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Crop Rotation and Soil Fertility

By

W. L. POWERS and C. V. RUZEK

CORVALLIS, OREGON

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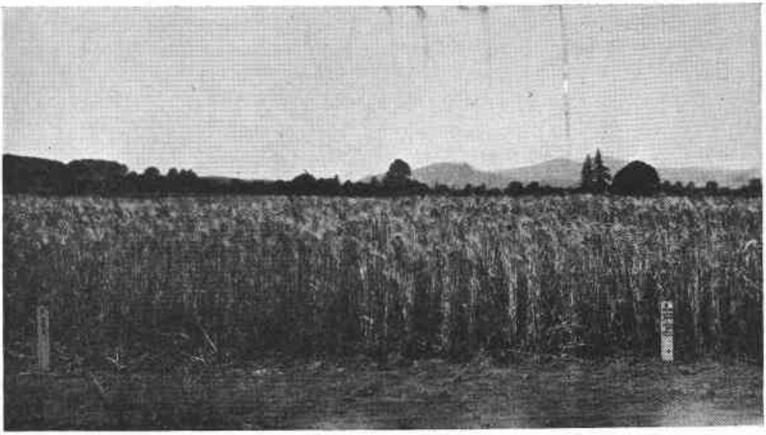
Crop Rotation and Soil Fertility

By

W. L. POWERS and C. V. Ruzek

The soil is the greatest source of wealth. Soil is our greatest natural resource; it is the basis of all agriculture; it has supported and must support all life. According to the fourteenth census it represents two-thirds of the agricultural value of the state. Though our mines may be dug out and our forests cut down, the fertility of our soil must be maintained so that our increasing population may continue to be fed. Successful, profitable production in the long run depends largely upon practicing a system of soil building. The wise farmer will farm not alone for the immediate crop but for the soil. He should be a soil builder and not a soil robber. The highest productive values will only be realized as we develop, utilize, and maintain the producing power of our lands and thereby establish a permanent system of agriculture.



Grain continuous yield 41 bushels. Grain after clover and corn in rotation, 63 bushels. Nine-year experiment.

Much cropped land of Oregon needs rotation and fertilizers. The time is at hand when much of the cropped land of this state requires careful handling, and proper use of fertilizer will pay on many of our soil types. Crops are not made out of nothing. Definite amounts of plant food, especially nitrogen, sulfur, phosphorus, and potassium, are required per unit crop. These amounts should be maintained and replenished by crop rotation and fertilizers.

CROP ROTATION AN AID TO PERMANENT AGRICULTURE

To conserve fertility, secure the most economical use of land and any irrigation water employed, and to make the greatest profit in farming, a careful and scientific system of crop rotation is necessary. Crop rotation means a system of farming giving a recurring succession of field crops with differing plant food requirements. Under the present conditions of moderate crop prices and heavy cost of production, it is important for the farmer to increase yields with the least possible outlay. The large yields are the most profitable ones. The larger yield obtained by crop rotation is almost "clear velvet."

Benefits of crop rotation. (1) The greatest benefit from crop rotation comes from the humus and nitrogen gained from plowing under clover or other legume sod and crop residues. At least one legume crop should be included in each rotation, and red clover is the great humus and nitrogen gatherer. Alfalfa is excellent for long rotation on sandy, mellow, well-drained Western Oregon lands. Red clover and vetch are best for the short rotations on land with good drainage. Alsike clover is good on the moderately wet lands. Vetch and alsike clover withstand moderately arid conditions. Legume straw is worth several dollars a ton as fertilizer. From the standpoint of soil fertility, the acreage of clover and vetch is far too low in Western Oregon.

(2) Crop rotation makes possible a diversity of crops with steady output.

(3) Crop rotation affords steady employment, the work being more evenly distributed.

(4) Crop rotation helps to eradicate weeds and to avoid insect pests, plant disease, and toxins.

(5) Crop rotation conserves fertility through the different demands of the root systems of different crops and by allowing recuperation after crops which make heavy demands on the soil.

(6) Crop rotation helps improve tilth and available fertility by permitting plowing in of sod, use of deep-rooted legumes, crop residues, and barnyard manure, and pasturing with farm animals.

(7) Under irrigation, upkeep of water capacity and available fertility are important in lessening the irrigation requirement.

(8) One-crop farmers all need water at once, whereas a diversity of crops in a neighborhood permits distribution in time of use of irrigation water.

(9) Rotation permits use each year of some cultivated cash crops of low water requirement which give large returns per unit of land and water.

(10) Crop rotation keeps the land occupied, systematizes farming, and results in larger yields and profits.

Essentials of a good rotation. Every rotation should contain (1) a cash crop; (2) at least one legume crop; (3) a manured cultivated crop; and (4) a livestock feeding crop. These should be grouped to distribute farm labor economically. Grain may be disked in following a row crop, the land seeded to clover following the grain crop, and the clover sod turned under for a row crop, plowing being thus necessary only once in three years.

The rotation should fit the farmer's business; fit the soil and crop requirements; fit the climate and location and afford a minimum of labor. It is desirable to have fields of nearly equal size; to alternate legumes and humus builders with rank-feeding nitrogen-loving crops; to alternate shallow- with deep-rooted crops; to alternate crops as to food required, character of growth, and time they cover the soil. Use any fertilizer needed for weak feeding crops or to meet the need of cash crops and build up the weak point in the soil's fertility.

Long-time experiments. The oldest recorded rotations are at Rothamsted, England, where in sixty years the wheat yield decreased to 12 bushels an acre with continuous cropping. With a rotation of turnips, barley, clover, and wheat the yield held up to 28 bushels an acre.

The oldest experiments in this country are at the Illinois Agricultural Experiment Station, where the initial corn yield was about 70 bushels an acre. Forty years' continuous corn growing decreased the yield to 14 bushels of nubbins. With a two-year rotation, corn-oats, the corn yield held up to 39.6 bushels. With a three-year rotation, corn-oats-clover, the corn yield has been held up to 50 bushels an acre. With the addition of lime, manure, and phosphorus the corn in part of the latter rotation has been increased to 90 bushels an acre.

Oregon experiments. The oldest experiment plots in Oregon showing the cumulative effect of crop rotation are maintained at Corvallis as a part of Oregon Soil Investigations of the Experiment Station and are of fifteen years' duration. These plots are located south of the railroad in the irrigation field of the Agricultural Experiment Station Farm. The main results follow.

Rotation gives one-half more yield. In some of these trials, rotation has resulted in 50 percent more yield than is secured with continuous cropping, and the difference is increasing with each rotation.

EFFECT OF 9 YEARS' ROTATION ON YIELD

Beans continuous	9.85 bu. an acre
Beans rotated after grain and clover	15.74 bu. an acre

TABLE I. RESULTS OF ROTATION VS. CONTINUOUS CROPPING

Rotation Field

Oregon Agricultural Experiment Station, Started 1914

	Barley per acre	Grain continuous adjoining plots	Gain for rotation
	bu.	bu.	bu.
Grain-fallow	46.5	40.3	6.2
Grain-vetch hay	69.2	48.4	20.8
Grain-vetch seed (straw returned)	60.9	49.6	11:3
Grain-vetch seed (straw returned) vetch hay	53.4	45.0	8.4
Grain-vetch seed (straw returned) vetch hay-corn	50.2	42.5	7.7
Grain-vetch (green manure) corn-vetch hay	51.3	48.0	3.3
Grain-vetch-corn-grain-vetch	58.4	......	......
Grain-clover	50.7	45.3	5.4
Grain-clover-potatoes	50.5	42.3	8.2
Grain-clover-corn	66.93	48.7	18.23
Grain-clover-clover-corn	63.4	44.9	18.5
Grain-grain-clover-clover-corn (after corn)	58.8	54.2	4.6
(after grain)	64.2	51.9	12.3
Grain-clover-clover-corn-flax	54.8	44.0	10.8
	49.8	50.2	.4

Beans continuously grown on one plot for nine years give an average yield of 9.85 bushels for the period. In a three-year rotation, grain-clover-beans, the average bean yield for the period is 15.74 bushels, and with manure applied each rotation the average yield is 18.29 bushels.

A rotation experiment is located in the field of the Experiment Station north of the railroad and near the oak grove. Thirty-two rotations and eight plots are used in the experiment initiated by H. D. Scudder in 1914. Twenty-six check plots in this rotation experiment have been cropped to small grain for nine years and their average yield of winter barley, 1922, was 48.7 bushels an acre. Seven plots of the same variety of barley in a three-year rotation of grain-clover-corn in the same field yielded 67 bushels an acre. Grain and fallow gave a gain in yield the eighth year of 6.2 bushels over grain continuous; yet the average annual yield with the grain fallow system is three-fifths as much as with grain continuous. Fallowing is practiced only with limited precipitation or to control bad weeds. A two-year rotation of grain-vetch gave an increase of 11.3 bushels barley. Barley in a rotation of grain-clover-clover-corn yielded 18.5 bushels more the ninth year than the barley grown continuously.

Water Requirement Low. Rotation has enriched the soil solution and lowered the water required per pound of dry crop produced as follows:

EFFECT OF ROTATION ON WATER REQUIREMENT.
BEANS NINE-YEAR AVERAGE

Treatment	Pounds water used to one pound of dry crop produced
Beans continuous	2622
Beans after clover and grain	1794

Average Net Profit Increased. Rotation has greatly increased the nine-year average annual net profit an acre.

EFFECT OF ROTATION ON NET PROFIT

Treatment	Average net profit an acre	Average yearly gain from rotation
Beans continuous	$15.37	....
Beans rotated	29.46	$14.09

Rotation has resulted in better tilth and moisture conditions, lower water requirement, larger yields per unit of water, and greater net profit. This gain is almost "clear velvet." In these times of moderate prices and costly production the farmer should aim to increase yields by the most inexpensive means. Crop rotation will greatly extend the productiveness of our soils.

VALUE AND USE OF FARM MANURE

Willamette Valley soils respond to barnyard and green manures, which increase the organic-matter content of the soil. By such additions the tilth and water capacity of the soil are improved; plant foods are returned to and liberated from the soil and beneficial bacteria are added to the land.

Points on the Use of Farm Manure. (1) Follow a cultivated crop with fall seeding to provide cover or furnish green manure over winter.

(2) Apply barnyard manure ahead of rank-feeding cash crops.

(3) Manure is a complete fertilizer, yet it is not a balanced fertilizer. While it tends to balance itself through losses, this process is wasteful. Best results may be expected from reinforcing manure with phosphate fertilizers.

(4) Losses in barnyard manure can be cut down
- (a) By protecting it from leaching during the rainy season.
- (b) By keeping it moist during the dry season.
- (c) By adding land-plaster or superphosphate to prevent the escape of nitrogen as ammonia.
- (d) By applying it promptly to the soil.

(5) Turn all crop residues under to add organic matter. Legume straw is worth several dollars a ton for fertilizer, largely due to its high nitrogen content.

Straw Increases Yield. In an experiment in the irrigation field on the Experiment Station clover and grass hay yielded as follows:

Straw three tons an acre disked in the year previous	6.83 tons
Untreated yield per acre	5.34 tons
Gain	1.49 tons

Manure Increases Yield. In the same field, manure has been applied each rotation at the rate of about 12 tons an acre. Where supplemental irrigation was used the results on nine years are as follows:

Treatment	Bushels per acre, ninth year
Beans manured	18.29
Beans not manured	15.74
Gain	2.55

Manure Increases Net Profit. In the same experiment good cash returns have resulted from the manurial treatment as given below:

Treatment	Nine-year average yearly net profit
Beans manured	$38.39
Beans not manured	29.46
Gain	$ 8.93

No charge was made for the manuring, and the gain represents the value received from the ten-ton application through the bean crop. A three-year rotation, grain-clover-beans, is practiced, and last year, 1922, the manure produced 8 bushels more wheat and .73 ton more clover in this rotation.

Disk and Plow in Manure. In this experiment field top dressing and disking in have been compared with disking and plowing under. The latter practice appears to give larger yields.

Moisture Goes Farther With Manure. In this experiment the manure has increased the moisture capacity and enriched the soil solution so that less water was required per pound of dry matter produced.

Treatment	Water used per pound dry crop produced, nine-year average
Beans manured	1794 pounds
Beans not manured	1425 pounds

USE AND VALUE OF LIME

(1) Most of the soils of Willamette Valley are acid and respond to liming. Naturally drained soils in the valley floor and stream bottoms show slight to medium acidity and show but moderate response to liming. Soils with poor natural drainage in these sections respond well to lime application at the rate of 1 to 1½ tons an acre. Red hill soils are distinctly acid and generally give marked response to liming.

Use of lime on acid soils of humid regions on legume crops is fundamentally sound.

(a) Lime makes soil sweet.
(b) Lime improves the tilth and water capacity of the soil.
(c) Lime promotes the growth of desirable bacteria.
(d) Lime renders more plant food available.
(e) Lime increases crop yields, especially clover.

(2) Soil acidity is unfavorable to the best growth of clover, which is needed to retain and increase nitrogen for plant growth.

(3) Ground limestone, burned lime, air- and water-slacked lime, and ground shells are the principal kinds of lime available to Western Oregon farmers. Particulars regarding their use may be found in Oregon Agricultural College Extension Bulletin 305.

(4) For best results lime should be disked into the soil previous to seeding down a legume crop such as clover.

Lime Increases Yield. Lime has been used for nine years in a fertilizer experiment on brown (Willamette) silty clay loam soil in the rotation field. During the past three years the increase in all crops for the rotation grain-clover-corn had a total value of $15.30. Where 1½ tons of hydrated lime was applied each rotation, there is some residual benefit from the treatment.

The past dry year the lime appeared to keep the soil mellow and moist. Barley on limed, unfertilized plots in the rotation field yielded as follows:

With lime	66.6 bushels per acre
Without lime	58.4 bushels per acre
	8.2 bushels per acre

Fertility in Willamette Valley Soils. Soil analyses are made for the purpose of securing an inventory of plant food elements in various soil types and to secure data upon which to base procedure in fertilizer experiments. Analyses for lower Willamette Valley counties are reported in Oregon Station Bulletin 185 (Table II) as pounds of nitrogen, phosphorus, sulfur, and potassium contained in the surface soil (6½ inches), the depth one would ordinarily turn with the plow. Generally speaking, soil types low in phosphorus may safely be assumed to stand in need of immediate application of phosphorus, and trials may well be made on soils containing less than 1600 pounds of phosphorus, 500 pounds sulfur in 2,000,000 of soil.

SOME SOILS LOW IN PHOSPHORUS AND SULFUR

From a study of Willamette Valley soil analyses in connection with soil surveys made by the Experiment Station, it is learned that with comparatively few exceptions, as in deep peat, these soils are comparatively liberally supplied with potassium. The phosphorus supply in the upper valley soils is generally good and in lower valley and hill lands, fair. In most of these soils these elements are slowly available and decaying organic matter and lime will aid their liberation for plants. Only the truly organic soils are rich in sulfur. The extremely small amount of this element in many valley and most hill soils suggests at least the desirability of determining by direct trial the response to be expected from application of sulfur-carrying fertilizer, especially upon legumes. The total nitrogen content with few exceptions is comparatively good in the valley soils. This element is in combination in organic matter. Heavy rainfall with heavy drainage tends to slow up the activities that liberate nitrogen and to remove it when in available form. Some manure and rotation with legumes should meet the nitrogen need.

TABLE II. FERTILITY REMOVED IN CROPS

	Nitrogen	Phosphorus	Potassium	Sulfur
	lbs.	lbs.	lbs.	lbs.
Alfalfa, 4 tons	200	18	96	28
Clover, 4 tons	160	20	120	13
Field pea hay, 4 tons	......	......	......	7
Wheat, 50 bushels	33	6	8	6
Wheat straw, 2½ tons	31	5	52	9
Barley, 50 bushels	42	8	10	3
Barley straw, 1¼ tons	16	3	24 T	3
Potatoes, 200 bushels	42	8	60	3
Corn, 15 tons, fodder	90	30	120	5
Rutabagas, 20 tons	76	48	160	......
Sugar beets, 10 tons	50	18	157	2
Cabbages, 10 tons	60	8	66	39
Fat cattle, 100 pounds	25	7	1	......
Milk, 10,000 pounds	57	7	12	......
Butter, 400 pounds	0.8	0.2	0.1	......
3 yr. rotation (Wheat, 50 bushels +	96	16	58	11
(2½ tons straw	......	......	......	......
(Clover, 4 tons	+	20	120	13
(Potatoes, 200 bushels	42	8	60	3
	+	44	238	27

Legumes, corn, and root crops are heavy feeders on both phosphorus and potassium. Potassium is used in especially large amounts by root crops. Nitrogen is drawn on heavily by corn and root crops, while sulfur is very important to growth of legumes and the cabbage family.

TABLE III. FERTILITY RETURNED IN FERTILIZERS

Material	Pounds per ton			
	Nitrogen	Phosphorus	Potassium	Sulfur
Fresh farm manure	10	3	8	5
Barnyard manure	10	3	8	5
Sodium nitrate	310	......	......	......
Ammonium sulfate	400	......	......	500
Raw rock phosphate	......	250	......	......
Acid phosphate	......	125	......	144
Potassium sulfate	......	......	850	324
Potassium chloride	......	......	850	......
Wood ashes	......	......	......	......
"Complete" fertilizer (average)	33	88	33	......
Gypsum	......	......	......	360
Crude sulfur (98%)	......	......	......	1960

Table III shows the pounds of valuable elements per ton in commonly used fertilizers. High grade or concentrated fertilizers are best to build up the weakest point or points in the soil.

Sulfur may be supplied by use of powdered sulfur, gypsum, superphosphates, ammonium sulfate, or manure. The crude ground sulfur is over 99 percent elemental sulfur.

Phosphates may be secured in acid phosphate, steamed bone-meal, and ground raw rock phosphates. The first contains phosphorus in available form and should be used for immediate results. Rock phosphate and bone-meal should be used in larger amounts and in combination with organic matter.

Potassium can be purchased as either the sulfate or muriate of potash. The former supplies 16 pounds of sulfur per 100 pounds of the material.

Nitrogen is commonly secured in sodium nitrate, in which form it is available. It is also present in ammonium sulfate and in manure.

FIELD FERTILIZER TRIALS AND RECOMMENDATIONS

Fairly complete and permanent fertilizer trials are in progress on a dozen of the main soil types of the Willamette Valley. Certain applications have proved regularly profitable, and their use is recommended.

Crop rotation including use of legumes is very profitable and necessary to keep up economically the nitrogen and organic matter in valley soils.

Manure and crop residues have been highly profitable and should be utilized before purchase of fertilizers.

Liming is more certain to be profitable on red hill soils and worn grain lands in the more humid sections and on the heavy tiled lands previous to seeding down to clover. Where legumes fail, due to acidity, lime becomes essential to maintenance of nitrogen.

NITROGEN MAKES LEAFY GROWTH

Nitrogen is essential, especially for leafy growth, and is often the first element to be depleted. Nitrogen can be supplied from the unlimited supply in the air by means of legume crops turned under. Nitrate may be used as a "starter" and applied early in spring on non-legume or the unmanured land. Manure, straw, and other farm refuse contain nitrogen and are usually worth several dollars a ton as fertilizer.

PHOSPHORUS HELPS SEED YIELD

Phosphorus, a necessary plant food, has been regarded as the master key to permanent agriculture in humid sections. Crops use relatively large amounts of phosphorus and sulfur compared to the amounts in the soil. Two-thirds of the phosphorus taken by crops goes to the seed and is lost from the farm when grain is sold. The only way to replace this is through use of phosphate fertilizer.

TABLE IV. EFFECT OF PHOSPHATE FERTILIZER, MULTNOMAH COUNTY

Crop	Treatment	Tons per acre	Gain
Corn 1920	(None	11.04	
	(Superphosphate 250 lbs. per acre	12.59	1.55 tons
Potatoes 1921	(None	181.5 (bu.)	
	(Superphosphate	217.5	36.0 (bu.)
Oat hay 1922	(None	.97	
	(Superphosphate	1.10	.13 tons

SULFUR HELPS LEGUMES

Sulfur is essential, especially for legumes and crops of the cabbage family. Sulfur is present in limited amounts in most Oregon soils. It is lost by leaching in much greater amounts than are received in rainfall. Analyses and field fertilizer trials indicate that its use will give good results, especially on hill land. Sulfur, gypsum, superphosphate, and manure can be used to supplement the supply of sulfur in these soils. Field trials strongly indicate that the benefit derived from top dressing clover or alfalfa with gypsum (calcium sulfate) can be much more cheaply secured by use of sulfur.

EFFECT OF SULFUR ON CARLTON SILTY CLAY LOAN, BENTON COUNTY

Crop and year	Treatment	Yield per acre	Gain per acre
		bu.	bu.
Clover seed 1921	(None	3.28	......
	(Sulfur 150 pounds per acre	4.66	1.38
Spring wheat 1922	(None	12.5	......
	(Sulfur 150 pounds per acre	20.5	8.00

POTASH PAYS ON DEEP PEAT

Potassium is present in relatively large amounts in most of the soils of Willamette Valley and should last indefinitely if liberated in amounts needed through the use of decaying clover sod, manure, and lime. Lake Labish peat soil, however, contains about ten times as much nitrogen and sulfur and only one-tenth as much potassium as our normal brown (Willamette) loam soil. In experiments on this land, application of potash has proved highly profitable.

Permanent Agriculture. Permanent agriculture refers to a system of farming whereby the vital fertility elements are removed in valuable crops and returned to the soil in amounts at least equal to removal plus losses, through the cheapest forms of refuse, in a way that will make agriculture permanently profitable. It is cheaper to keep good soil productive than to restore exhausted land.

In order to establish a system of farming to provide for soil maintenance it is necessary to learn:

(1) The amount of vitally important plant food elements in each soil type.

(2) The amounts of plant food removed by different crops.

(3) The amounts of plant food contained in fertilizers and farm refuse.

(4) The results of actual field fertilizer trials on representative soil types.

The amount of plant food removed by crops is definitely known and the composition of the common commercial fertilizers is fairly definite, but the fertility in our many different soil types, or the elements or applications to which they respond, is being explored through the systematic soil survey and fertility work, which is an important part of Oregon Soil Investigations. Crop rotation and the use of farm manure or crop residues are first essentials in any permanent plan for most soils, with occasional liming for soils of the humid section.