A VEGETATION EXPERIMENT ON THE AVAILABILITY OF NITROGENOUS FERTILIZERS IN AN ARID SOIL¹

By

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In a series of papers which either have recently appeared (2, 3) or are soon to appear (4, 5) the senior author alone, or together with P. S. Burgess, has furnished experimental evidence which amounted in general to the following:

1. The nitrification method, in the direct soil culture, for determining the relative availabilities of nitrogenous fertilizers of the organic or ammonia type was entirely feasible, and more logical and specific in nature than other methods employed heretofore.

2. By the use of that method an important distinction is observable between humid and arid soils as regards ability to nitrify the nitrogen of soils.

3. Humid soils, contrary to the general impression created by Hilgard's teachings, are superior in nitrifying power to the arid soils when they are considered by and large.

4. Dried blood and other high grade nitrogenous fertilizers nitrify relatively slowly in arid soils and rapidly in humid soils.

5. The situation is reversed when the low grade organic nitrogenous fertilizers or sulfate of ammonia are employed. These nitrify much more readily in arid than in humid soils.

6. The foregoing results and conclusions appeared to justify the recommendation to farmers that, on the truly arid soils of California and under circumstances in which availability was the desideratum, low grade organic nitrogenous fertilizers or sulfate of ammonia be employed.

7. It was also pointed out that nitrates, and especially nitrate of soda, did not under most circumstances in arid soils, behave like the other nitrogenous fertilizers mentioned in the foregoing paragraph. The reason for this is that nitrates, being immediately soluble in the soil moisture when applied to the soil, begin to rise with the moisture upwards from the bottoms of irrigation furrows and tend to accumulate in the dry surface soil. The latter cannot, of course, be of use to plants since it is used largely as a dust mulch, and hence the surface soil may contain an ample quantity of nitrates and still the roots of plants in the subsoil may starve for want of available nitrogen. That this accumulation of

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nitrate occurs in the surface layers of arid soils has been well known through the publications of Hilgard on alkali salts in soil. It has, however, been more fully explained and emphasized recently by the investigations of McBeth at the Citrus Experiment Station, Riverside, Cal.

8. Sulfate of ammonia which showed itself to be unusually well suited to nitrification in arid soils according to our results, was applied on the senior author's recommendation to orchards in which "little leaf" or in which "chlorosis" was seriously injuring the trees. In nearly all such cases, the trees were brought back to a normal condition by the soil treatment. In some of these cases high grade organic nitrogenous fertilizers, nitrates, and barnyard manure had been used for years with little or no effect.

9. In general the senior author has become convinced through our various studies that, owing to the low nitrogen content of arid soils, not enough available nitrogen is elaborated and not enough remains in the feeding zone of the roots, also, that in many cases in which the soil's total nitrogen content is high, our climatic conditions and tillage have operated to lower the nitrifying power of the soils to such a degree that insufficient available nitrogen is maintained in the root zone for normal crop production.

The method employed in the various nitrification studies upon which the foregoing conclusions were based is as follows: 100-gm. portions of the soil to be studied are either incubated under optimum moisture conditions for one month at 28° to 30° C. and the nitrates formed determined, or the soil portion as above is mixed with 1 per cent of the organic fertilizer to be tested and otherwise similarly treated. Usually soils both with and without fertilizer are studied in the case of every type.

The validity of this method has been called in question by Kelley (1) on the ground that it allows an excessive use of fertilizer as compared with soil material, and hence cannot be used as a criterion for field studies in which relatively small quantities of fertilizer per acre are employed. Our reply to this argument is that undoubtedly the conditions of our experiments are unlike those of the field, and that the use of small quantities of fertilizers in the soils to be studied will soon gain in favor and probably be adopted for nitrification work. However, we also claim that our results are valid for determining sufficiently accurately the *relative* availabilities of different organic nitrogenous fertilizers; and particularly as a reliable guide to the choice of nitrogenous fertilizers for soils.

In order, however, to test this idea more definitely, we decided to carry out a vegetation experiment with an arid soil which gave us the following results by our method of determining the nitrifiability of nitrogen fertilizers. The soil contained .03 per cent of total nitrogen as determined by our modification of the Gunning method.

It is clear from these data that cottonseed meal and steamed bone meal are practically equally nitrifiable by our method and that sulfate of ammonia, although used in smaller amounts, yields about as much nitrate as the other two. Dried blood, however, encourages a loss of even the small quantity of nitrate originally present in the soil. If, therefore, our method could be employed as a guide in the choice of nitrogenous fertilizers for the soil here studied, it would indicate that steamed bone meal, cottonseed meal and sulfate of ammonia are of about equal value, and that dried blood is decidedly inferior. It is of course obvious that the method is not perfect because of the fact that when used in small quantities dried blood gives better crop results, as Table II shows, than the soil without fertilizer, yet the latter soil gives better nitrification results than the blood by our method. On the other hand, it must be observed that in a special test with some of the same fertilizers in the

TABLE I
NITRIFICATION OF NITROGEN IN DIFFERENT FERTILIZERS IN OAKLEY BLOW SAND

Fertilizer Used	Amount Per cent	Nitrate N. Found Mg.	Nitrate N. Produced Mg.
None	...	0.42	0.36
None	...	0.60	0.55
Dried Blood	1.0	....	....
Dried Blood	1.0	Trace	....
Steamed Bone Meal	1.0	3.00	2.95
Steamed Bone Meal	1.0	2.40	2.35
Cottonseed Meal	1.0	2.24	2.19
Cottonseed Meal	1.0	2.40	2.35
(NH ₄) ₂ SO ₄	0.1	2.24	2.19
(NH ₄) ₂ SO ₄	0.1	2.48	2.43

same soil, in all cases small quantities being used equivalent to the same amount of nitrogen which is found in .05 gm. of dried blood, the cottonseed meal is distinctly superior to the others, dried blood takes second place, and the sulfate of ammonia is distinctly last.

Let us now see how these results harmonize, if at all, with the vegetation tests. The latter were carried out in 9-inch earthenware pots which were paraffined to prevent absorption of moisture and salts by the walls of the pot. About ten pounds of the Oakley blow sand were placed in each pot and every treatment was run in triplicate. A selected strain of the Beldi variety of barley was employed as the crop plant. The fertilizers were applied in different amounts in two series. In one series amounts equivalent to those employed in the laboratory tests were incorporated with the soil. In the second series amounts of the different fertilizers were used which contained a quantity of nitrogen equivalent to that used when dried blood is applied at the rate of 800 pounds per acre. The fertilizers tested were dried blood, steamed bone meal, cottonseed meal,

sulfate of ammonia, nitrate of soda, and nitrate of calcium. From a number of seeds planted at first the plants which appeared were thinned to four per pot.

It almost goes without saying that scarcely any growth, and in some cases none, was obtained in the series containing the large fertilizer applications. In those pots in which plants came up normally they grew to a height of three or four inches and then gradually turned yellow and withered. This occurred primarily in the pots containing the organic fertilizers and was doubtless due to the absorption of excessive amounts of ammonia by the plants, which exercised a marked toxic effect. That this was probably so is indicated by the strong odor of ammonia which was always noticeable in the vicinity of the pots under consideration. The possibility also exists, of course, that organic compounds of a toxic nature formed from the decomposition of the fertilizers may have been the cause of the poisoning of the plants. In the case of the inorganic fertilizers the effects were probably nothing more nor less than alkali effects which are already well known.

In the second series of pots the plants came up and developed normally but the difference between the different treatments was visible almost from the very start. Until the plants arrived at a height of eight or ten inches, the steamed bone meal treatment was slightly but distinctly superior to the other ones employed, but later in the growth of the plants the sulfate of ammonia and cottonseed meal treatments caught up with and finally surpassed the first named. The dried blood treatment showed itself from the start to be inferior to the three treatments just given. The nitrate of soda treatment was about equal to that of the dried blood in efficiency, but the calcium nitrate was inferior to both. Table II gives the results of studies on the grain, straw and root yields obtained.

Considering first the total weights of dry matter produced, we note the striking effect which nitrogenous fertilizers exercise on barley growth in the Oakley sand. That available nitrogen is sorely needed in that soil there can be no question. In the second place, we note clearly the superiority of sulfate of ammonia and cottonseed meal to all the other fertilizers. The two fertilizers just named are but very slightly different from each other. Thirdly, it should be noted that steamed bone meal comes next in order to the first two fertilizers named. Unfortunately, the plants in one of the three pots in the steamed bone meal treatment were injured and the yield made of no value to a closer appraisal of the actual effects of the steamed bone meal nitrogen. The dried blood treatment was distinctly behind the three just discussed as regards the total yield of dry matter. The nitrate of soda treatment was about equal to the dried blood treatment with respect to the yield of total dry matter, and the calcium nitrate treatment was distinctly inferior to both. We

see, therefore, in the first place a close resemblance between total dry matter yields and the appearances of the plants in the pots. In the second place we note a very close resemblance between the availability of the nitrogen in the different fertilizers as shown by both the laboratory and the vegetation methods.

On the basis of the grain and straw yields alone, and disregarding the root yields, sulfate of ammonia, cottonseed meal and steamed bone meal are even closer together in regard to availability than they are when the

TABLE II
SHOWING AVAILABILITY OF DIFFERENT NITROGENOUS MATERIALS FOR
BARLEY IN OAKLEY SAND

No. and Treatment	Weight of Grain and Straw	Average Weight of Grain and Straw	Weight of Grain	Average Weight of Grain	Weight of Roots	Average Weight of Roots	Total Dry Weight Produced	Average Total Dry Weight
	gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.
1. Blood	22.6	22.7	6.59	6.63	4.00	3.87	26.60	26.57
2. Blood	25.5	....	6.19	....	4.80	....	30.30	....
3. Blood	20.0	....	7.12	....	2.80	....	22.80	....
4. Steamed Bone Meal ...	24.6	26.6	6.24	7.59	3.90	3.70	28.50	30.85
5. Steamed Bone Meal ...	Lost	....	....	....	Lost	....	Lost	....
6. Steamed Bone Meal ...	28.6	....	8.93	....	4.60	....	33.20	....
7. Cottonseed Meal	31.0	29.9	8.44	7.61	6.70	6.13	37.70	36.30
8. Cottonseed Meal	30.0	....	8.63	....	6.70	....	36.70	....
9. Cottonseed Meal	28.6	....	5.75	....	5.00	....	33.60	....
10. (NH ₄) ₂ SO ₄	30.0	31.2	9.17	8.62	8.40	7.27	38.40	38.80
11. (NH ₄) ₂ SO ₄	32.1	....	8.45	....	7.00	....	39.10	....
12. (NH ₄) ₂ SO ₄	31.5	....	8.27	....	7.40	....	38.90	....
13. NaNO ₃	24.0	22.3	5.93	6.19	4.50	4.50	28.50	26.76
14. NaNO ₃	19.8	....	6.70	....	4.10	....	23.90	....
15. NaNO ₃	23.0	....	5.96	....	4.90	....	27.90	....
16. Ca(NO ₃) ₂	22.3	18.5	8.34	6.52	5.00	4.00	27.30	22.80
17. Ca(NO ₃) ₂	17.6	....	6.73	....	4.50	....	22.10	....
18. Ca(NO ₃) ₂	15.5	....	4.49	....	3.50	....	19.00	....
19. Control	12.5	12.1	4.00	3.63	1.20	1.10	13.70	13.20
20. Control	11.7	....	3.25	....	1.00	....	12.70	....

weights of total dry matter are employed as criteria. Nevertheless, we find again that sulfate of ammonia is superior to all the other fertilizers, cottonseed meal is a close second, and steamed bone meal a good third in order of availability. Dried blood and nitrate of soda are again equal as between themselves, and considerably behind the others. The calcium nitrate treatment gives distinctly the poorest of all yields with the exception, of course, of the untreated soil.

As regards the production of grain alone, the situation is almost the same as in the case of the combined grain and straw production. Sulfate of ammonia stands first and cottonseed meal and steamed bone meal, which are about equal to each other, stand as close seconds. In the

case of the other fertilizers we find that dried blood and nitrate of soda are again about equal, and that calcium nitrate is not inferior to them as it was in the case of the combined grain and straw yields, but is about equal to them.

In the case of the root yields we find the first evidence of strong differentiation between sulfate of ammonia and cottonseed meal on the one hand and steamed bone meal on the other. Sulfate of ammonia appears to exert its most marked effects with respect to availability on the root yields. Cottonseed meal is a fairly close second, and in about the same class, but the other fertilizers are distinctly in the third class and about the same among themselves.

In general, it would appear therefore that as regards their availability for barley production on the Oakley sand, the fertilizers here under examination (the nitrates being excluded for obvious reasons) stand nearly in the same relation to each other in the vegetation tests as they do in the laboratory tests as carried out by our method. We deem it justifiable, therefore, to urge the use of the nitrification method in some form for the determination of the relative availabilities of organic and inorganic nitrogenous fertilizers. Our results would lead us also to ask if we have not by means of them at least brought forward some evidence in favor of employing the nitrification method as a criterion in studies such as those considered in this paper?

*The Relative Availabilities of the Different Fertilizers as Determined
by Our Experiments*

Adopting now the method of Voorhees in his book on fertilizers and also that employed by other agricultural chemists in the past, we may determine the relative values of the different fertilizers used by us for

TABLE III
RELATIVE AVAILABILITIES OF NITROGEN FERTILIZERS IN OAKLEY SAND
(Values based on dry yields of straw and grain)

Nitrate of Sodium	100
Nitrate of Calcium	82+
Sulfate of Ammonia	139+
Dried Blood	101+
Cottonseed Meal	134+
Steamed Bone Meal	119+

the Oakley soil, barley being the crop plant. Assuming the value of nitrate of soda to be 100, as is usually done, the values for the other fertilizers would be those shown in Table III.

The figures in Table III speak for themselves and appear to us to bear out the contention which is supported also by our laboratory data that the low grade organic nitrogenous fertilizers and sulfate of ammonia

are far more available in arid soils like the Oakley blow sand than the high grade organic nitrogenous fertilizers. They also show that mere solubility in water does not under arid soil conditions necessarily constitute the highest availability. This seems to be supported by the data given for sodium and calcium nitrates.

SUMMARY

1. Vegetation experiments with barley on the availability of nitrogenous fertilizers in the Oakley blow sand (an arid soil) show the low grade organic nitrogenous fertilizers and sulfate of ammonia to be far more available than dried blood.

2. This confirms the values as to *relative availabilities* of these fertilizers obtained by our laboratory nitrification method.

3. Nitrates, and especially nitrate of calcium, are far less available in the Oakley soil than are the other fertilizers with the exception of dried blood, which is about equal to nitrate of soda but superior to nitrate of calcium.

4. These data furnish further evidence in support of our proposal to adopt the nitrification method in some form for the determination of the relative availabilities of fertilizer and soil nitrogen and for determining the needs of a soil for available nitrogen.

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