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Soil Experiments on the Red Limestone Upland of Southwest Missouri

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SOIL EXPERIMENTS ON THE RED LIMESTONE UPLAND OF SOUTHWEST MISSOURI

(SOIL TYPE—CRAWFORD SILT LOAM)

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The Missouri Agricultural Experiment Station in 1905 began a series of experiments at Billings, Christian County, for the purpose of determining the most profitable methods of handling the soils in that region.[1] The field on which these experiments have been conducted is located three and one-half miles south of Billings on the farm of E. G. Napper.

The soil is a phase of the red limestone land of Southwest Missouri. It is a rolling upland type and is technically known as the Crawford silt loam. It is derived from limestone and contains varying amounts of flint or chert, considerable quantities of which may be found on the surface over large sections of this region. The soil is reddish brown in color, averaging about 8 inches in depth, and merging into a yellowish red subsoil. The color and clay content of the subsoil gradually increases to a depth of 20 inches where the color is usually a bright red and much soft chert is found. At 30 to 40 inches there is a layer of cherty gravel so compact as to be difficult to penetrate.

The soil is friable and loose. Where the surface stone does not interfere or where it has been removed the soil is easily handled. It washes readily under cultivation, owing to its texture and the rolling topography. In general these red limestone soils are among the best of the upland soil types of Southwest Missouri. They vary considerably in fertility, however, and in many cases have been worn by continuous grain cropping. For this reason they are especially deficient in organic matter and nitrogen. The experiment field is located on an eastern slope. The upper and central portions of the slope have considerable surface chert while the lower third has very little.

A chemical analysis shows this soil to be deficient in nitrogen and phosphorus but only very slightly deficient in potassium. The low nitrogen content as well as the rather light brown color of the soil denotes a lack of organic matter, a very important factor in the fertility of soils. This suggests at once the need of a good rotation as well as manures and green manures to increase the supply of organic matter and nitrogen. Phosphorus would seem to be needed in some form,

[1] An earlier report on these experiments was issued in 1910, as Bulletin 86 of the Missouri Agricultural Experiment Station.

and as there is so little organic matter present to help make plant food available, even potassium which is present in fair amount might be expected to be deficient in available forms. As the soil was derived from limestone it would scarcely be expected to need applications of lime to keep it sweet. In many cases, however, much of the lime carbonate has been dissolved and leached away. Such soils are really made up of the impurities contained in the limestone and not of the lime carbonate itself. In general, however, they are not so likely to be sour as soils derived from other rocks such as shale or sandstone.

Plan of Experiment. With these considerations in view the experiment field was laid out as shown in the following diagram.

PLAN OF EXPERIMENT

SERIES A

1	Legume
2	Legume, Lime
3	No treatment
4	Legume, Lime, Bonemeal
5	Legume, Lime, Bonemeal, Potash

SERIES B

6	Legume
7	Legume, Lime
8	No treatment
9	Legume, Lime, Bonemeal
10	Legume, Lime, Bonemeal, Potash

SERIES C

11	Legume
12	Legume, Lime
13	Legume, Lime, Bonemeal
14	Legume, Lime, Bonemeal, Potash
15	No treatment

Three series of plots were staked out permanently in 1905 and a special soil treatment given each plot as shown in the diagram. The three series have been devoted to a four-year rotation of corn, cowpeas, wheat, and clover; three of the crops being grown each season, one crop on each series. This made it necessary to omit one crop of the rotation each year.

The legume treatment was given for the purpose of adding nitrogen and organic matter to the soil. It consisted chiefly in sowing cowpeas in the corn. These were sown at the last cultivation until 1913, when the plan was changed so as to put the peas in the hill when planting the corn. The growth of peas thus secured was turned under before the next crop. The second crop of clover on these legume treated plots was also turned under for additional nitrogen and organic matter. The lime was applied on the lime treated plots in the form of ground limestone at the rate of two tons per acre. One application was made at the time the experiment field was started and a second application during the seasons of 1913 and 1914. It was scattered by hand, tho this is not feasible on large areas. The lime was applied just after plowing and worked into the soil while the seed bed was being prepared. The phosphorus was applied in steamed bonemeal at the rate of 150 pounds per acre before corn and 150 pounds before wheat, or a total of 300 pounds in the four year rotation. From 1905 until 1912 the bonemeal used was a form containing 1¾ to 2½ per cent nitrogen and 20 to 24 per cent phosphoric acid. Since 1912 a bonemeal containing .82 per cent nitrogen and 29 per cent phosphoric acid has been used. Except during the first year, potassium has been applied as muriate of potash at the rate of 50 pounds per acre before

corn and 50 pounds before wheat. Sulphate of potash was used on series A and B in 1905. The cowpea and clover crops received no fertilizer directly but the yields have been increased considerably from the fertilizer applied for corn and wheat. Both the bonemeal and the potash were applied with a fertilizer drill at the time the crops were planted.

Basis of Calculations. In figuring the tables giving the results with various crops on this field it was thought best to figure the crops at the average farm prices given by the State Board of Agriculture for the last five years. Fertilizers are figured at the average retail prices collected by fertilizer inspectors from many parts of the state, and green manure crops at the cost of seed and seeding. This method gave the following list of prices:

FARM CROPS

Corn	$ .55 per bushel
Wheat	.90 per bushel
Clover hay	11.25 per ton
Cowpea hay	11.21 per ton
Soybean hay	11.21 per ton

FERTILIZERS

Cowpea green manure crop	$2.00 per acre per treatment
Ground limestone	$3.00 per ton applied
Steamed bonemeal	$28.00 per ton
Muriate of potash	47.50 per ton
Sulphate of potash	56.00 per ton

All net returns are figured after the cost of treatment has been deducted, and losses are indicated by minus signs. No account is taken of the extra labor involved in handling the increased crop but on the other hand no value is given to the increase in straw and stover so that one of these will about balance the other.

Table I. Results of Experiments with Corn (8 Crops) Billings Field

Soil treatment	Average yield bushels per acre	Average increase bushels per acre	Average value of increase per acre	Average cost of treatment per acre	Average net returns per acre per year
Legume	27.4	−1.45	−$ .80	$ .63	−$1.43
Legume, lime	30.7	1.9	1.01	1.38	− .37
No treatment	28.8				
Legume, lime, bonemeal	38.9	10.2	5.58	2.60	2.98
Legume, lime, bonemeal, potash	40.1	11.3	6.21	3.40	2.81

Experiments with Corn. Eight crops of corn have been grown on this field. The average yields, together with the costs and returns from the various soil treatments are shown in Table I. From this table it may be seen that cowpeas in the corn have decreased the yield on an average of about a bushel and a half per acre during the eight years. This, with the cost of sowing cowpeas, represents a financial loss which the following tables will show is not made up entirely by the crops following corn. Cowpeas usually make but little growth in corn except during favorable seasons when there is plenty of moisture and when the peas are sown before the corn is large enough to shade them badly. When conditions are favorable the growth is usually sufficiently heavy to produce an appreciable amount of green manure.

Lime has increased the corn yield enough to more than make up for the loss due to compeas, but hardly enough to balance this loss and pay the cost of liming. Used without peas lime should at least return its cost in increased corn yields.

Figure 1.—Corn on no treatment (left) and legume—bonemeal—lime (right), plots 1909.
Soil treatment increased the yield 11 bushels per acre.

The most profitable treatment for corn has been the use of steamed bonemeal to supply phosphorus. It was applied with an ordinary fertilizer drill ahead of the planter at the rate of 150 pounds per acre. This distributes the fertilizer in drills 7 or 8 inches apart and more may be used safely than where it is applied in the hill. Other experiments have shown that where fertilizers are applied in the hill with an attachment on the planter, it is not safe to use more than 75 to 100 pounds per acre owing to the fact that it tends to "fire" the corn, especially in dry years. Such small amounts must not be considered

sufficient to maintain soil fertility but rather to give the crop a quick vigorous start. This will enable the plants better to withstand the attack of insects and fungus diseases as well as to get ahead of the weeds.

Table I also shows that potash, in addition to lime and phosphorus, has increased the yield of corn, but not quite enough to pay for itself. This may be due to the fact that the rate of application was somewhat heavier than is commonly used which made the cost high. The rate of application has been 50 pounds of the muriate of potash, except during the first year when it was still higher. It was applied by mixing with the bonemeal and drilling. Altho this soil is well supplied with potash it seems to have too little of it in available form. Lighter applications should prove to be more profitable.

Table II. Results of Experiments with Wheat (7 Crops) Billings Field

Soil treatment	Average yield bushels per acre	Average increase bushels per acre	Average value of increase per acre	Average cost of treatment per acre	Average net returns per acre per year
Legume	11.7	.9	$ .81	$ .65	$ .16
Legume, lime	12.9	2.1	1.89	1.40	.49
No treatment	10.8				
Legume, lime, bonemeal	17.6	6.6	5.94	2.64	3.30
Legume, lime, bonemeal, potash	19.1	8.3	7.47	3.47	4.00

Experiments with Wheat. The average results with seven crops of wheat grown on this field may be seen in Table II. It should be noted that every soil treatment tried has more than paid its cost on wheat, altho in some cases the net profit is not large. It requires only small increases in the wheat crop to pay for better soil management since wheat usually sells for a higher price per bushel than most other crops. The increase in the yield of wheat due to the use of cowpeas in the preceding crop of corn is small, amounting to only about a bushel per acre. There is, however, some indication that this increase is steadily becoming greater. Only slightly greater increases have been obtained from the use of lime. This is a common result of experiments with lime on wheat as this crop is not very sensitive to a somewhat acid condition of the soil.

The most profitable treatment on wheat, as well as on corn, was the use of bonemeal. Unlike the corn crop, however, the increase in wheat has justified the use of potash even with the rather large amounts

applied. In general, wheat above all other crops can be depended upon to return a profit on reasonable applications of fertilizer containing phosphorus and potash in available form. The percentage of potash in such fertilizers should be kept low, and that of phosphorus high.

Table III. Results of Experiments with Cowpeas (8 Crops) Billings Field

Soil treatment	Average yield pounds per acre	Average increase pounds per acre	Average value of increaseper acre	Average cost of treatment per acre	Average net returns per acre per year
Legume	2397	211	$1.18	$ .60	$ .59
Legume, lime	2661	475	2.66	1.34	1.32
No treatment	2186				
Legume, lime bonemeal	3237	1051	5.88	2.40	3.48
Legume, lime, bonemeal, potash	3405	1219	6.82	3.03	3.79

Table IV. Results of Experiments with Clover (3 Crops) Billings Field

Soil treatment	Average yield pounds per acre	Average increase pounds per acre	Average value of increase per acre	Average cost of treatment per acre	Average net returns per acre per year
Legume	1316	– 120	–$ .67	$ .72	–$1.39
Legume, lime	1553	117	.65	1.47	– .82
No treatment	1436				
Legume, lime, bonemeal	3200	1764	9.88	3.03	6.85
Legume, lime, bonemeal, potash	3412	1976	11.06	4.18	6.88

Table V. Results of Experiments with Soybeans (1 Crop) Billings Field

Soil treatment	Average yield pounds per acre	Average increase pounds per acre	Average value of increase per acre	Average cost of treatment per acre	Average net returns per acre per year
Legume	2675	75	$ .42	$ .50	–$ .08
Legume, lime	3550	950	5.32	1.25	4.07
No treatment	2600				
Legume, lime, bonemeal	4200	1600	8.96	2.30	6.66
Legume, lime, bonemeal, potash	4550	1950	10.92	2.89	8.03

Experiments with Cowpeas and Clover. Eight crops of cowpeas have been harvested from the experiment field and the average results are shown in Table III. This is a good record for soil treatment on cowpeas, particularly since no fertilizers were applied directly before them. The yearly records show that the increases have been consistent from year to year. Lime does not ordinarily increase the yield of cowpeas much, but on the Billings field it has given a satisfactory increase when the size of the investment is considered. The use of bonemeal has been the most profitable soil treatment for cowpeas, altho it should be noted that this is the effect of the bonemeal applied before the preceding crops. Potash has increased the yield sufficiently to more than pay for its cost, but the profit, as will be seen from the table, is not very great. In general, cowpeas will do well on thin ground but these experiments indicate that they will respond profitably to better soil management on soils of the type under discussion.

Only three crops of clover have been secured from these experiments owing, chiefly, to a series of dry years and to the fact that this soil dries out rapidly. The record is shown in Table IV. One of the most noticeable features of this table is the fact that lime made so little increase in the clover when it has given some return on other crops. On similar experiment fields in other parts of the state, lime has been more effective on clover than on the other crops of this rotation. This particular soil type evidently does not need lime as much as many other Missouri soils.

Bonemeal has returned a greater profit on clover than on any other crops of the rotation. In deciding whether or not to use available phosphate fertilizers for wheat, this effect on the following clover should always be considered. Other experiments have shown similar increases and bear out this conclusion. Potash has made a slight improvement in the clover crop, but only barely enough to pay the additional cost.

The soybean is a comparatively new crop in the vicinity of Billings. This crop was not used on the experiment field until 1914 when it was adopted as a substitute for clover which failed to make a stand. The soybean is much like the cowpea except that it grows more upright and ordinarily produces more seed. It usually yields better after the first year on a piece of land, because of increased inoculation. The yields in this case have been satisfactory but the seed used had been hand-threshed and carried considerable dust from the field on which it grew. This seed may have carried sufficient inoculation as nearly every plant examined showed nodules in early fall. Experience has shown that soybeans generally respond to inoculation more readily than do cowpeas on land where they have never been grown before

Table V shows that, judging from this one year, soybeans will respond profitably to applications of lime, bonemeal, and potash on this soil.

Looking at the tables for the various crops it is interesting to note that phosphate and potash fertilizers have paid best on the legume crops, cowpeas, clover and soybeans. This is probably due to the fact that this soil is low in nitrogen, and such a condition tends to limit the yield. The legume crops, however, have the ability to secure much of their nitrogen from the air, hence, additions of the next limiting element, phosphorus, can increase the yield of legumes more than that of non-legumes. Liberal use of legume crops in connection with the

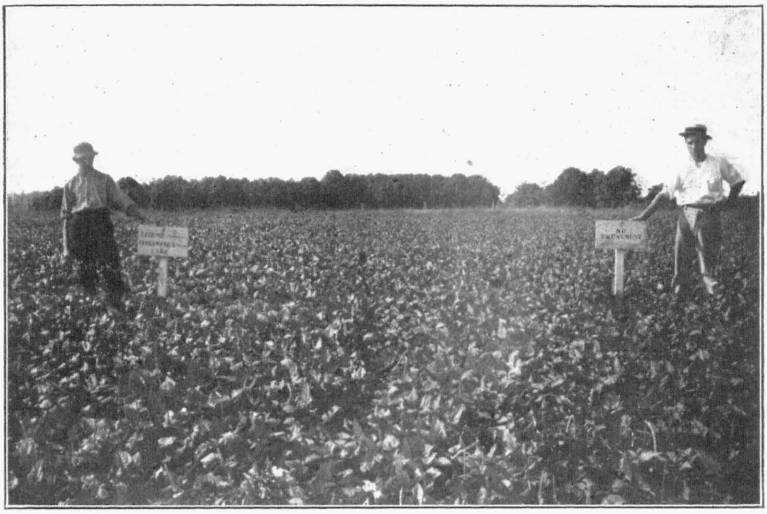

Figure 2.—Cowpeas on Billings experiment field.

maintenance of supplies of available phosphates and potash will do much for this soil. Table VI is a summary of the results of these soil experiments on all the crops used. Since this covers every season from 1905 to 1914 inclusive and a total of 27 crops harvested, it should represent just what can be expected from the various soil treatments given. All combinations have given some increase, but in the case of the cowpeas sown in the corn this gain was not large enough to cover the cost. Even tho this soil is not in serious need of lime the increase from its use turns the loss from cowpeas into a substantial gain. It should be noted that the addition of bonemeal to the combination of cowpeas and lime gives the most marked increase in the value of all crops taken together. This, together with the low supply of phosphorus shown in the soil analysis, points to a profitable use of the available

forms of phosphate. Potash has proved profitable on the whole, but might be more profitable if used in smaller amounts. If manure and other decaying material be applied in sufficient quantity to build up the organic matter in this soil the processes of decay thus fostered should help to make enough potash available from the supply in the soil.

Table VI. Average Results with All Crops Grown on Billings Experiment Field

Soil treatment	Average value of increase per acre	Average cost of treatment per acre	Average net returns per per acre per year
Legume	.26	$ .63	−$ .37
Legume, lime	1.85	1.38	.47
No treatment			
Legume, lime, bonemeal	6.36	2.59	3.77
Legume, lime, bonemeal potash	7.43	3.37	4.06

RECOMMENDATIONS FOR HANDLING THE RED LIMESTONE SOILS OF SOUTHWEST MISSOURI

The results of the chemical analysis of this soil as well as the results of these experiments indicate very strongly a lack of both nitrogen and phosphorus. Lime is needed, but not badly. Potassium, while fairly abundant in this soil, may be profitably used in small amounts, particularly on the thinner areas. Since nitrogen is contained in the organic matter in soils the lack of nitrogen indicates a lack of this essential soil constituent.

The Supply of Organic Matter. The importance of a large supply of organic matter or humus can hardly be overestimated, since it is upon this, more than any other one factor, that the productiveness of a soil depends. The decay of organic matter in a soil is largely responsible for the making available of plant food, and a large supply is usually essential to maximum yields. Evidently, then, the first essential to increased productiveness is the building up of this supply thru the use of a good crop rotation, careful returning of all manure possible, and frequent use of either green manure or pasture crops. Crops that are cultivated and those that allow the land to remain bare for considerable lengths of time, as corn and wheat, tend toward a rapid depletion of organic matter and an injury to the land thru washing. Land should not lie bare over winter if it is rolling enough to wash. The use of winter pasture crops such as rye, barley, or even wheat is of much value in keeping the soil from washing and in building up the supply of organic matter, as well as in furnishing a profitable return in pasture. In case such crops are turned under, as green manure, the amount of organic matter added is still greater.

Figure 3.—A poor stand of clover in wheat, on no treatment plot.

Figure 4.—Bonemeal and lime improve the clover stand as well as the wheat.

Crop Rotation. The crop rotation to be recommended for any farm depends largely upon the kind of farming, the labor supply, and on the size of the farm. A very good rotation for the main fields of a live stock farm on this soil, is one of corn, cowpeas or soybeans, wheat, and clover. Such a rotation allows a wide use of legume crops for building up the organic matter and nitrogen in the soil if the hay crops are fed and the manure returned.

A system that can be used where more corn is needed is two years of corn, followed by cowpeas or soybeans, wheat, and clover. In this case rye may be sown in the corn in early September to be pastured during the fall and early spring and plowed under before the following crop. This works especially well after the second corn crop since the cowpeas or soybeans that follow are sown late enough to give plenty of time to turn the rye under and get the seed bed in good condition. The rye should not be allowed to grow too late in the spring, however. A growing rye crop removes water from the ground very rapidly and if not turned under by the time the spring rains cease the soil becomes very dry and hard and difficult to plow. It is also very difficult to make a good seed bed when a heavy growth of rye is turned under late. Even with these disadvantages, rye as a winter pasture and green manure furnishes one of the quickest methods of building up the organic matter in this soil.

A rotation of corn, wheat, clover and timothy two years, is a good one where the corn is cut and the wheat properly sown. It has the advantages of a single breaking in four years, of giving a large amount of mixed hay for feed and of allowing half the land to be in grass. Rotations in which small seeded crops, such as clover, are used are difficult to maintain continuously, owing to the fact that a stand of clover cannot always be secured. Where clover fails a legume crop should be substituted and the scheme of rotation changed as little as possible. Soybeans or cowpeas make good substitutes for clover as they can be sown after it is definitely known that the clover stand has failed. Either will make a hay crop and will have much the same effect as clover on the land.

The use of alfalfa is to be recommended for the better phases of this red limestone soil, particularly where the fertility has been maintained and where the soil has plenty of lime. Some plots on the experiment field at Billings have shown that it can be grown successfully when manure is used liberally, the soil inoculated and the shallow rooted weeds and grasses kept out by cultivating with a disk or spring tooth harrow immediately after the second cutting each season. Bonemeal has also been very beneficial for alfalfa on this field. Experi-

ments on the same type of soil near Carthage, in Jasper county, have led to the same conclusions.[1]

The Use of Phosphates. These experiments strongly indicate the value of using phosphates on this soil type. For wheat, steamed bonemeal is probably the best form as it is quickly available and is particularly helpful on the grass and clover following the wheat. For spring-sown crops acid phosphate is probably as good, when its cost is considered. It contains less phosphorus than steamed bonemeal but approximately the same amount is immediately available and it sells at a lower price. Raw bonemeal contains more nitrogen than steamed bonemeal and sells at a higher price, but it usually contains less phosphorus and is not ground fine enough for this to be so readily available. Since the extra nitrogen can be supplied more cheaply in legume crops than in bonemeal, the steamed bonemeal is to be preferred.

Acid phosphate is ground phosphate rock treated with sulphuric acid to make the phosphorus more easily dissolved and hence more available. The amount of acid added to the soil in ordinary applications of this material is not large enough to be of importance and as the supply of bonemeal will not meet the demand for available phosphates, acid phosphate must be relied upon in many cases.

The finely ground phosphate rock, without acid treatment, is used to supply phosphates in some parts of the country, it being the cheapest phosphate that can be had. Experiments have shown it to be very slow in becoming available on soils of the type under discussion, however, and it is recommended only as a long time soil building proposition. To hasten its becoming available it should always be applied in close contact with organic matter such as manure, green manure, straw, or sod in order that the process of decay will help dissolve it. It does not pay to use rock phosphate in small applications since the cost of handling becomes relatively greater. Where it is used, at least 800 to 1000 pounds, or even more in some cases, should be applied to the acre. Such applications should not be made oftener than once in four or five years in the rotation and immediate results should not be expected. This system will increase the phosphates in the soil, however, and will eventually prove to be profitable.

Wheat seems to be the best crop on which to use available phosphates such as bonemeal or acid phosphate. This is especially true where clover is the next crop as it helps materially in getting a stand. About 150 pounds per acre should be used. Where acid phosphate is substituted, 175 to 200 pounds per acre is a better rate. Good

[1] *Hutchinson, C. B.*, and *Douglass, T. R.* Experiments with Farm Crops in Southwest Missouri. Mo. Agr. Exp. Sta. Bul. 123: 163-185, 1915.

results have also been secured with phosphates on corn. An application of 150 to 200 pounds of bonemeal or 175 to 225 pounds of acid phosphate applied with a fertilizer drill ahead of the planter will give good returns.

The Use of Potash. Potash fertilizers have given better returns on this field for the average of the nine years of experiment than they gave up to the time the first publication was issued in 1910.[1] The chloride of potash (muriate of potash) is the cheapest form to use on general crops. The sulfate of potash should be used for tobacco and it is generally preferred for potatoes. Most mixed fertilizers contain potash in the form of chloride of potash.

It would rarely pay to apply potash fertilizers alone to this soil. They should be applied in connection with phosphates. The addition of 10 pounds of chloride of potash to 100 pounds of steamed bonemeal or of acid phosphate would give fair proportions of available phosphoric acid and potash. The use of 150 to 175 pounds of such mixtures on wheat or 200 to 225 pounds on corn should give good returns.

The Use of Mixed Fertilizers. Since both phosphates and potash give good returns on this soil a fertilizer containing 10 per cent available phosphoric acid and 3 to 5 per cent potash should give good results on this land, particularly when applied with wheat. Such fertilizers contain approximately the same amounts of available phosphoric acid and potash as the mixtures of bonemeal or acid phosphate with potash suggested above. Fertilizers with this composition are found very commonly on the market. The same rates of application are recommended as for the home mixtures of phosphates and potash.

Mixed fertilizers containing all three elements of plant food, nitrogen, phosphorus and potassium, are commonly handled by fertilizer companies. On the poorer phases of this soil where the nitrogen supply is low these may be used to good advantage. It is usually better policy, however, to depend on crop rotation, legumes and farm manures for keeping up the supply of nitrogen and organic matter, and to buy as little nitrogen as possible. Where the plain phosphates or the phosphate and potash fertilizers are not available, or where a man is farming the poorer phases of this soil, mixed fertilizers may be used with good results. In such cases a fertilizer containing 2 to 3 per cent nitrogen, 10 to 12 per cent available phosphoric acid and 3 to 4 per cent potash, applied at the rate of 150 to 175 pounds for wheat or 200 to 225 pounds for corn should give good net returns.

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[1] Miller, M. F., and Hutchinson, C. B. "Soil Experiments on the Rolling Limestone Upland of Southwest Missouri." Mo. Agr. Exp. Sta. Bul. 86: 75-94, 1910.

The desirability of mixing fertilizers at home depends on the delivered price of the raw materials and the facilities one has for mixing. If the materials are to be purchased in less than car lots the local freight rate usually increases the delivered price to such a figure that there is little profit to be made in home mixing. Where several farmers cooperate in buying raw materials, however, so as to get a car lot, or where a man orders the materials thru his local dealer to be shipped in the car with the mixed goods, fertilizers can be mixed at home with a reasonable profit.

The use of fertilizers in the hill or drill for corn is a somewhat common practice in the various sections where this soil occurs. Such a practice is justified in the case of the tenant or the man who must have immediate returns. For the landowner who is attempting to farm the land properly, the plan is rarely advisable. Fertilizers when so used are applied in rather small amounts, from 50 to 100 pounds as a rule. Larger amounts than 100 pounds are very apt to cause the corn to "fire," particularly in dry seasons. The prime function of the fertilizer in such cases seems to be to give the corn a quick thrifty start thus enabling it better to overcome the attacks of insects and fungi and to get ahead of the weeds. A complete fertilizer containing from 2 to 3 per cent nitrogen, 8 to 10 per cent available phosphoric acid, and 2 to 3 per cent potash, used at the rate of 75 to 90 pounds per acre in the hill or drill is a very satisfactory application.

A word of caution should be given regarding the continued use of commercial fertilizers alone. It should be understood that the use of fertilizers without the application of those principles of soil management which keep up the supply of organic matter in the soil is not to be recommended. One cannot depend upon fertilizers alone. The only satisfactory use of fertilizers for the man who wishes to maintain soil fertility is in connection with systems of rotation, legume growing and manuring which will maintain the supplies of organic matter and nitrogen in the soil. Thus used they will prove continually profitable. If not so used they will be of temporary value only.

The Use of Lime.* The returns from lime, according to these experiments, are sufficient to warrant its use on the more worn areas of this soil type. The best form to apply under most conditions is the finely ground limestone. It should be applied at the rate of 2000 to 4000 pounds per acre once in six or eight years. It is best applied

*Note: The Department of Soils of the Agricultural Experiment Station will furnish on request the names of companies handling ground limestone, limestone spreaders, and limestone grinders. A list of dealers in rock phosphate can be furnished, also.

after plowing, and mixed with the soil while preparing the seed bed. Lime should not be plowed under as this does not mix it sufficiently with the surface soil. If not plowed in too deep, however, it should eventually become fairly well mixed with the soil. The best method of applying it is to use a special lime spreader where much is to be handled. The same spreader can be used for rock phosphate. The main point in selecting one of the several makes on the market is to see that it is built strong enough to handle such heavy material. On small areas the limestone may be distributed by hand altho this is expensive owing to the labor required. Other forms of lime that may be used are air-slaked lime, which is the same compound as limestone, and lump lime, either ground or with just enough water added to bring it to a powder. Lump lime that has been slaked to a powder is known as hydrate of lime. It may be bought in this form from dealers in such materials.

The chief purpose of applying lime to this soil is to correct acidity thus making conditions more favorable for the growth of beneficial bacteria, particularly those growing in connection with legumes. Lime is especially beneficial, therefore, in keeping soil in proper condition for growing clovers and alfalfa. It should not be considered as a fertilizer, however, as it is not applied for the purpose of adding plant food.

The results with lime on this soil have not been marked. The soil is not seriously in need of it, except on some of the more worn areas. It is little needed on the better areas, especially where the land has not been in cultivation long. The use of lime should be associated particularly with those systems of farming which are fairly intensive rather than with extensive systems.

The Handling of Manure. The need of this soil for organic material makes it highly essential that all the manure possible be applied. Other experiments on similar soils have shown it to be worth from $2 to $3 per ton which makes it well worth saving. Much manure is lost by feeding along side of a ravine where most of it washes away. A great deal also is wasted under the barn eaves. Another source of loss is from piling it up in loose piles so that air can penetrate easily and decay takes place very rapidly. Probably the best method of handling manure is to spread it on the field as soon as it is made. Dairy farming, which is so common in Southwest Missouri, is the system best suited to this plan of hauling the manure to the fields as soon as it is made. When it cannot be hauled at once care should be taken to keep it well compacted and protected from the leaching of rain. Much valuable fertility is in the liquid portion of the manure and this is easily leached away. If it be on the fields this drains into the soil and is saved. One of the best places for the manure is under the

feeding shed where the stock keeps it tramped down, particularly if plenty of bedding be used to absorb the liquid portion and keep the shed dry.

Small applications evenly spread return larger profits for the amount of manure used than do larger applications. For this reason the manure spreader is to be recommended.

Manure is best applied to the corn crop as a general rule, altho its use as a top dressing on meadows and on wheat is also to be recommended. Where used on meadows the hay crop is not only increased but the corn crop following as well. A top dressing of 5 to 6 loads of manure on wheat, which is being used as a nurse crop for clover or grass, will aid materially in securing a stand.

Summary of Recommendations. Adopt a good crop rotation such as corn two years, wheat, clover and timothy for hay one year, followed

Figure 5.—This soil will grow alfalfa but good soil management is essential to its success. From left to right are shown (1) the no treatment plot, (2) the manured plot, and (3) the manure-bonemeal plot.

by pasture two years; or corn, cowpeas or soybeans, wheat, and clover. Feed all the crops except wheat on the farm and carefully return this manure to the land. Apply 150 pounds of steamed bonemeal before wheat and 200 pounds of acid phosphate before corn on the thinner lands. Where the soil shows a need for lime apply one or two tons of finely ground limestone once in six or eight years. Where much green manure is being plowed under and it is satisfactory to wait for returns, the bonemeal and acid phosphate may be replaced by the cheaper form of phosphate, in finely ground untreated rock phosphate. Care should be taken, however, that this material always is applied

in close contact with decaying material. A good application is 1000 pounds per acre once during a round of the rotation.

Where the soil is being kept in a good state of fertility by the above means, profits may be increased somewhat by putting 50 to 75 pounds of a mixed fertilizer containing about 2 per cent nitrogen, 10 per cent phosphoric acid and 2 per cent potash in the hill with corn. This is not recommended as a soil building process, however.

SUMMARY

I. The most marked return secured from the soil treatments given in these experiments has been with phosphates, the second with potash, the third with lime.

II. The practice of drilling cowpeas in the corn at the last cultivation has not been profitable. This has been partially due to the rather small growth often secured and to the fact that the peas slightly decrease the yield of corn. Where peas are so used it is recommended that they be pastured down in order to secure some return from the forage.

III. Since the supply of organic matter and nitrogen is somewhat deficient in this soil, it is recommended that a systematic crop rotation be followed, which shall contain such legume crops as clover, soybeans or cowpeas. In addition to the rotation, the feeding of crops and the careful return of manure, or the use of green manures should form a part of the system. The following rotations are suggested:

1. Corn, cowpeas or soybeans, wheat and clover;
2. Corn, wheat, clover and timothy, two years;
3. Corn, corn, cowpeas or soybeans, wheat, clover and timothy, two years.

IV. Stock farming, particularly dairy farming, is especially adapted to this region. In every live stock system great care should be exercised in returning the manure to the land. Pure grain farming is not to be recommended altho mixed farming may be very satisfactory where green manures are used in addition to barnyard manure, particularly as cover crops to prevent soil washing.

V. The application of 150 pounds of bonemeal or 175 to 200 pounds of acid phosphate will give good returns with wheat, altho a fertilizer containing 10 to 12 per cent available phosphoric acid and 3 to 5 per cent potash will usually give larger immediate profits. Where clover or grass follows the wheat these crops will likewise be greatly benefited.

VI. The use of fertilizers high in phosphates such as bonemeal or acid phosphate or a mixed fertilizer containing 2 to 3 per cent

nitrogen, 10 to 12 per cent available phosphoric acid, and 2 to 3 per cent potash may be used for corn by the intensive farmer. It should be applied ahead of the planter with a fertilizer drill at the rate of 150 to 225 pounds per acre. The nitrogen may be maintained by proper crop rotation and manuring.

VII. The application in the hill or drill with corn of 75 to 90 pounds of a fertilizer, containing around 2 per cent nitrogen, 8 to 10 per cent available phosphoric acid and 2 to 3 per cent potash, is recommended for the man who must have immediate returns at the lowest possible cost. Such a system of fertilization should be considered as a temporary practice for securing an immediate crop.

VIII. On the older farmed and more worn areas of this soil type the use of 2000 to 4000 pounds of ground limestone per acre applied once in 4 to 6 years will be accompanied by good net returns.

IX. The man who wishes to farm this land to best advantage, and who has a reasonable amount of capital with which to work, will find that a system of live stock farming, usually dairy farming if near the railroad, will prove most satisfactory. He should adopt a careful system of rotation including an abundance of legumes and should use freely of phosphates with some potash as suggested above. Rock phosphate may be used as a part of the phosphate application where much organic matter is added to the soil. From 800 to 1000 pounds per acre may be used once in 6 to 8 years. This should be supplemented with readily available phosphates and some potash, applied before wheat.