00	5	168	20	3.94 \pm	0.061

Cakiness.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Crushing wt. lbs. per sq. in.	Difference	
97.50	13	14	20	21.43 \pm 1.66	40.44 \pm	3.87
87.75	17	14	20	61.87 \pm 3.50	33.13 \pm	4.55
78.00	20	20	20	28.74 \pm 2.92		

Condition.

97.50	Part of the material in solution.
87.75	Saturated but the granules were apparently intact.
78.04	Very moist but no free water.
73.00	Moist with a very little visible moisture on the granules.
68.00	Very slightly moist.

Ammonium Sulphate Nitrate.Hygroscopicity.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	36.21 \pm 0.207
87.75	5	7	20	25.88 \pm 0.113
78.04	5	7	20	11.59 \pm 0.059
73.00	5	7	20	7.19 \pm 0.079
68.00	5	7	20	2.62 \pm 0.150

Cakiness.

Humidity per cent	No. of samples	Time days.	Temp. ° C.	Crushing force per sq. in.	Difference
97.50	10	14	20	73.38 \pm 3.39	
87.75	11	14	20	170.54 \pm 7.86	97.16 \pm 8.56
78.04	17	14	20	183.82 \pm 4.92	13.38 \pm 9.27

Condition.

97.50	Nearly all of the material in solution.
87.75	A thick syrupy solution with but few crystals remaining.
78.04	Very moist but no visible moisture and the crystals still intact.
73.00	Quite moist. Apparently nearly at the point of saturation.
68.00	Very slightly moist and very little compacted. But little change, if any.

Calcium NitrateHygroscopicity.

Humidity per cent.	No. of samples.	Time days	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	64.08 \pm 0.125
87.75	10	7	20	53.49 \pm 0.088
78.04	10	7	20	42.14 \pm 0.112
73.00	5	7	20	30.61 \pm 0.186
68.00	5	7	20	19.60 \pm 0.057

Cakiness.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Crushing force lbs. per sq. in.	Difference.
		14	20		

97.50 } Of 30 samples tried, 29 failed to break with a
 87.75 } crushing force of 751.40 lbs. per sq. inch. One
 78.04 } broke with a force of 631.86 lbs.

Condition.

97.50 Nearly all in solution with a white precipitate
 formed in the several cc. of liquid.
 87.75 Nearly all dissolved.
 78.04 Partly dissolved.
 73.00 Partly dissolved.
 68.00 A thick syrupy mass.

Sodium Nitrate.Hygroscopicity.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	37.48 \pm 0.135
87.75	10	7	20	23.97 \pm 0.121
78.04	10	7	20	17.36 \pm 0.075
73.00	5	7	20	5.82 \pm 0.093
68.00	5	7	20	4.10 \pm 0.038

Cakiness.Unground material.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Crushing force lbs. per sq. in.	Difference
97.50	16	14	20	42.54 \pm 1.72	
87.75	21	14	20	14.89 \pm 1.01	27.65 \pm 1.99
78.04	16	14	20	11.81 \pm 0.85	3.08 \pm 1.40

Ground Material.

Humidity per cent	No. of samples	Time days.	Temp. ° C.	Crushing force lbs. per sq. in.	Difference
97.50	16	14	20	60.45 \pm 2.40	
87.75	16	14	20	46.67 \pm 2.68	13.78 \pm 3.73
78.04	25	14	20	34.68 \pm 0.97	11.99 \pm 2.85

Condition.

97.50 Material partly in solution.

87.75 Saturated with moisture. A little free water.

78.04 Quite moist but no visible moisture. But little, if any, of the material dissolved.

73.00 Moist but no evidence of any being in solution.

68.00 Moist, but little compacted.

Ammonium Sulphate.Hygroscopicity.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	22.38 \pm 0.652
87.75	10	7	20	16.04 \pm 0.291
78.04	10	7	20	2.41 \pm 0.043
73.00	5	7	20	0.57 \pm 0.008
68.00	5	7	20	0.47 \pm 0.001

Cakiness.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Crushing force lbs. per sq. in.	Difference.
97.50	26	14	20	60.74 \pm 1.50	
87.75	17	14	20	39.44 \pm 1.77	21.33 \pm 2.32
78.04	20	14	20	\pm 0.00	39.44 \pm 1.77

Condition.

Humidity

97.50	Saturated, but very little of the material had gone into solution.
87.75	Very moist but no free water.
78.04	Slightly moist.
73.00	No change apparent.
68.00	Seemingly drier than when exposed.

Urea.Hygroscopicity

Humidity per cent	No. of samples.	Time days.	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	40.87 \pm 0.222
87.75	5	7	20	26.76 \pm 0.199
78.04	5	7	20	8.69 \pm 0.110
73.00	5	7	20	3.17 \pm 0.026
68.00	5	7	20	1.97 \pm 0.016

Cakiness.

Humidity per cent.	No. of samples	Time days.	Temp. ° C.	Crushing force lbs. per sq. in.	Difference.
97.50	12	14	20	27.42 \pm 0.76	
87.75	14	14	20	43.06 \pm 1.63	15.64 \pm 1.07
78.04	16	14	20	28.30 \pm 1.17	14.76 \pm 1.39

Condition.

Humidity

97.50	Material saturated with moisture and partly dissolved.
87.75	Saturated with moisture. No free water. Little, if any, dissolved.
78.04	Quite moist. Crystals intact and none dissolved.
73.00	Very slightly moist. No apparent change in appearance.
68.00	No change in appearance.

Calcium CyanamideHygroscopicity.

Humidity per cent.	No. of samples.	Time days..	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	21.12 \pm 0.287
87.75	5	7	20	13.02 \pm 0.009
78.04	5	7	20	6.11 \pm 0.010
73.00	5	7	20	4.69 \pm 0.026
68.00	5	7	20	3.76 \pm 0.032

Cakiness.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Crushing force lbs. per sq. in.	Difference
97.50	21	14	20	24.42 \pm 0.88	15.01 \pm 1.15
87.75	18	14	20	9.41 \pm 0.74	1.27 \pm 1.02
78.04	16	14	20	8.14 \pm 0.71	

Condition.

Humidity

97.50	Quite moist. Compact enough to hold together but no visible moisture.
87.75	Moist enough to hold together.
78.04	Very slightly moist. Not much change from the condition when exposed.
73.00	No change in appearance.
68.00	No change in appearance.

Tankage.Hygroscopicity.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	27.65 \pm 0.068
87.75	5	7	20	20.74 \pm 0.030
78.04	5	7	20	12.83 \pm 0.009

Condition.

Humidity

- 97.50 Apparently saturated with moisture. Quite compact.
- 87.75 Very moist and compact enough to hold together.
- 78.04 Not moist enough to hold together. But little change
in condition.

Dry Ground Fish.Hygroscopicity.

Humidity per cent	No. of samples.	Time days.	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	20.07 \pm 0.030
87.75	10	7	20	17.52 \pm 0.019
78.04	5	7	20	10.86 \pm 0.003

Condition.

Humidity.

- 97.50 Very moist. Not sticky or compacted.
- 87.75 Moist. In much better condition than above.
- 78.04 In appearance, as dry as when set for exposure.

Bone MealHygroscopicity.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	16.07 \pm 0.017
87.75	5	7	20	10.44 \pm 0.008
78.04	5	7	20	9.19 \pm 0.008

Condition.

Humidity

- 97.50 Very moist and compact. Would not crumble. No visible water.
- 87.75 Moist and compact. Moist enough to hold together.
- 78.04 No apparent change in condition. Apparently dry.

Cotton seed Meal.Hygroscopicity.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	29.60 \pm 0.049
87.75	5	7	20	22.89 \pm 0.003
78.04	5	7	20	15.68 \pm 0.004

Condition.

Humidity.

- 97.50 Moist but not sticky. Somewhat friable.
- 87.75 Very slightly moist in appearance. Friable.
- 78.04 No apparent change in condition.

Acid Phosphate.Hygroscopicity.

Humidity per cent.	No. of samples.	Time days.	Temp. °C.	Average per cent moisture.
97.50	10	7	20	29.60 \pm 0.228
87.75	10	7	20	15.74 \pm 0.071
78.04	10	7	20	4.12 \pm 0.026

Cakiness.

Humidity per cent.	No. of samples.	Time days.	Temp. °C.	Crushing force lbs. per sq. in.	Difference
97.50	22	14	20	94.84 \pm 2.72	
87.75	20	14	20	68.19 \pm 2.41	31.65 \pm 3.63
78.04	14	14	20	17.69 \pm 1.46	45.50 \pm 2.81

Condition.

97.50 Very moist. Slightly compacted and would hold together.

87.75 Moist. Would barely hold together.

78.04 Slightly moist but friable.

Calcined Phosphate.Hygroscopicity.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	1.50 \pm 0.050
87.75	5	7	20	0.486 \pm 0.009
78.04	5	7	20	0.354 \pm 0.006

Cakiness.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Crushing force lbs. per sq. in.	Difference
97.50		14		No caking.	
87.75		14		No caking.	
78.04		14		No caking.	

Condition.

Humidity

- 97.50 Seemingly moist and just a little compact but not sticky. Friable if loosened.
- 87.75 Very slightly moist and quite friable.
- 78.04 No noticeable change in appearance.

Rock Phosphate.Hygroscopicity.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Average per cent moisture.
97.75	5	7	20	6.66 \pm 0.008
87.75	5	7	20	4.19 \pm 0.007
78.04	5	7	20	2.82 \pm 0.074

Condition.

Humidity
per cent.

97.75	Slightly moist but not sufficiently so to hold together. Friable.
87.75	But very slightly moist. No effects of exposure evident that might be detrimental to its physical condition.
78.04	No apparent change in condition.

Kainite.Hygroscopicity.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	30.94 \pm 0.059
87.75	5	7	20	23.54 \pm 0.085
78.04	5	7	20	12.70 \pm 0.035
73.00	5	7	20	9.27 \pm 0.027
68.00	5	7	20	5.37 \pm 0.060

Cakiness.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Crushing force lbs. per sq. in.	Difference
97.50	17	14	20	191.58 \pm 7.93	13.85 \pm 10.24
87.75	21	14	20	177.73 \pm 6.48	
78.04	20	14	20	85.00 \pm 2.22	92.73 \pm 6.84

Condition.

Humidity

97.50	Partly in solution.
87.75	Very moist and compact but no free water.
78.04	Quite moist and somewhat compacted. No visible moisture.
73.00	Quite moist.
68.00	Very slightly moist.

Muriate of Potash.Hygroscopicity.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	39.98 \pm 0.313
87.75	10	7	20	32.82 \pm 0.158
78.04	10	7	20	14.54 \pm 0.062
73.00	5	7	20	6.13 \pm 0.037
68.00	5	7	20	4.92 \pm 0.057

Cakiness.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Crushing force lbs. per sq. in.	Difference.
97.50	23	14	20	427.64 \pm 19.91	
87.75	21	14	20	515.09 \pm 5.44	87.45 \pm 25.04
78.04	23	14	20	281.35 \pm 9.22	233.74 \pm 17.81

Condition.

Humidity

97.50	Partly dissolved. All of the material saturated.
87.75	Very moist with visible moisture. Some dissolved.
78.04	Moist but no visible water. None dissolved.
73.00	Moist and a little compacted.
68.00	Moist enough to hold together.

Potassium Sulphate.Hygroscopicity.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	15.54 \pm 0.030
87.75	5	7	20	9.92 \pm 0.085
78.04	5	7	20	2.64 \pm 0.025

Cakiness.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Crushing force lbs. per sq. in.	Difference.
97.50	24	14	20	97.03 \pm 5.44	
87.75	29	14	20	44.00 \pm 1.44	53.03 \pm 5.62
78.04	No caking.			None	44.00 \pm 1.44

Condition.

Humidity.

- 97.50 Very moist but no visible water. Probably a little dissolved.
- 87.75 Moist and compact. Apparently at the point of saturation with moisture.
- 78.04 Nearly as dry as when exposed. When loosened it was friable and showed no evidence of moisture.

4 - 8 - 4 Mixture.Sodium Nitrate, Muriate of Potash, Acid Phosphate.Hygroscopicity.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	60.20 \pm 0.148
87.75	5	7	20	43.36 \pm 0.144
78.04	5	7	20	27.12 \pm 0.084

Cakiness.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Crushing force lbs. per sq. in.	Difference.
97.50	5	14	20	233.20 \pm 3.62	
87.75	7	14	20	161.45 \pm 20.81	71.75 \pm 21.12
78.04	No. caking that could be measured.			None.	161.45 \pm 20.81

Condition.

Humidity.

97.50	Very moist, compact and sticky.
87.75	Moist and a little sticky. It was too compact and sticky to move readily.
78.04	Slightly moist in appearance. It was not sticky and in a fair condition of friability.

4 - 8 - 4 Mixture.Sodium Nitrate, Tankage, Muriate of Potash, Acid Phosphate.Hygroscopicity.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	55.84 \pm 0.274
87.75	5	7	20	36.72 \pm 0.086
78.04	5	7	20	19.98 \pm 0.161

Cakiness.

Humidity per cent.	No. of samples.	Time hours.	Temp. ° C.	Crushing force lbs. per sq. in.	Difference.
97.50	17	14	20	89.50 \pm 6.02	
87.75	14	14	20	66.05 \pm 3.42	23.45 \pm 6.92
78.04	No caking.				66.05 \pm 3.42

Condition.Humidity
per cent.

97.50	Material saturated with moisture. Some of the salts were dissolved. Also a very little free water visible.
87.75	Very moist. In appearance, saturated. Somewhat sticky.
78.04	Quite moist. Slightly sticky and compact.

4 - 8 - 4 Mixture.Sodium Nitrate, Muriate of Potash, Acid Phosphate and Peat Filler.Hygroscopicity.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Average per cent moisture.
97.50	5	7	20	65.84 \pm 0.148
87.75	5	7	20	57.36 \pm 0.160
78.04	5	7	20	31.80 \pm 0.132

Cakiness.

Humidity per cent.	No. of samples.	Time days.	Temp. ° C.	Crushing force lbs. per sq. in.	Difference.
97.50	7	14	20	83.28 \pm 8.17	
87.75	6	14		15.18 \pm 1.51	68.10 \pm 8.30
78.04	No caking.			None.	15.18 \pm 1.51

Condition.Humidity
per cent.

97.50	Very moist. Compact but not sticky.
87.75	Quite moist. A little compacted.
78.04	Moist but not compact. The appearance would not suggest the moisture content.

Summary of Results.Hygroscopicity.

<u>Material</u>	Humidity		Humidity		Humidity	
	97.50 %		87.75 %		78.04 %	
Ammonium nitrate ^{1/2 cryst}	36.54	± 0.107	27.53	± 0.152	16.99	± 0.066
Ammonium nitrate ^{2/3 gran.}	29.79	± 0.252	23.56	± 0.081	11.50	± 0.113
Am. Sulphate nitrate	36.21	± 0.207	25.88	± 0.113	11.59	± 0.059
Calcium nitrate	64.08	± 0.125	53.49	± 0.088	42.14	± 0.112
Sodium nitrate	37.48	± 0.135	23.97	± 0.121	17.36	± 0.075
Ammonium sulphate	22.38	± 0.652	16.04	± 0.291	2.41	± 0.043
Urea	40.87	± 0.222	26.76	± 0.199	8.69	± 0.110
Calcium cyanamid	21.12	± 0.287	13.02	± 0.009	6.11	± 0.010
Tankage	27.65	± 0.068	20.74	± 0.030	12.83	± 0.009
Dry ground fish	20.07	± 0.030	17.52	± 0.019	10.86	± 0.003
Bone meal	16.07	± 0.017	10.44	± 0.008	9.19	± 0.008
Cottonseed-meal	29.60	± 0.049	22.89	± 0.003	15.68	± 0.004
Acid phosphate	29.60	± 0.228	15.74	± 0.071	4.12	± 0.026
Calcined phosphate	1.50	± 0.050	0.48	± 0.009	0.35	± 0.006
Rock phosphate	6.66	± 0.008	4.19	± 0.007	2.82	± 0.074
Kainite	30.94	± 0.059	23.54	± 0.085	12.70	± 0.035
Muriate of potash	39.98	± 0.313	32.82	± 0.158	14.54	± 0.062
Sulphate of potash	15.54	± 0.030	9.92	± 0.085	2.64	± 0.025
4 - 8 - 4	60.20	± 0.148	43.36	± 0.144	27.12	± 0.084
4 - 8 - 4 Tankage	55.84	± 0.274	36.72	± 0.086	19.98	± 0.161
4 - 8 - 4 Peat	65.84	± 0.148	57.36	± 0.160	31.80	± 0.132

Table I.

Summary of Results.

Hygroscopicity.

<u>Material</u>	Humidity	Humidity
	73.00 %	68.00 %
Ammonium nitrate ²	8.87 \pm 0.107	3.94 \pm 0.061
Am. sulphate nitrate	7.19 \pm 0.079	2.62 \pm 0.150
Calcium nitrate	30.61 \pm 0.186	19.60 \pm 0.057
Sodium nitrate	5.82 \pm 0.093	4.10 \pm 0.038
Ammonium sulphate	0.57 \pm 0.008	0.47 \pm 0.001
Urea	3.17 \pm 0.026	1.97 \pm 0.016
Calcium cyanamid	4.69 \pm 0.026	3.76 \pm 0.032
Kainite	9.27 \pm 0.027	5.37 \pm 0.060
Muriate of potash.	6.13 \pm 0.057	4.92 \pm 0.057

Table II.

Summary of Results
of Hygroscopicity.

Comparison with Calcium Nitrate Rated 100.

<u>Material</u>	<u>Humidity</u> <u>97.50 %</u>	<u>Material</u>	<u>Humidity</u> <u>87.75 %</u>
Calcium nitrate	100.00 ✓	Calcium nitrate	100.00 ✓
4 - 8 - 4 peat ³	102.74 ✓	4 - 8 - 4 peat ³	107.23 ✓
4 - 8 - 4 — 1	93.94 ✓	4 - 8 - 4 — 1	81.06 ✓
4 - 8 - 4 tankage ✓	87.14 ✓	4 - 8 - 4 tankage ²	68.64 ✓
Urea	63.78 ✓	Muriate potash	61.35 ✓
Muriate of potash	62.39 ✓	Ammonium nitrate ¹	51.46 ✓
Sodium nitrate	58.52 ✓	Urea	50.02 ✓
Ammonium nitrate ¹	57.02	Am. sulphate nitrate	48.38 ✓
Am. sulphate nitrate	56.50	Sodium nitrate	44.81
Kainite	48.31 ✓	Ammonium nitrate ²	44.04 ✓
Ammonium nitrate ²	46.49	Kainite	44.01 ✓
Cottonseed-meal	46.09 ✓	Cottonseed-meal	42.79 ✓
Acid phosphate	46.09 ✓	Tankage	38.77 ✓
Tankage	43.15 ✓	Dry ground fish	32.75 ✓
Ammonium sulphate	34.95	Ammonium sulphate	29.98 ✓
Calcium cyanamid	32.95 ✓	Acid phosphate	29.42 ✓
Dry ground fish	31.32 ✓	Calcium cyanamid	24.34 ✓
Bone meal	25.08 ✓	Bone meal	19.51 ✓
Potassium sulphate ✓	24.25 ✓	Potassium sulphate	18.54 ✓
Rock phosphate	15.27 ✓	Rock phosphate	7.83 ✓
Calcined phosphate	3.43 ✓	Calcined phosphate	0.91 ✓

Table III.

Summary of Results.

Comparison of Hygroscopicity with Calcium Nitrate Rated 100.

<u>Material</u>	<u>Humidity</u> <u>78.04 %</u>	<u>Material.</u>	<u>Humidity.</u> <u>73.00 %</u>
Calcium nitrate	100.00 ✓	Calcium nitrate	100.00
4 - 8 - 4 Peat ³	75.46 ✓	Kainite	30.28
4 - 8 - 4 -	64.35 ✓	Ammonium nitrate ²	28.97
4 - 8 - 4 Tankage	47.41 ✓	Am. sulphate nitrate	23.49
Sodium nitrate	41.19 ✓	Muriate of potash	20.02
Ammonium nitrate ¹	40.31 ✓	Sodium nitrate	19.01
Cottonseed-meal	37.21 ✓	Calcium cyanamid	15.32
Muriate of potash	34.50 ✓	Urea	10.35
Tankage	30.44 ✓	Ammonium sulphate	1.68
Kainite	30.14 ✓		
Ammonium nitrate ²	27.99 ✓		
		<hr/> Humidity 68 %.	
Ammonium sul.nitrate	27.50 ✓	Calcium nitrate	100.00
Dry ground fish	25.77 ✓	Kainite	27.39
Bone meal	21.81 ✓	Muriate of potash	25.10
Urea	20.62 ✓	Sodium nitrate	20.91
Calcium cyanamid	14.49 ✓	Ammonium nitrate ²	20.10
Acid phosphate	9.78 ✓	Calcium cyanamid	19.18
Rock phosphate	6.69 ✓	Am. sulphate nitrate	13.37
Potassium sulphate	6.26 ✓	Urea	10.05
Ammonium sulphate	5.71	Ammonium sulphate	2.40
Calcined phosphate	0.84 ✓		

Table IV.

Summary of Results.

Cakiness.

Material	Humidity	Crushing force lbs. per sq. in.	Difference
Ammonium nitrate ¹ (crys)	97.50	54.44 \pm 3.65	
Ammonium nitrate ¹	87.75	71.06 \pm 5.83	(195.43 \pm 11.18)
Ammonium nitrate ¹	78.04	266.49 \pm 9.54	26.62 \pm 6.88
Ammonium nitrate ²	97.50	21.43 \pm 1.66	
Ammonium nitrate ²	87.75	61.87 \pm 3.50	40.44 \pm 3.87
Ammonium nitrate ²	78.04	28.74 \pm 2.92	33.13 \pm 4.55
Am. sulphate nitrate	97.50	73.38 \pm 3.39	
Am. sulphate nitrate	87.75	170.54 \pm 7.86	97.16 \pm 8.56
Am. sulphate nitrate	78.04	183.82 \pm 4.92	13.38 \pm 9.27
Calcium nitrate	97.50	Out of 30 trials 29 failed to break with a force of 751.40 lbs. One broke at 631.86 lbs.	
Calcium nitrate	87.75		
Calcium nitrate	78.04		
Sodium nitrate(ground)	97.50	60.45 \pm 2.40	
Sodium nitrate	87.75	46.67 \pm 2.68	13.78 \pm 3.73
Sodium nitrate	78.04	34.68 \pm 0.97	11.99 \pm 2.85
Sodium nitrate (not)	97.50	42.54 \pm 1.72	
Sodium nitrate(ground)	87.75	14.89 \pm 1.01	27.65 \pm 1.99
Sodium nitrate	78.04	11.81 \pm 0.97	3.08 \pm 1.40

Table V.

Summary of Results.

Cakiness.

Material	Humidity	Crushing force lbs. per sq. in.	Difference
Ammonium sulphate	97.50	60.74 \pm 1.50	
Ammonium sulphate	87.75	39.44 \pm 1.77	21.33 \pm 2.32
Ammonium sulphate	78.04	None	39.44 \pm 1.77
Urea	97.50	27.42 \pm 0.76	
Urea	87.75	43.06 \pm 1.63	15.64 \pm 1.07
Urea	78.04	28.30 \pm 1.17	14.76 \pm 1.39
Calcium cyanamid	97.50	24.42 \pm 0.88	
Calcium cyanamid	87.75	9.41 \pm 0.74	15.01 \pm 1.15
Calcium cyanamid	78.04	8.14 \pm 0.71	1.27 \pm 1.02
Acid phosphate	97.50	94.84 \pm 2.72	
Acid phosphate	87.75	68.19 \pm 2.41	31.65 \pm 3.63
Acid phosphate	78.04	17.69 \pm 1.46	45.50 \pm 2.81
Calcined phosphate	97.50	None	
Calcined phosphate	87.75	None	
Calcined phosphate	78.04	None	
Kainite	97.50	191.58 \pm 7.93	
Kainite	87.75	177.73 \pm 6.48	13.85 \pm 10.24
Kainite	78.04	85.00 \pm 2.22	92.73 \pm 6.84

Table VI.

Summary of Results.

Cakiness.

Material	Humidity	Crushing force lbs. per sq. in.	Difference.
Muriate of potash	97.50	427.64 \pm 19.91	
Muriate of potash	87.75	515.09 \pm 5.44	87.45 \pm 25.02
Muriate of potash	78.04	281.35 \pm 9.22	233.74 \pm 17.81
Potassium sulphate	97.50	97.03 \pm 5.44	
Potassium sulphate	87.75	44.00 \pm 1.44	53.03 \pm 5.62
Potassium sulphate	78.04	None	44.00 \pm 1.44
4 - 8 - 4	97.50	233.20 \pm 3.62	
4 - 8 - 4	87.75	161.45 \pm 20.81	71.75 \pm 21.12
4 - 8 - 4	78.04	None	161.45 \pm 20.81
4-8-4 Tankage	97.50	89.50 \pm 6.02	
4-8-4 Tankage	87.75	66.05 \pm 3.42	23.45 \pm 6.92
4-8-4 Tankage	78.04	None	66.05 \pm 3.42
4-8-4 Peat	97.50	83.28 \pm 8.17	
4-8-4 Peat	87.75	15.18 \pm 1.51	68.10 \pm 8.30
4-8-4 Peat	78.04	None	15.18 \pm 1.51

Table VII.

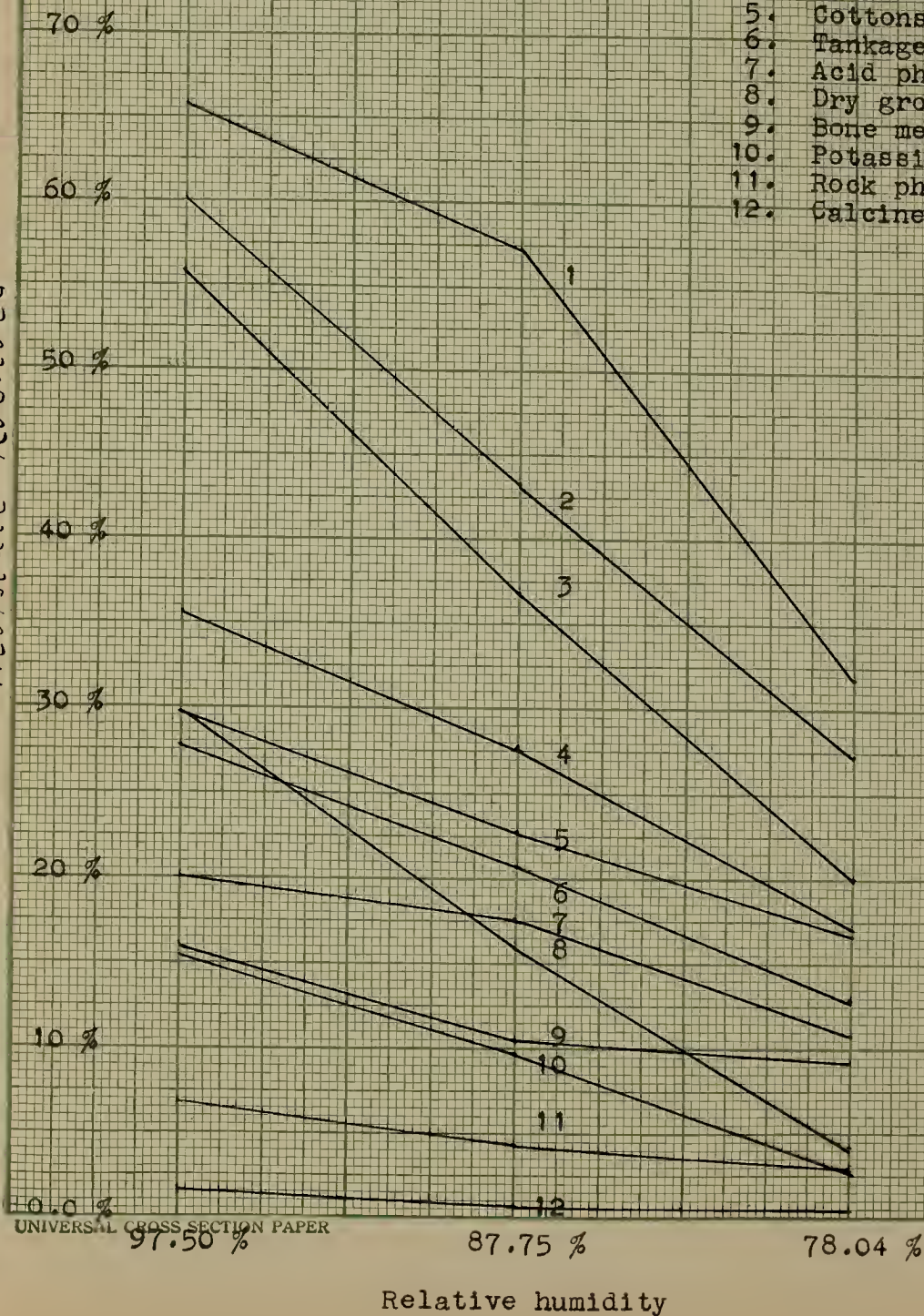
Graphical Representation of Data.

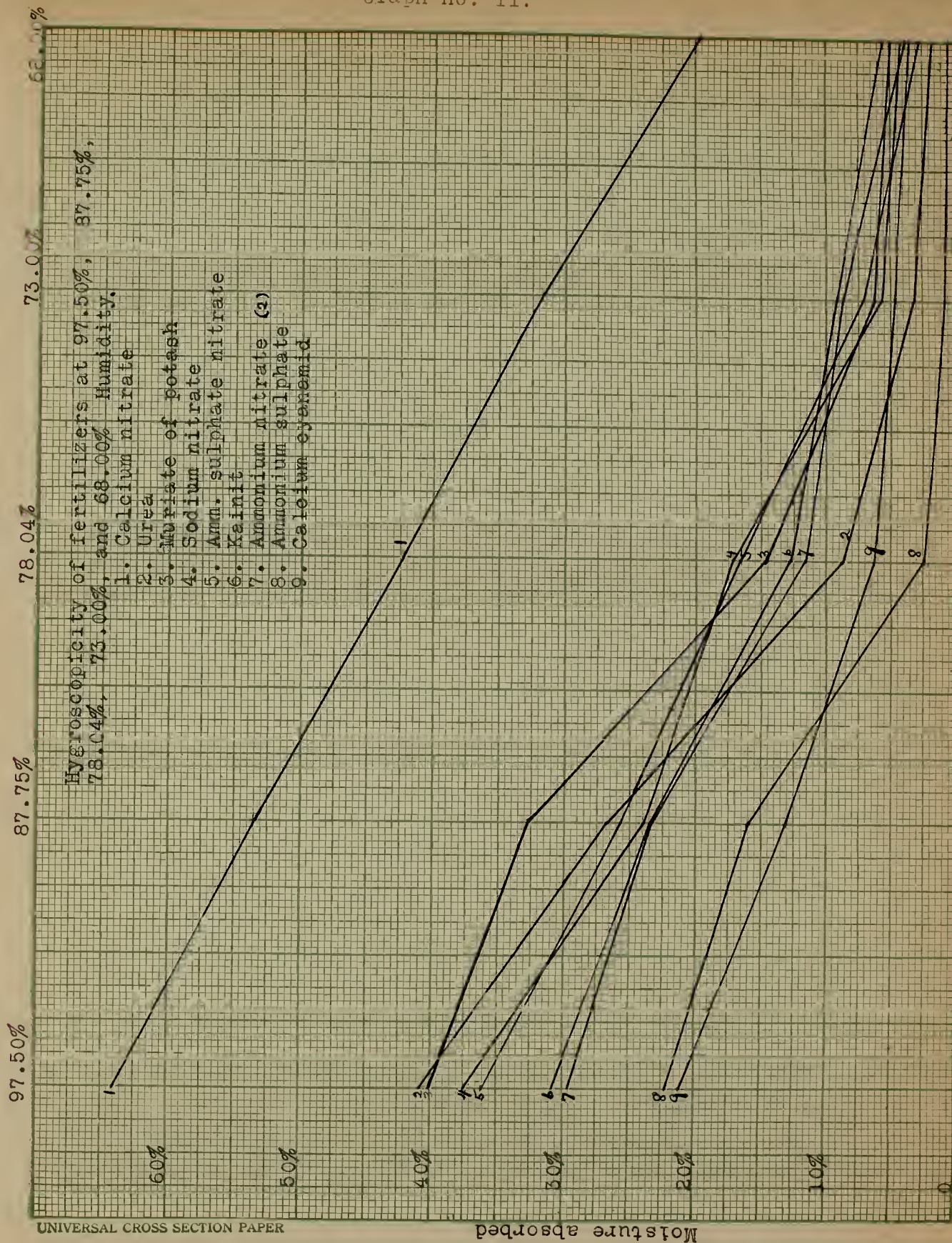
- Graph no. I. Hygroscopicity of the fertilizers at 97.50%, 87.75%, and 78.04% humidity.
- Graph no. II. Hygroscopicity of fertilizers at 97.50%, 87.75%, 78.04%, 73.00% and 68.00% humidity.
- Graph no. III. Comparison of hygroscopicity with calcium nitrate rated at 100. Humidity 97.50%.
- Graph no. IV. Comparison of hygroscopicity with calcium nitrate rated at 100. Humidity 87.75%.
- Graph no. V. Comparison of hygroscopicity with calcium nitrate rated at 100. Humidity 78.04%.
- Graph no. VI. Comparison of hygroscopicity with calcium nitrate rated at 100. Humidity 73.00%.
- Graph no. VII. Comparison of hygroscopicity with calcium nitrate rated at 100. Humidity 68.00%.

Hygroscopicity of the fertilizers at 97.50 %, 87.75 % and 78.04 % humidity.

Moisture Absorbed

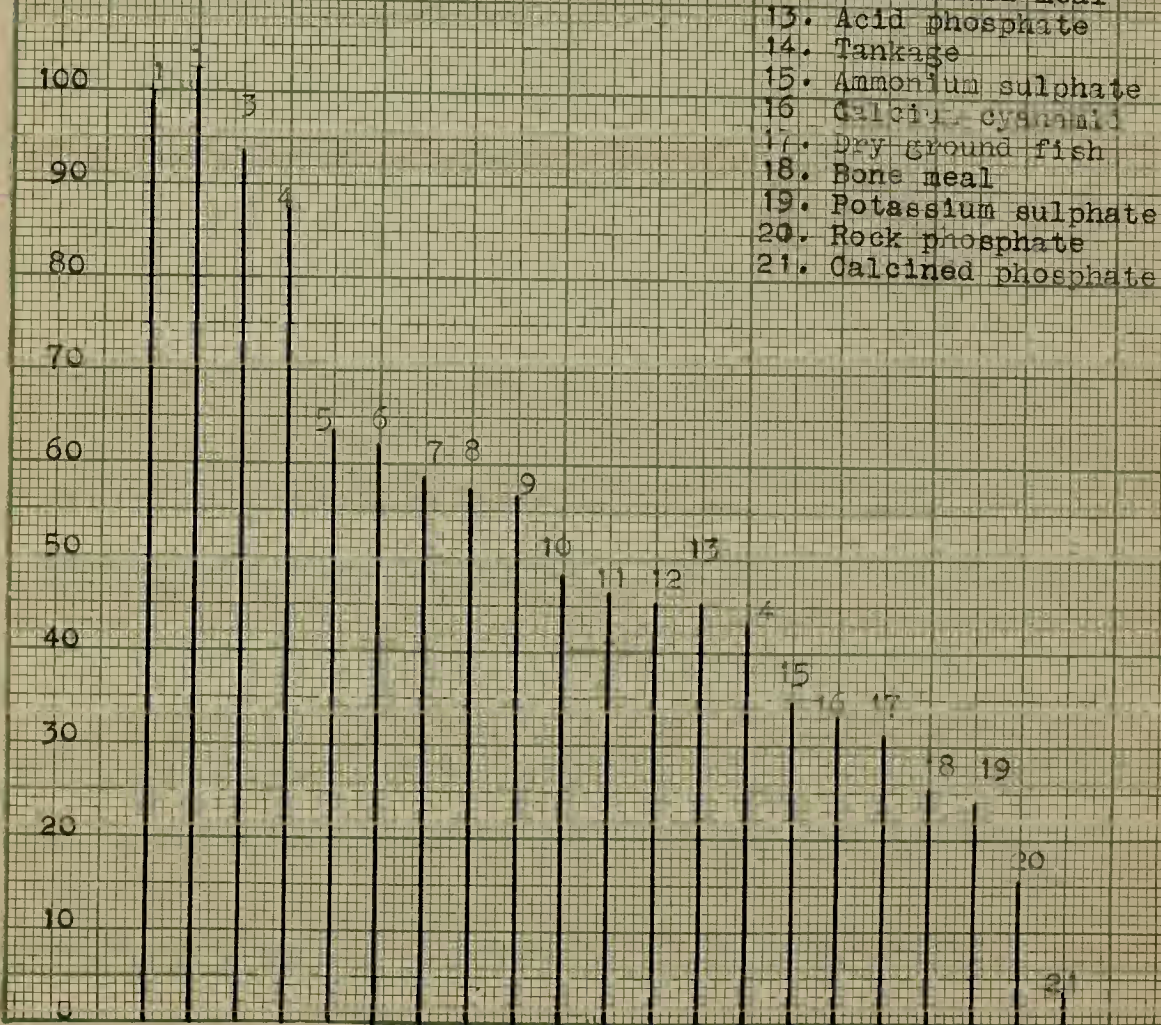
1. 4 - 8 - 4 peat
2. 4 - 8 - 4
3. 4 - 8 - 4 tankage
4. Ammonium nitrate
5. Cottonseed-meal
6. Tankage
7. Acid phosphate
8. Dry ground fish
9. Bone meal
10. Potassium sulphate
11. Rock phosphate
12. Calcined phosphate





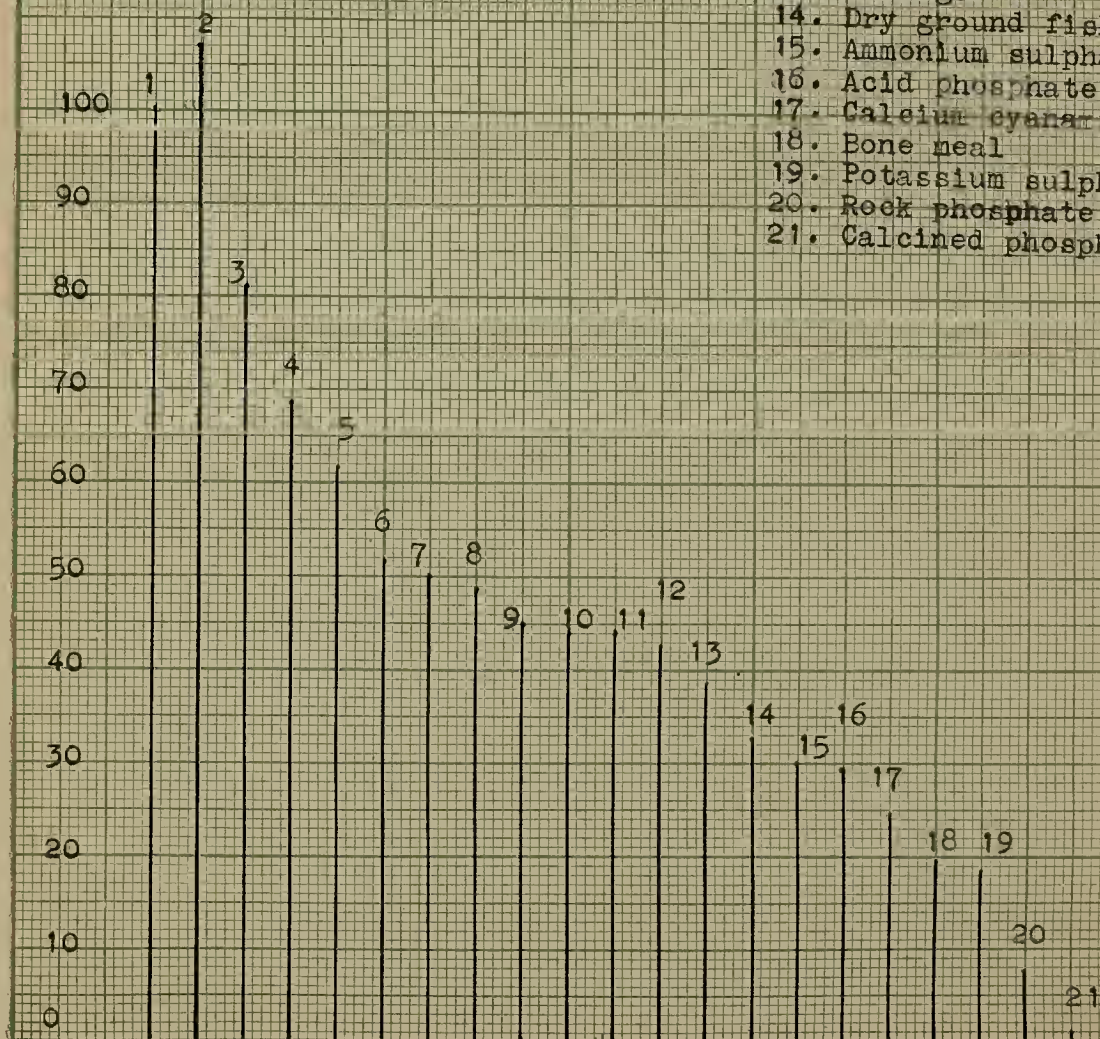
Comparison of hygroscopicity with calcium nitrate
rated at 100. Moisture determinations based on dry
weight of material. Humidity 97.50 %.

1. Calcium nitrate
2. 4 - 8 - 4 peat
3. 4 - 8 - 4
4. 4 - 8 - 4 tankage
5. Urea
6. Muriate of potash
7. Sodium nitrate
8. Ammonium nitrate (1)
9. Am. sulphate nitrate
10. Kainite
11. Ammonium nitrate (2)
12. Cottonseed-meal
13. Acid phosphate
14. Tankage
15. Ammonium sulphate
16. Calcium cyanamid
17. Dry ground fish
18. Bone meal
19. Potassium sulphate
20. Rock phosphate
21. Calcined phosphate



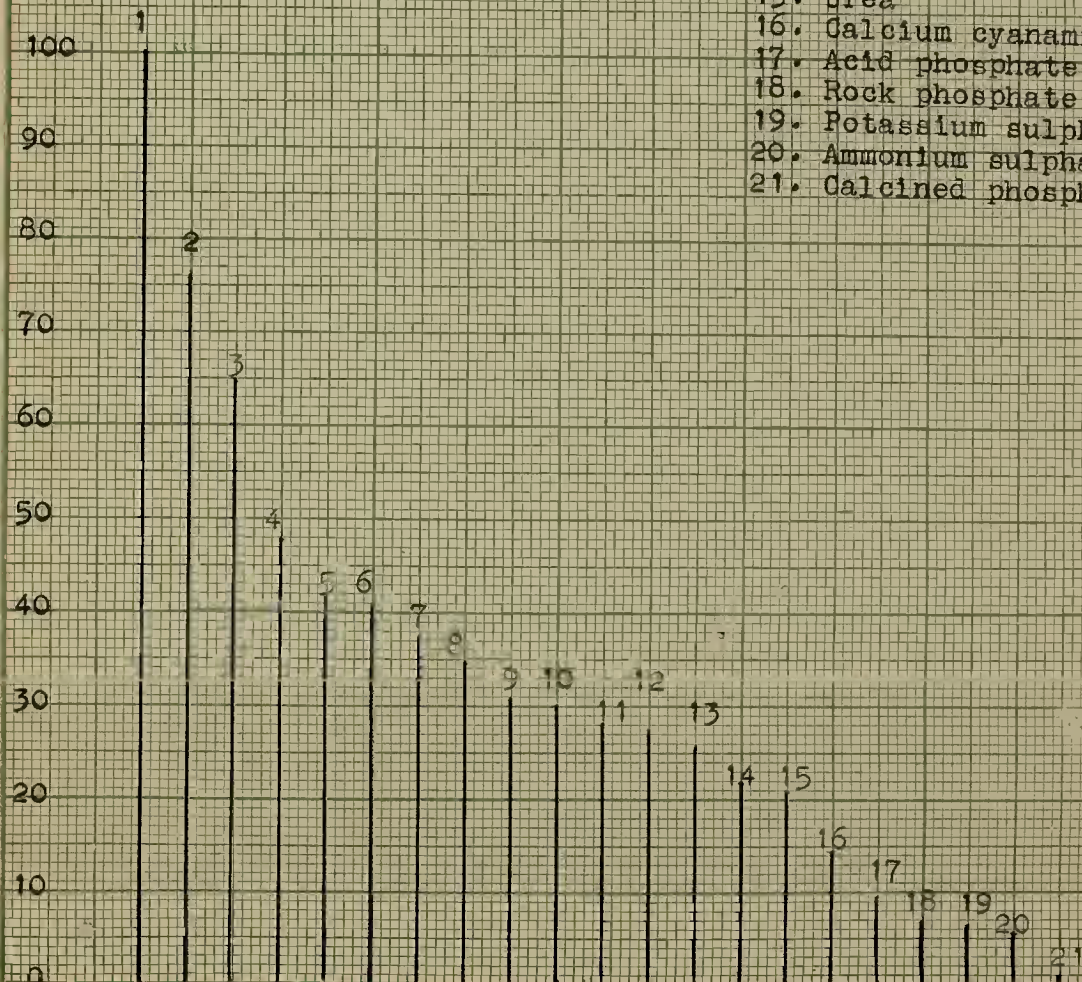
Comparison of hygroscopicity with calcium nitrate
rated at 100. Moisture determinations based on dry
weight of material. Humidity 87.75 %.

1. Calcium nitrate
2. 4 - 8 - 4 peat
3. 4 - 8 - 4
4. 4 - 8 - 4 tankage
5. Muriate potash
6. Ammonium nitrate (1)
7. Urea
8. Am. sulphate nitrate
9. Sodium nitrate
10. Ammonium nitrate (2)
11. Kainite
12. Cottonseed-meal
13. Tankage
14. Dry ground fish
15. Ammonium sulphate
16. Acid phosphate
17. Calcium cyanarid
18. Bone meal
19. Potassium sulphate
20. Rock phosphate
21. Calcined phosphate

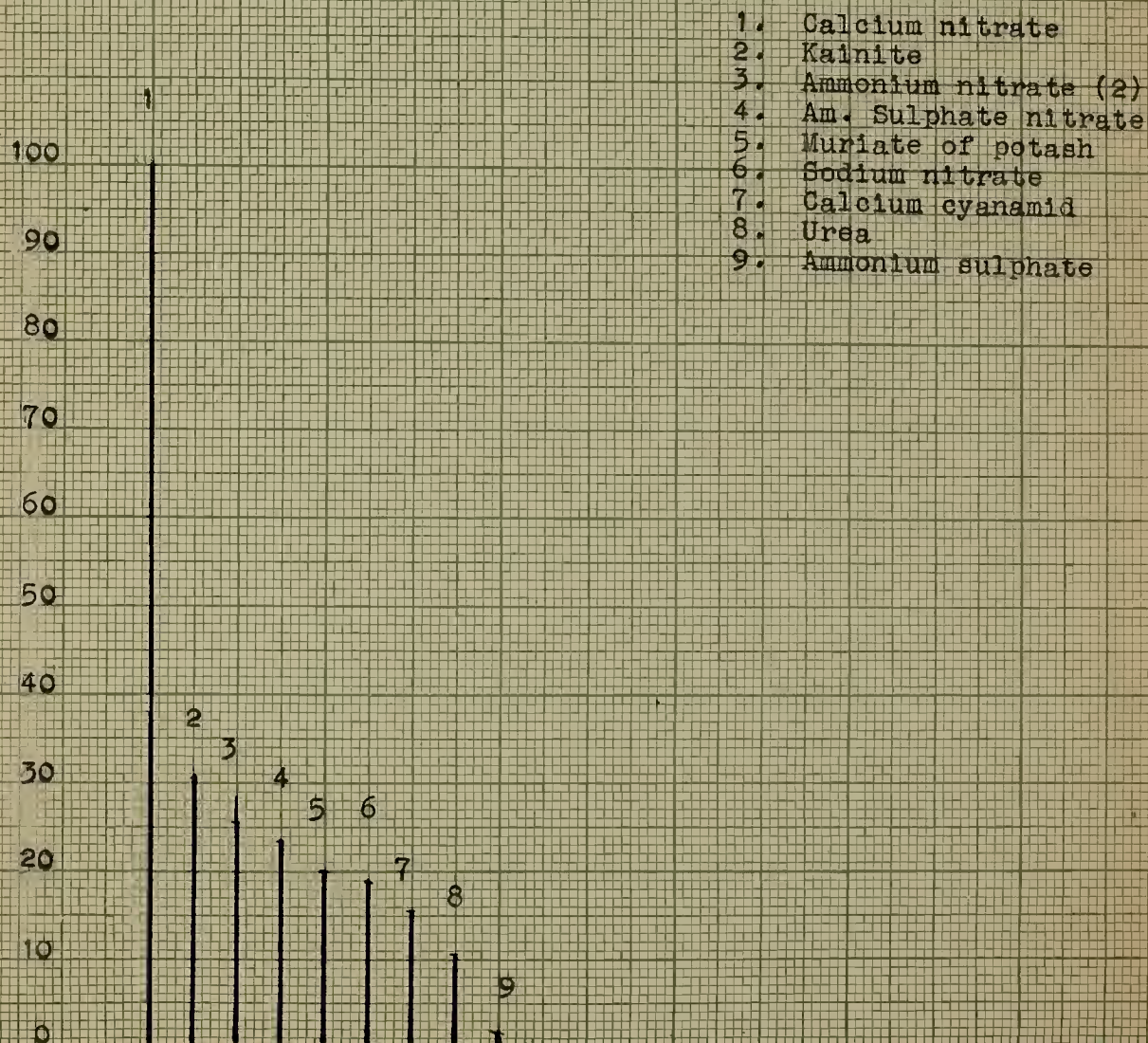


Comparison of hygroscopicity with calcium nitrate
rated at 100. Moisture determinations based on dry
weight of material. Humidity 78.04 %.

1. Calcium nitrate
2. 4 - 8 - 4 peat
3. 4 - 8 - 4
4. 4 - 8 - 4 tankage
5. Sodium nitrate
6. Ammonium nitrate (1)
7. Cottonseed-meal
8. Muriate of potash
9. Tankage
10. Kainite
11. Ammonium nitrate (2)
12. Am. sulphate nitrate
13. Dry ground fish
14. Bone meal
15. Urea
16. Calcium cyanamid
17. Acid phosphate
18. Rock phosphate
19. Potassium sulphate
20. Ammonium sulphate
21. Calcined phosphate



Comparison of hygroscopicity with calcium nitrate
rated at 100. Moisture determinations based on dry
weight of material. Humidity 73.00 %.



Comparison of hygroscopicity with calcium nitrate
rated at 100. Moisture determinations based on dry
weight of material. Humidity 68.00 %.

1. Calcium nitrate
2. Urea
3. Muriate of potash
4. Sodium nitrate
5. Am. Sulphate nitrate
6. Kainite
7. Ammonium nitrate
8. Ammonium sulphate
9. Calcium cyanamid

100

90

80

70

60

50

40

30

20

10

0

2

3

4

5

6

7

8

9

Discussion of Results.

An examination of the results here reported shows that the moisture absorbed by all of the materials except rock phosphate and calcined phosphate at humidities of 97.50% and 87.75% is of an amount sufficient to affect their monetary value. For example, sodium nitrate at a humidity of 97.50% increased in weight 37.48%; this would mean a decrease in monetary value of 27.3 [#] %.

Ammonium sulphate, calcium cyanamid, tankage, fish, bone meal, acid phosphate and potassium sulphate were the only materials which remained in good physical condition after exposure to a humidity of 78.04%.

The following materials were more or less in complete solution after an exposure to a humidity of 97.50%; ammonium nitrate¹, ammonium nitrate², ammonium sulphate nitrate, calcium nitrate, sodium nitrate, ammonium sulphate, urea, kainite and muriate of potash. The actual amount in solution would be dependent upon the solubility of the material. This factor may have influenced hygroscopicity.

The following materials contained free water, and, consequently, were partly in solution at a humidity of 87.75%: ammonium nitrate¹, ammonium nitrate², ammonium sulphate nitrate, calcium nitrate, sodium nitrate and muriate of potash. The granules of the ammonium nitrate²

This decrease in value is more than is likely to occur except in extremely unfavorable conditions of storage.

remained almost wholly intact due assumably to the treatment to which they had been subjected in the process of manufacture.

Calcium nitrate was the only material that absorbed moisture in amount sufficient to give free water at a humidity of 78.04%.

An examination of graphs I and II shows that all the curves have the shape of the typical adsorption isotherm which indicates that under the conditions of the experiment adsorption plays an important role. The curves for the organic materials and inert inorganics point toward the zero point and it is very likely that extra data taken under more extensive conditions would show the true adsorption isotherms for these substances. Surface phenomena no doubt dominate the intake and retention of moisture by organic materials and thus contribute to the value of such substances as driers and conditioners in fertilizer mixtures.

The curves for moisture in the inorganics drop down rather abruptly from the vapor pressure corresponding to a humidity of 97.50% to about 70% and from the latter point tend to flatten out. These curves indicate that there is for most of the inorganics studied a critical humidity somewhere about 70%, above which the vapor pressure of the atmosphere exceeds that of the saturated salt solution and absorption becomes dominant. Below the

critical humidity the intake is slight and is due to adsorption.

A possible explanation of the high moisture content of the 4 - 8 - 4 mixtures is that the acid phosphate, tankage and peat are able to retain a large amount of moisture which tends to keep the salt solutions more concentrated and, therefore, with correspondingly lower vapor pressures. There is also much greater opportunity for adsorption with the tankage and peat than with the salts.

The lack of agreement of the data with that submitted by certain workers may be explained in part by the presence of impurities present in commercial fertilizer materials. As Edgar and Swan⁽²⁾ point out the vapor pressure of a mixture of salts is lower than that of either. This fact also explains in part the high moisture content of the 4 - 8 - 4 mixture.

A study of the data and graphs on hygroscopicity shows that there is a changing relationship among the materials as to their adsorptive capacities, and that differences tend to lessen with increasing humidity. For example, as shown by the differences and the probable error of the difference for urea and muriate of potash there are significant differences at 78.04 and 87.50 but not at 97.50. In all cases there are significant differences between the adsorption at different humidities for the same substance, although

in some cases the difference is very slight as for example ammonium sulphate.

The data on cakiness show some of the inorganics may require considerable pressure to crush them and reduce them to a pulverulent condition suitable for distribution in the soil. The experimental error of the method employed in measuring cakiness is shown to be high and an examination of the data shows that in many cases the differences in cakiness at the humidities studied are not significant. The fact that the ground sodium nitrate shows more cakiness than the unground material may be due to the method of determination. With molds $1\frac{1}{2}$ " in diameter the coarser material did not form as uniformly compact cylinders as did the ground material.

Summary.

As shown by the data the fertilizers decrease in hygroscopicity in the order named: calcium nitrate, muriate of potash, ammonium nitrate¹, sodium nitrate, ammonium sulphate nitrate, kainite, cottonseed-meal, urea, ammonium nitrate², tankage, acid phosphate, ammonium sulphate, calcium cyanamid, dry ground fish, bone meal, potassium sulphate, rock phosphate, and calcined phosphate. The mixtures would follow calcium nitrate in the order named: 4 - 8 - 4 with peat filler, 4 - 8 - 4 and 4 - 8 - 4 with tankage. The above is based on the actual amount of moisture absorbed and not on the amount of material in solution. As already suggested, at the higher humidities many of the materials absorb moisture in an amount sufficient to be detrimental to their value.

The new materials, ammonium nitrate², ammonium sulphate nitrate, and urea, if proper precautions are taken in storage, should give no more trouble, because of their hygroscopicity, than sodium nitrate or muriate of potash.

The appearance of the material may not be a reliable criterion for judging the moisture content of a fertilizer.

Cakiness of inorganics is correlated with humidity up to the point of critical moisture content.

It should be possible, with reasonable accuracy, to anticipate the condition of the fertilizer from a knowledge of the humidity of the storage space.

Sodium nitrate and similar salts carry much less moisture content than their appearance would indicate.

Ammonium sulphate absorbed very little moisture at 78%, urea and ammonium sulphate nitrate at 68% humidity.

Cakiness of inorganic materials may become very great at humidities likely to occur during period of storage.

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Acknowledgments.

The author takes this opportunity to acknowledge his indebtedness to Dr. A. B. Beaumont for the interest, encouragement and assistance given in the preparation of this thesis; to Dr. C. A. Peters for many helpful suggestions; and to the Departments of Chemistry and Rural Engineering for the courteous loan of apparatus.

