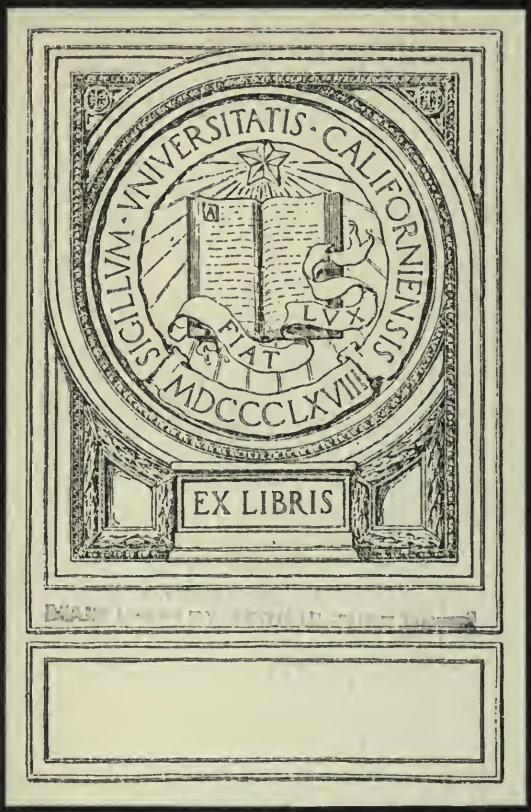
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Some Observations on Manuring with Bone-dust.

BY

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The observation of Kellner and Böttcher that the availability of bone dust, but not that of secondary calcium phosphate,[1] Thomas phosphate and superphosphate is depressed by calcium carbonate has been repeatedly confirmed and was explained by the neutralization of the soil acidity by liming.[2] In order to gain some further information the action of bone dust in the presence of gypsum and of magnesium sulphate respectively was compared with the depressions caused by the presence of the carbonates of lime, magnesia and potassa with both sand and soil cultures.

Sand-culture : The experiment was carried out with of barley in six series, each in three pots. Each pot contained 6 kilo. pure quartz sand, and received the following manures[3] :

15.64 g. bone dust.
3.86 g. ammonium nitrate (In Series F substituted by $NaNO_3$)
2.7 g. potassium sulphate (,, ,, ,, partly besides K_2CO_3)
0.5 g. ferric hydrate.

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1). It might therefore be supposed that carbonic acid of the soil-air suffices to render this phosphate available to the roots, while for bone dust a more powerful acid seems to be necessary to render it thoroughly available.

2). Also the acidity of the rootlets doubtless plays a part.

3). The bone dust (steamed and partly deprived of glue) was of extreme fineness, <0.5 m.m. and contained 1.39 % N, 29.58 % P_2O_5, 37.88 % CaO and 1.27 % MgO.
The magnesit contained 47.05 % MgO.
The other manuring compounds were chemically pure.

Series A, received so much magnesia in the form of 8 g. powdered magnesit (<0.5 m.m.) that the ratio $\frac{CaO}{mg}$ was $=\frac{1}{1}$. The bone dust was here the only source of lime.

Series B, contained the magnesia in the form of 0.78 g. crystallized sulphate which dose will be about agronomically equivalent in sand to 8 g. magnesit.

Series C, contained 3.42 g. lime-stone meal, every other particular=A; hereby the ratio $\frac{CaO}{MgO}=\frac{1.5}{1}$ resulted.

Series D, contained 6.84 g. limestone meal, every particular=A; hereby the ratio $\frac{CaO}{MgO}=\frac{2}{1}$ was produced.

Series E, like A, but 11.76 g. gypsum were added, yielding thus the ratio $\frac{CaO}{MgO}=\frac{2}{1}$; but one half of the lime is here more easily available than the other half.

Series F, like A, but a certain portion of potassium sulphate was replaced by 0.4 g. K_2CO_3. Ammonium nitrate had here to be replaced by an equivalent amount of *sodium nitrate*[1] in order to avoid the formation of the injurious ammonium carbonate.

The following table will show the quantitative data in regard to manuring conveniently:

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1). Seelhorst as well as Prianishnikow and Söderbaum have already observed that in the presence of sodium nitrate the phosphoric acid of rock and bone phosphate is not so easily available as in the presence of ammonium sulphate or ammonium nitrate. In the former case, sodium carbonate was believed to be gradually formed.

Manure.	A	B	C	D	E	F
Bone dust	15.64 g.	ditto.	ditto.	ditto.	ditto.	ditto.
Ammonium nitrate ...	3.86 g.	ditto.	ditto.	ditto.	ditto.	—
Sodium nitrate	—	—	—	—	—	8.19 g.
Potassium sulphate ...	2.7 g.	ditto.	ditto.	ditto.	ditto.	2.2 g.
Potassium carbonate ...	—	—	—	—	—	0.4 g.
Ferric hydrate	0.5 g.	ditto.	ditto.	ditto.	ditto.	ditto.
Magnesit	8 g.	—	8 g.	ditto.	ditto.	ditto.
Magnesium sulphate ...	—	0.78 g.	—	—	—	—
Limestone	—	—	3.42 g.	6.84 g.	—	—
Gypsum	—	—	—	—	11.76 g.	—
Ratio $\frac{CaO}{MgO}$	$\frac{1}{1}$	$\frac{1}{\left(\frac{1}{80}\right)}$	$\frac{1.5}{1}$	$\frac{2}{1}$	$\frac{2}{1}$	$\frac{1}{1}$

On Nov. 4, 1904, bone dust, magnesit, limestone, gypsum, and ferric hydrate,[1] were applied to the respective pots; and a part of the soluble nutrients the next day in solution, the rest Feb. 20.

On December 12, the young plants of sixsided barley of about 6 cm. were transplanted, each pot receiving three bundles, each consisting of three plants. During vegetation, the plants of the pots B and E showed a most luxuriant development and a *deep green color*, while those of the other pots showed a poor growth and a somewhat pale color; the poorest of all were the plants in E. The following table shows the height of plants, and numbers of stems and ears:

1). The ferric hydrate was freshly precipitated and applied in suspension.

Average of three parallel pots.

	January 17.		May 24.	
	Height (cm.).	No. of stems.	Height (cm.).	No. of ears.
A	16.7	24	85.5	18
B	16.4	25	79.1	18
C	16.1	24	87.9	14
D	17.0	25	76.1	11
E	17.9	24	80.6	19
F	16.1	25	60.6	7

The adjoining Plate xxv, Fig. 1 (photogr. May 12) shows the difference in development. The ears appeared gradually, about two weeks passing between the earliest and latest sproutings; the differences will be seen from the following table:

Average of three parallel pots.

	Ears appeared.
A	May 1
B	April 26
C	May 4
D	„ 8
E	April 24
F	May 9

The plants were harvested June 10, and weighed in the air-dry state with the following result, g.:

Average of three parallel pots.

	Grains.	Straw.	Chaffs.	Roots.	Total.
A	17.95	26.60	3.30	4.30	52.15
B	17.00	30.20	2.00	5.13	54.33
C	17.27	23.57	1.50	4.07	46.41
D	11.83	17.57	1.17	4.07	34.64
E	22.10	31.45	2.60	6.75	62.90
F	6.90	8.80	0.60	1.80	18.10

If we now assume the total yield of the pots B to be = 100, we obtain the following ratio:

A ($MgCO_3$) 96
B ($MgSO_4$) 100
C ($CaCO_3 + MgCO_3$) 85
D ($CaCO_3 + MgCO_3$) 64
E ($CaSO_4 + MgCO_3$) 116
F ($K_2CO_3 + MgCO_3$) 33

From the observations and this yield, it may be inferred:

1. Magnesit acts like limestone, depressing the availability of bone dust (compare A, C and D with B)[1].
2. The ratio CaO : Mg = 2 : 1 (D) depressed the harvest more than the ratio CaO : Mg = 1 : 1 (A) which is in full accordance with results obtained also in other cases with cereals.

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1). Recently Koch and Gröber (Fühlings Landw. Zeitg. 1906, p. 225) inferred from their experiments that this depressing effect is also due to the neutralization of the acids produced by bacteria in the soil. But the conditions in the soil are often entirely different from these in flasks. These authors applied solutions of 2–5 % dextrose to bone dust in the absence and in the presence of calcium carbonate, and of course observed that in the absence of calcium carbonate the phosphate was dissolved considerably by the bacterial action. But in the soil, suitable carbohydrates are generally absent, and therefore acid can not be produced. On the contrary, the soil-bacteria produce ammonium carbonate by the rottening process of the organic matter of the bone dust, and in this case the solubility of the tertiary phosphates will certainly be very much smaller than in the former case, i.e. in the presence of glucose.

3. Even a certain excess of gypsum produced the most favorable result. The different availability of calcium carbonate and sulphate[1] partly accounts for the fact that here the ratio CaO : MgO = 2 : 1[2] did not depress the harvest.
4. In the presence of sodium nitrate, the phosphoric acid of bone phosphate is not so easily available as in the presence of ammonium sulphate (compare F with the other pots) in accordance with the results of other investigators.
5. In the pot E with 0.4 g. potassium carbonate, the harvest was poorest; but in how far this was due to the substitution of ammonium nitrate by sodium nitrate and in how far to the increased alkaline reaction caused by potassium carbonate, could not directly be decided.
6. Since the plants grown with gypsum were of a deeper green than those grown with carbonates, it seems that the chlorophyll production was also somewhat interfered with in the latter cases. Further, investigations on this point however are contemplated.

The above observations with sand-culture rendered it desirable to compare also in soil-culture the effect of potassium carbonate and also of wood ash with that of potassium sulphate, when bone dust serves as a phosphatic manure.

Soil-culture : An alluvial sandy soil poor in humus was selected for this purpose, since the presence of much humus would have led probably to the neutralization of potassium carbonate.

Experiment with Barley.

The experiment was carried out in two parallel series. Eight zinc pots received 10 kilo. air-dry soil. On Nov. 4, 1904, 6 g. sodium

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1). O. Loew and K. Aso: "On Different Degrees of Availability of Plant Nutrients," The Bulletin, Col. of Agric., Tokyo, Vol. VI., No. 4, p. 335.

2). One plant showed here an average weight of 7 g. in the air-dry state, which is certainly a good result for sand-culture.

nitrate[1] and 2 g. bone dust[2] were applied as general manure to each pot. While 1.61 g potassium carbonate[3] was added to each of the first two pots, each of the second two pots received as much wood ash[4] as corresponded to potassium carbonate so that the potassa content was equal. Each of the third two pots with wood ash received less bone dust than the others, since the wood ash itself contained 3.5 % P_2O_5. This amount was calculated as bone dust and subtracted from the 2 g. bone dust applied to the other pots; probably the phosphoric acid in the wood ash is also present chiefly as tertiary calcium phosphate. To make up the difference in nitrogen the amount of sodium nitrate was raised to 6.2 g. In each of the fourth two pots, the potassa was applied as sulphate[5] in doses equivalent to the potassium carbonate, applied to the others. The following table gives the quantitative data in regard to manuring:

Nutrients.	I	II	III	IV
Sodium nitrate	6.0 g.	ditto.	6.2 g.	6.0 g.
Bone dust	2.0 g.	ditto.	0.8 g.	2.0 g.
Potassium carbonate	1.61 g.	—	—	—
Wood ash	—	9.5 g.	ditto.	—
Potassium sulphate	—	—	—	1.94 g.
Total nitrogen	1.01 g.	ditto.	ditto.	ditto.
„ phosphoric acid	0.56 g.	0.89 g.	0.56 g.	ditto.
„ potassa...	1.05 g.	ditto.	ditto.	ditto.

On Nov. 6, twenty seeds of sixsided barley were sown per pot, and after nine days the young shoots came up almost stimultaneously. The

1). Sodium nitrate (16 % N) was intentionally applied as a source of nitrogen, since ammonium sulphate, being physiologically acid, would have interferred with the alkalinity of the manure (potassium carbonate and wood ash), the effect of which was to be observed.

2). The bone dust (steamed and partly deprived of glue) was of extreme fineness, <0.5 m.m., and contained 2.71 % N and 27.73 % P_2O_5.

3). The potassium carbonate contained 65 % K_2O.

4). The wood ash contained 11 % K_2O, and 3.50 % P_2O_5.

5). The potassium sulphate contained 54 % K_2O.

plants were thinned to 15 per pot on December 7, taking care that they were all equal in size.

During vegetation, the plants showed no very great differences, as will be seen from the following table :

Average of two parallel pots.

Group.		I	II	III	IV
Manures per pot.		6 g. $NaNO_3$ 2 g. bone dust 1.61 g. K_2CO_3	6 g. $NaNO_3$ 2 g. bone dust 9.5 g. wood ash	6.2 g. $NaNO_3$ 0.8 g. bone dust 9.5 g. wood ash	6 g. $NaNO_3$ 2 g. bone dust 1 94 g. K_2SO_4
Dec. 7	Height of plants (cm.)	7.8	9.2	8.3	8.1
	No. of shoots	15	15	15	15
Jan. 17	Height of plants (cm.)	12.0	13 7	12.1	11.8
	No. of shoots	51	56	15	53
Feb. 2	Height of plants (cm.)	17.2	19.4	16.8	17.1
	No. of shoots	70	59	60	61
March 20	Height of plants (cm.)	28.9	29.5	31.1	26.3
	No. of shoots	71	68	68	71
April 19	Height of plants (cm.)	70.9	73.5	79.6	73.2
	No. of shoots	41	37	33	39
May 26	Height of plants (cm.)	103.2	110.8	103.0	104.7
	No. of ears	34	31	31	33

The plants were harvested on June 5, and weighed in the air-dry state with the following result, g. :

Average of two parallel pots.

Group.	I	II	III	IV
Manures per pot.	6 g. $NaNO_3$ 2 g. bone dust 1.61 g. K_2CO_3	6 g. $NaNO_3$ 2 g. bone dust 9.5 g. wood ash	6.2 g. $NaNO_3$ 0.8 g. bone dust 9.5 g. wood ash	6 g. $NaNO_3$ 2 g. bone dust 1.94 g. K_2SO_4
Grains	49.8	54.5	50.2	52.0
Straw	51.2	52.9	49.9	47.5
Chaffs	4.0	3.9	3.9	4.2
Total	105.0[1]	111.3	104.0	103.7[2]

If we now assume the total yield with the manure of the group IV to be = 100, we obtain the following ratio :

I	II	III	IV
101	107	100	100

Hence there was no decisive difference between the effects of potassium sulphate and potassium carbonate when the nitrogen was added as nitrate.

Experiment with Soy-bean.

Eight zinc pots were manured as follows :

1). The weight of one plant in the group I would therefore be 7 g. in the air-dry state (105÷15=7).

2). The average weight of one plant in the group IV was again 7 g. (103.7÷15=7). In the first experiment, when bone dust was applied together with ammonium nitrate and gypsum, the average weight of one plant was also 7 g. (62.7÷9=7).

Nutrients[1].	I	II	III	IV
Sodium nitrate	2.84 g.	ditto.	3.1 g.	2.84 g.
Bone dust	6.0 g.	ditto.	4 04 g.	6.0 g.
Potassium carbonate	2.5 g.	—	—	—
Wood ash	—	15.5 g.	15.5 g.	—
Potassium sulphate	—	—	—	3.2 g.
Total nitrogen	0.61 g.	ditto.	ditto.	ditto.
„ phosphoric acid	1.66 g.	2.29 g.	1.66 g.	ditto.
„ potassa...	1.70 g.	ditto.	ditto.	ditto.

Ten seeds of soy-bean previously steaped in water were sown per pot June 6. The young shoots appeared after five days, except in pots IV (K_2SO_4), which came up three days later. The plants were reduced later on to six per pot of about equal size. All plants showed nearly equal development, only those of the pots II seemed always somewhat a head[2]. The following table shows the height of the plants on Sept. 21 :

Average of two parallel pots.

Group.	I	II	III	IV
Manures per pot.	2.84 g. $NaNO_3$ 6 g. bone dust 2.5 g. K_2CO_3	2.84 g. $NaNO_3$ 6 g. bone dust 15.5 g. wood ash	3.1 g. $NaNO_3$ 4.04 g. bone dust 15.5 g. wood ash	2.84 g, $NaNO_3$ 6 g. bone dust 3.2 g. K_2SO_4
Height (cm.) ...	54.1	57.1	52.3	54.5

The plants were harvested on Sept. 21, and weighed in the air-dry state with the following result, g. :

1). The nutrients were the same as those applied in the former experiment, except the sample of potassium carbonate which was here quite pure.

2). In the pots II the amount of phosphoric acid was larger than in the other pots, since the phosphoric acid of the wood ash was added to the dose of bone dust in I and IV.

Average of two parallel pots.

Group.	I	II	III	IV
Manures per pot.	2.84 g. $NaNO_3$ 6 g. bone dust 2.5 g. K_2CO_3	2.84 g. $NaNO_3$ 6 g. bone dust 15.5 g. wood ash	3.1 g. $NaNO_3$ 4.04 g. bone dust 15.5 g. wood ash	2.80 g. $NaNO_3$ 6 g. bone dust 3.2 g. K_2SO_4
Grains	52.67	53.99	49.73	50.96
Stalks, husks, roots etc.	65.35	74.79	65.03	62.35
Total	118.02	128.78	114.76	113.31

If we now assume the total yield with the manure of the group IV to be = 100, we obtain the following ratio:

I	II	III	IV
104	114	101	100

This result coincides with that of the former experiment with barley.

Second Experiment with Barley.

This experiment was carried out in three parallel series, and with a different soil (alluvial sand). In order to examine here the productivity of the original phosphoric acid in the soil, pots without phosphatic manure served for comparison. On October 29, fifteen zinc pots received each 12 kilo. air-dry soil with the following manures[1].

1). Each manure had the following percentage amount of nutrient:

The sodium nitrate = 13.92 % N.

The wood ash = 17.24 % K_2O and 3.14 % P_2O_5.

The other manuring compounds were the same as in the former experiment with barley in sand-culture.

Nutrients.	I	II	III	IV	V
Sodium nitrate	20.25 g.	ditto.	20.6 g.	20.25 g.	21.25 g.
Bone dust	10.0 g.	ditto.	6.47 g.	10.0 g.	——
Potassium carbonate ...	8.8 g.	——	——	——	——
Wood ash	——	34.8 g.	ditto.	——	——
Potassium sulphate ...	——	——	——	11.09 g.	ditto.
Total nitrogen	2.96 g.	ditto.	ditto.	ditto.	ditto.
„ phosphoric acid...	2.96 g.	4.05 g.	3.00 g.	2.96 g.	——
„ potassa	5.99 g.	ditto.	ditto.	ditto.	ditto.

On December 15, the young plants of sixsided barley of about 6 cm. were transplanted so that each pot received five bundles, each consisting of three plants. During vegetation, all plants with bone dust (I, II, III, and IV) developed almost equally well, while those without phosphatic manure (V) showed a poor growth, as will be recognized from the following table :

Average of three parallel pots.

Group.		I	II	III	IV	V
Manures of pot.		20.25 g. $NaNO_3$ 10 g. bone dust 7.8 g. K_2CO_3	20.25 g. $NaNO_3$ 10 g. bone dust 34.8 g. wood ash	20.60 g. $NaNO_3$ 6.47 g. bone dust 34.8 g. wood ash	20.25 g. $NaNO_3$ 10 g. bone dust 11.09 g. K_2SO_4	No phosphatic manure
Jan. 17	Height of plants (cm.)	14.2	13.4	13.9	14.0	14.5
	No. of stems	35	36	34	36	30
May 24	Height of plants (cm.)	99 8	96.2	94.0	94.3	78.0
	No. of ears	36	36	36	37	21

The adjoining plate (photogr. May 24) XXV, Fig. 2 shows the general development.

The plants were harvested June 8, and weighed in the air-dry state with the following result, g. :

Average of three parallel pots.

Group.	I	II	III	IV	V
Manures of pot.	20.25 g. $NaNO_3$ 10 g. bone dust 7.8 g. K_2CO_3	20.25 g. $NaNO_3$ 10 g. bone dust 34.8 g. wood ash	20.6 g. $NaNO_3$ 6.47 g bone dust 34.8 g. wood ash	20.25 g. $NaNO_3$ 10 g. bone dust 11.09 g. K_2SO_4	No phosphatic Manure.
Grains	43.9	39.6	44.3	48.7	21.2
Straw	62.2	66.5	70.1	73.7	35.0
Chaff	7.0	6.2	7.1	7.5	4.1
Total	113.1⊕	112.3	121.5	129.9⊕	60.3

If we now assume the total yield with the manure of the group IV to be = 100, we obtain the following ratio:

I	II	III	IV	V
87	86	94	100	46

From these results, which differ partly from those obtained with plain sand-culture (see above) it may be concluded that the harvests of barley obtained on sandy soils with *bone dust and sodium nitrate as manure do not show great differences when in one case the potassa is supplied as potassium sulphate and in the other as potassium carbonate.* On one soil, the result was nearly equal, while on the second soil, potassium sulphate yielded a somewhat better result. Also the potassa in the form of wood ash yielded a result not behind the other case. *Wood ash and bone dust may therefore be applied together.*

This behavior of potassium carbonate in the soil manured with bone dust required some further chemical examination, for there was a direct action of it on the bone dust possible with gradual formation of potassium phosphate and calcium carbonate.

⊕ The weight of one plant in the group I would therefore be 7 g. in the air-dry state and of the group IV 8 g. In the first experiment when bone dust was applied together with ammonium nitrate and gypsum the average weight of one plant was also 7 g. In the second experiment, the average weights of one plant in the pots I and IV were again 7 g.

In order to decide this question, 25 g. bone dust[1] as well as equivalent doses of bone ash[2] were left with frequent shaking in 2.5 litres of water as well as of 1% potassium carbonate solution for $4\frac{1}{2}$ months[3] at room temperature; in one case 5 c.c. of neutral chloroform were added to prevent any bacterial action, while in the others chloroform was excluded. Phosphoric acid had indeed after that time passed into solution; therefore potassium phosphate must have been formed. The quantitative determinations in one litre of the liquid gave the following results:

		Milligr. P_2O_5 dissolved in one litre.		
		After 1 month.	After 2 months	After $4\frac{1}{2}$ months.
I	Bone dust in water	7.65	—	12.66
II	Bone ash „ „	0.57	—	0.71
III	Bone dust in water with chloroform... ...	5.29	—	7.46
IV	Bone ash „ „ „ „	0.19	0.51	0.64
V	Bone dust in 1% K_2CO_3 solution	45.91	47.82	68.95
VI	Bone ash „ „ „ „	8.16	8.99	—
VII	Bone dust in 1% K_2CO_3 solution with chloroform	44.51	45.78	56.04
VIII	Bone ash „ „ „ „ „ „	5.42	6.89[4]	8.42

These numbers show that *the bacteria play indeed a role causing solution of phosphoric acid from bone dust* (compare I with III). In the presence of bacteria (I), the amount of dissolved phosphoric acid had increased by 70%[5] after $4\frac{1}{2}$ months over the amount of dissolved phosphoric acid in the presence of chloroform.

When we further compare II and IV, we find that the absence of chloroform has not led to any notable increase of the dissolved phosphoric

1). The bone dust was the same as that applied in the above fourth experiment.

2). The bone ash was freshly prepared by igniting 25 g. bone dust mentioned.

3). From December 26, 1905 to May 11, 1906.

4). This figure is smaller than the corresponding figure of VI (8.99), which may be due to the gradual decomposition of chloroform by the potassium carbonate, whereby potassium chloride and potassium formate result.

5). 7.46 : 12.66 = 100 : 170.

acid. This different behavior from bone dust is very easily explained by the absence of organic matter in bone ash, excluding therefore the possibility of bacterial growth.

Further more, it becomes evident that potassium carbonate has acted chemically on the bone dust with the formation of potassium phosphate, as becomes clear in comparing V and VII. The presence of chloroform in this case, depressed the dissolution of phosphoric acid comparatively little, proving that *the chemical influence of potassium carbonate on bone dust was much more powerful, than the effect of the bacterial action.*

Further it becomes clear that the potassium carbonate acts with much more difficulty on bone ash than on bone dust (Compare IV and VIII with V and VII).

As a general result, however, it follows that the depressing effect which potassium carbonate would no doubt exert on account of its alkalinity on the availability of bone dust is counterbalanced by its chemical action on bone dust in which gradually potassium phosphate and calcium carbonate are produced.

EXPLANATION OF PLATE XXV.

Fig. 1.

A_{III} Manured with 15.64 g. bone dust, 3.86 g. ammonium nitrate, 2.7 g. potassium sulphate, 0.5 g. ferric hydroxide, and 8 g. magnesit.

B_{II}. Manured like A_{III}, but magnesit was here substituted by 0.78 g. crystallized magnesium sulphate.

C_{III} Manured like A_{III} with an addition of 3.42 g. limestone meal.

D_{III} Manured like C_{III}, but the amount of limestone was here increased to 6.84 g.

E_{III} Manured like D_{III}, but limestone was here replaced by the equivalent amount of gypsum (11.76 g.).

F_{II} Manured with 15.64 g. bone dust, 8.19 g. sodium nitrate, 2.2 g. potassium sulphate, 0.4 g. potassium carbonate, 0.5 g. ferric hydroxide and 8 g. magnesit.

Fig. 2.

I_3 Manured with 20.25 g. sodium nitrate, 10 g. bone dust, and 7.8 g. potassium carbonate.

II_1 Manured with 20.25 g. sodium nitrate, 10 g. bondust, and 34.8 g. wood ash.

III_3 Manured with 20.6 g. sodium nitrate, 6.47 g. bone dust, and 34.8 g. wood ash.

IV_3 Manured with 20.25 g. sodium nitrate, 10 g. bone dust, and 11.09 g. potassium sulphate.

V_3 Received no phosphatic manure.

(1)

To Page 108.

(2)

To Page 116.