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A Drawbar Dynamometer and Its Use in Soil Tillage Experiments

G. Wallace Giles

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SUMMARY

A hydraulic type of dynamometer was developed and was used during the spring and summer of 1934 in connection with the soil tillage experiment. It was found very satisfactory. It is easily and quickly adapted to any farm implement and a large volume of information covering a wide range of conditions can be quickly secured. A pneumatic mounting for the recorder was designed and proved to be an adequate protection against shock and jar.

Soil resistance maps were made, by the use of the dynamometer, for two ranges planted to corn for the 1934 season. It was found that for accurate maps of small areas it is necessary to secure very accurate depth measurements and correct the draft values accordingly. Since the average depth of plowing for each plot was the same and the average resistance for each plot range was nearly the same, the draft of the tillage machines can be directly compared.

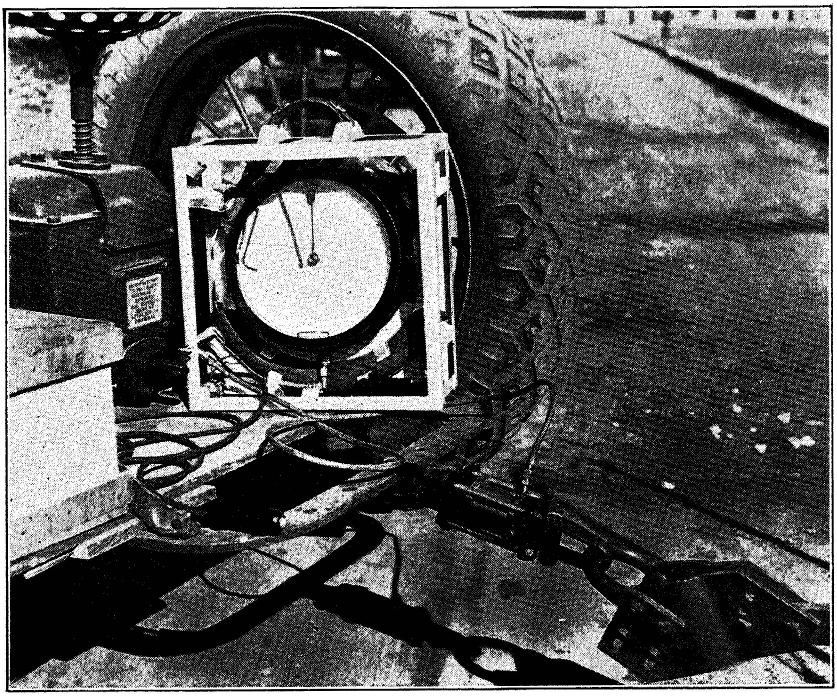

Figure 1.—Dynamometer Attached to a Tractor Plow.

A Drawbar Dynamometer and Its Use in Soil Tillage Experiments

G. Wallace Giles*

INTRODUCTION

Tillage, because of its tremendous utilization of farm power, is a problem of utmost importance. Kinsman[1] estimated in 1924 that 30 per cent of farm power was used in tillage and that 60 per cent of the cost of producing a crop was spent for power and labor. With this vast expenditure of power for tillage operations, increased knowledge about these operations, which should lead to more efficient methods, would result in a saving that would be invaluable to the American farmer.

One phase of the method of approach to this problem of increasing the efficiency of our mechanical farm equipment and its use in tillage methods must be made from the standpoint of dynamics. The energy input must be determined and the manner in which it is translated into soil tilth must be studied. The total reaction of soils to any specific implement may be determined with the use of a dynamometer.

The Missouri Experiment Station has set up an experiment in soil tillage to study the effect of different methods of seedbed preparation and different methods of cultivation upon the cost of production and yield of corn, and upon the physical properties of the soil. It is the purpose of this bulletin to describe the drawbar dynamometer that was designed and built for this study and to discuss its use in this soil tillage experiment.

REQUIREMENTS OF A DRAWBAR DYNAMOMETER

Experiments in tillage, carried out by field plots, that are made to approach as nearly as possible actual farming conditions, require that the dynamometer be adapted to the securing of a quantity of data quickly and accurately. There are many widely varying operations and series of operations that need to be tried. It is desirable during uncertain weather that all data, including soil measurements, on all operations be taken in one day, since if rain falls before the operations are completed the soil tilth on the finished and unfinished plots may differ greatly.

The dynamometer must be suitable to any form of work, lightest to the heaviest, and adaptable to either tractor or horse drawn implements. It is therefore necessary to have a load range up to 3000 pounds.

In addition to being easily adapted to the hitch, the drawbar unit must permit a reasonably short coupling. Any extension of the hitch is likely to affect the operation of the implement and may give draft values slightly in error.

*Research Assistant in Agricultural Engineering, University of Missouri.

(1) C. D. Kinsman, "An Appraisal of Power Used on Farms", United States Department of Agriculture Bulletin No. 1348.

As a last requirement the dynamometer must be light in order to permit ease of handling.

A thorough study was made of the various types of dynamometers. The hydraulic principle was selected on which to construct the dynamometer because it is simple and more dependable. It will also permit the recorder to be separate and apart from the drawbar unit.

THE DRAWBAR DYNAMOMETER

The dynamometer developed consists of three major parts: (1) the hydraulic units, (2) pressure recording instrument, (3) oil transmission line.

Hydraulic Units.—To meet a wide variation in loads and to secure a trace well out from the center of the chart, three units were designed and built. It would have been possible to design one cylinder and use a lever system to adapt it to a wide range of loads. This, however, has the disadvantage of being rather cumbersome and requiring considerable space. The hydraulic units were designed to withstand a maximum internal fluid pressure of 350 pounds per square inch. The cylinders, which were designed for maximum loads of 300, 1000 and 3000 pounds, have diameters of 1.040 inches, 1.907 inches, and 3.300 inches respective -

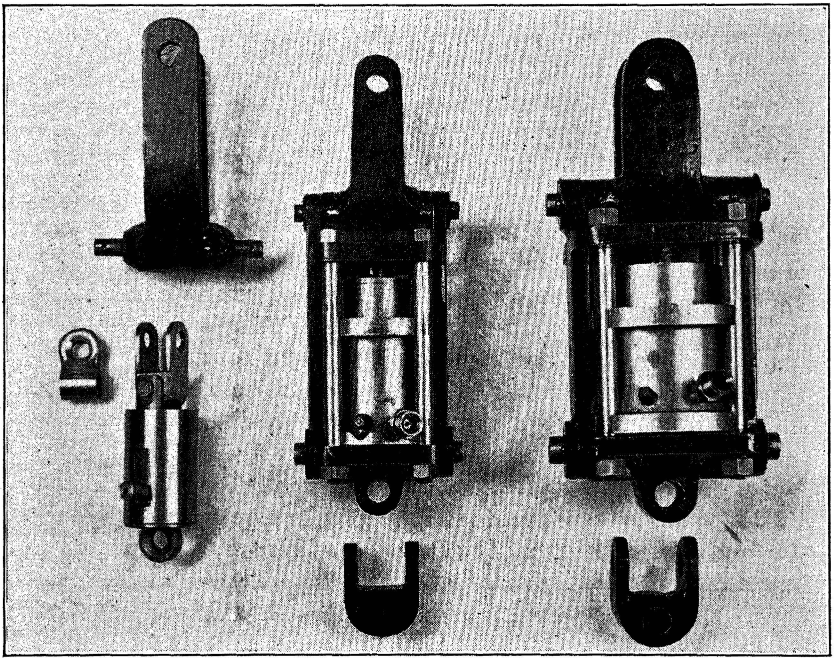

Figure 2.—Dynamometer Hydraulic Units with Capacities of 300, 1000 and 3000 Pounds Draft.

ly. These are shown in Figure 2. It will be noticed that all the units are designed for direct pull. The extension of the hitch to accommodate the units is very small. This small extension is not objectionable and has the advantage of doing away with any lever system. These hydraulic units are very easy to adapt to any implement.

Small Unit. A working drawing of the small unit of 300 pounds capacity is shown in Figure 3. The outside encasement completely

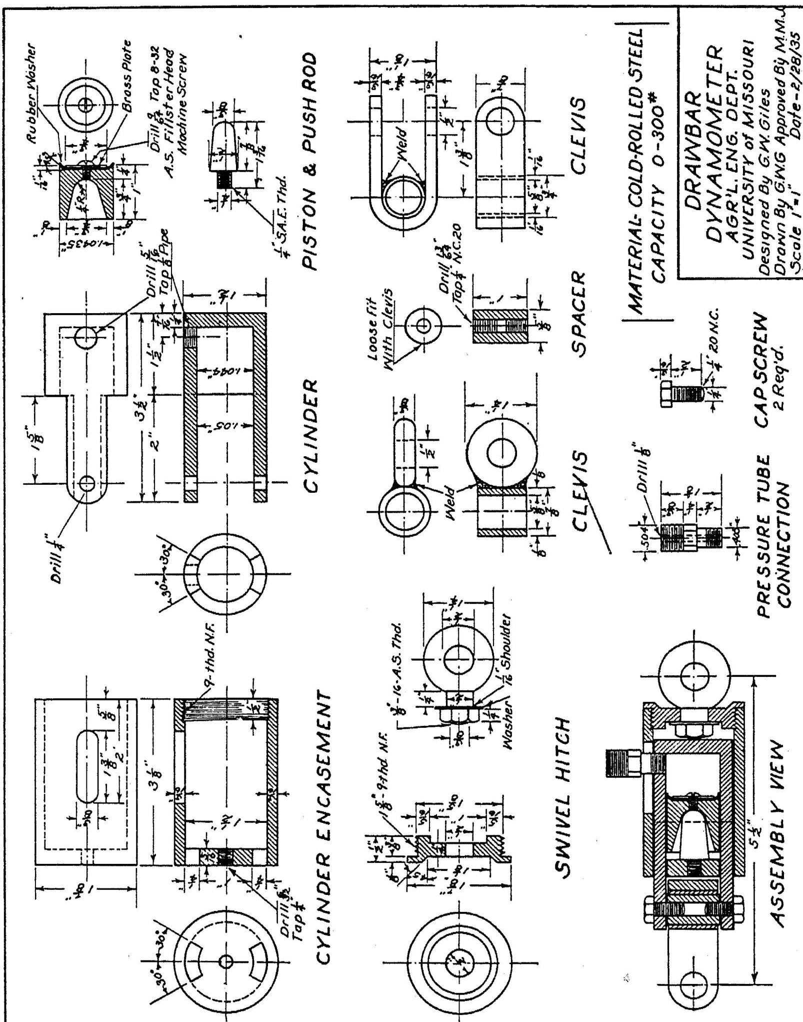

Figure 3.—Working Drawing of the Small Hydraulic Unit of 300 Pounds Capacity.

encloses the cylinder and permits the pull to be transmitted to the rear, where it pushes the piston into the cylinder. This eliminates any packing around the piston rod, which is always necessary when pulling the piston into the cylinder. The use of a packing gland would complicate the unit and result in undue friction and more or less trouble with oil leakage. The extension of the push rod well into the head end of the piston produces the same effect as pulling the piston. This insures the free movement of the piston. The two end hitches are universal in action, permitting correct alignment for power transmission from the source to the implement. Figure 4 shows pictures of steps taken in assembling the small cylinder. The small cylinder is particularly adapted to the measurement of the draft of one horse, as on a one-row cultivator, where it would be necessary to rearrange the hitching system in order to secure a record

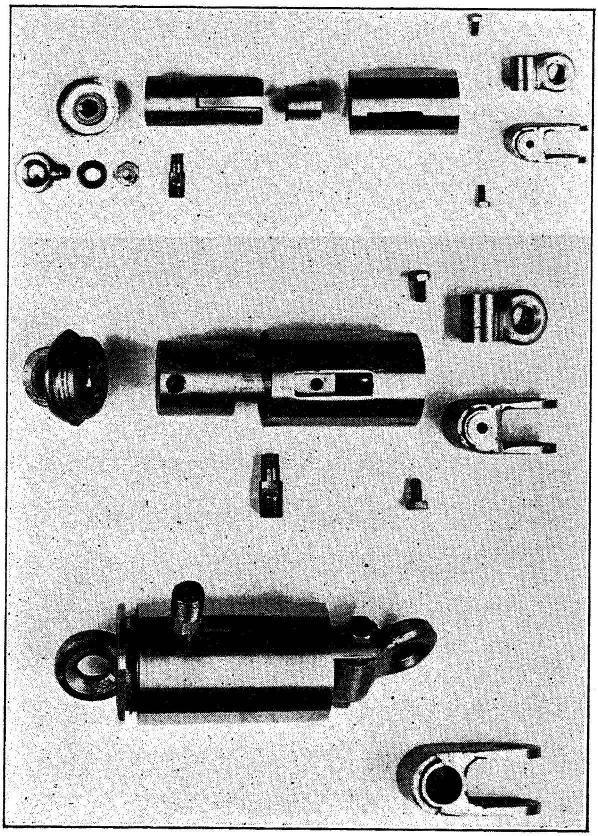

Figure 4.—Views of the Small Hydraulic Unit at Different Stages of Assembly.

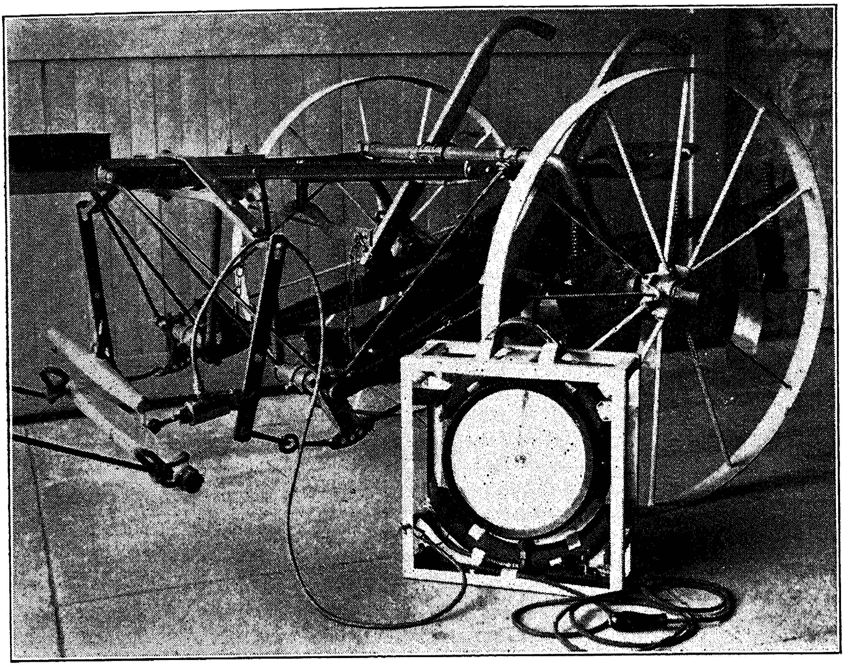

Figure 5.—View of Small Hydraulic Unit as Adapted to a One-Row Cultivator for Measuring the Draft of One Horse.

of the total draft. A picture of this unit as adapted to a one-row cultivator is shown in Figure 5. The total weight of the unit is 3 pounds and the length is 5½ inches.

Medium Sized Unit. A working drawing of this unit of 1000 pounds capacity is shown in Figure 6. It is built similar to the small cylinder except that four side rods are used for transmitting the pull to the rear of the piston. Two interchangeable clevises are used: one for a tractor drawbar and the other for doubletrees. A universal attachment may or may not be used for the implement hitch. Since the cylinder is not enclosed, as is the small cylinder, a felt washer, retained by a brass ring, is placed in the outer end of the cylinder. This prevents dust and dirt from working into the cylinder. The length of the unit with the universal attachment is 12 inches and without it 10¾ inches. The total weight is 13.5 pounds. Figure 7 shows this unit disassembled.

Large Unit. This unit has a capacity of 3000 pounds. It is built like the medium sized unit except that all parts are built larger to withstand the heavier pull. Since it will be used for a pull in excess of 1000 pounds, it is necessary to have only one clevis, and that one for the tractor draw-

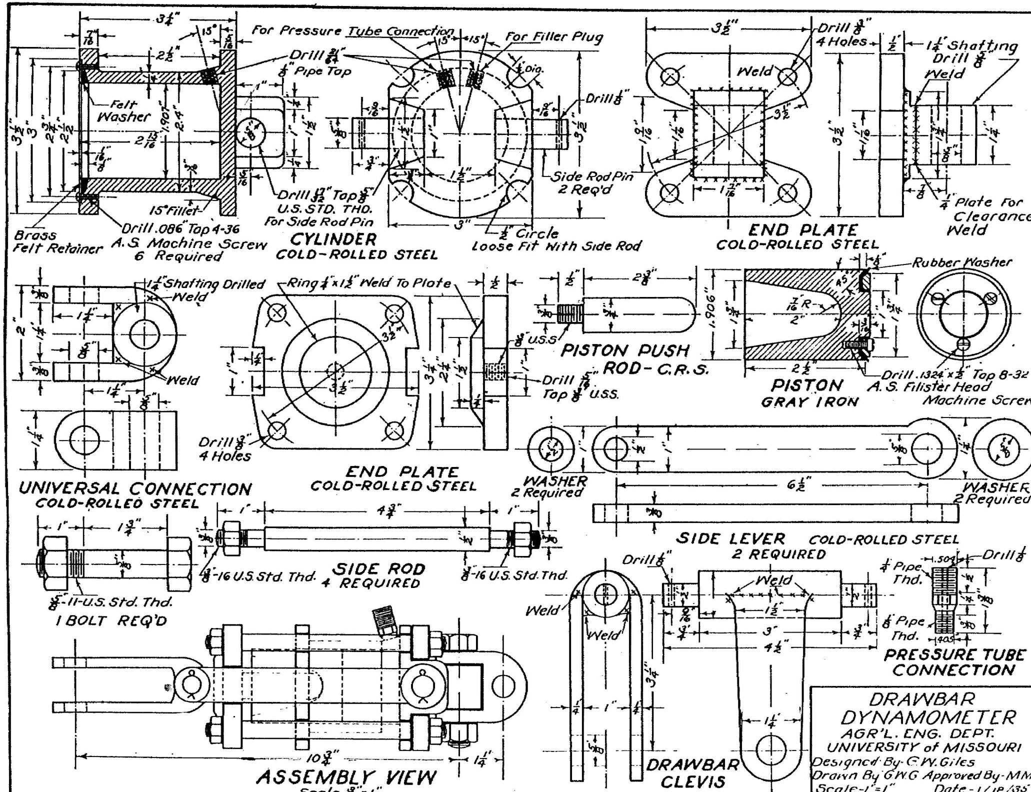

Figure 6.—Working Drawing of the Medium Sized Hydraulic Unit with Capacity of 1000 Pounds Draft.

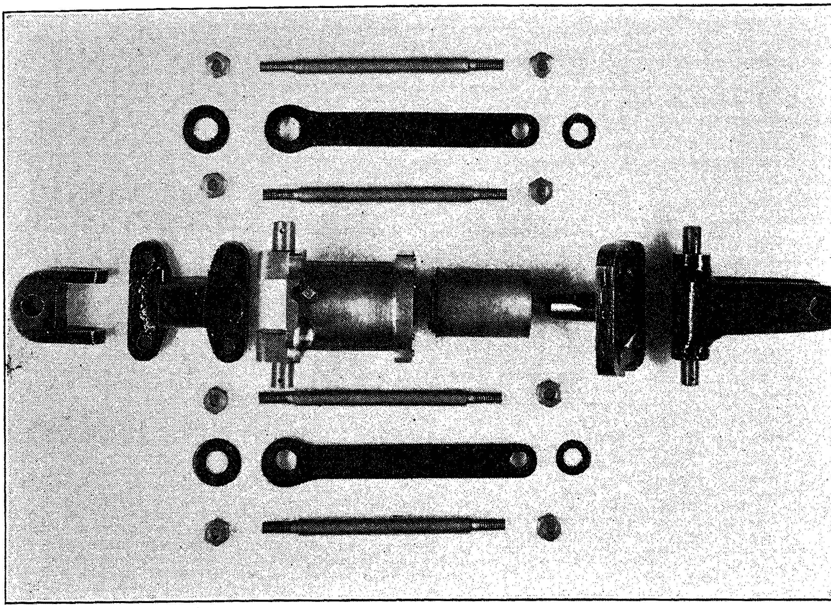

Figure 7.—Medium Sized Hydraulic Unit Disassembled.

bar. The overall length of this unit is 12 inches and the weight is 25 pounds.

PREVENTION OF OIL LEAKAGE

It is possible to fit the piston into the cylinder so that no oil leakage will result. However, this would require the use of precision instruments and special lapping material. It was found that a rubber washer on the head end of the piston worked very satisfactorily. A light lubricating oil, diluted with about one-third kerosene, gave no leakage. The light fluid will insure a trace with no time lag.

PRESSURE-RECORDING INSTRUMENT

A 12-inch pressure-recording gage is used. It takes a round chart, which is considered superior to the strip chart because of its ease in handling in the field and in filing. The case is dust proof and made of aluminum. The glass front permits inspection of the chart during the test. It is equipped with a bronze helical spring movement, calibrated for pressure of 0 to 350 pounds per square inch and protected for overloading. The pen is a special reservoir type to prevent spattering where fluctuations may be wide and rapid. A second pen, operating on the same time arc, marks on the periphery of the chart. It is actuated by an electro-magnet operated by a 1½-volt flash-light battery mounted on the instrument frame. With the use of a push-button switch placed on the end of an electric cord and carried by the operator, the start and stop of a test may be indicated.

The recorder was purchased with two interchangeable clocks, one of a 30-minute rotation and the other of a 15-minute rotation. However, in securing soil resistance maps it is desirable to secure a longer trace for a given distance traveled than the 15-minute rotation will give. A clock with a seven and one-half minute rotation could not be purchased; therefore a 15-minute clock was rebuilt. It was necessary to add an additional mainspring to secure sufficient power. The clocks may be started and stopped at will by a small lever mounted on the outside of the case.

Either of two kinds of charts is used. One chart, graduated from 0 to 1000 pounds is used with the medium-sized cylinder. The other chart, graduated from 0 to 3000 pounds, when used with the large cylinder reads pounds of pull directly, and when used with the small cylinder reads ten times actual draft.

PNEUMATIC MOUNTING FOR INSTRUMENT

The reader is perhaps aware that a recording instrument of this type is very delicate and not designed for the rough use that may be encountered in field work. The first method of attack of this problem was to mount the recorder on springs in a wooden box. This was unsatisfactory in adequately protecting the instrument from mechanical shock and also from the standpoint of weight. The final solution, which proved entirely satisfactory, was to cushion the instrument by mounting it, as shown in Figure 8, between two 15-inch lengths cut from a 30 x 3 standard auto inner tube and vulcanized at the ends. The tubes were inflated to a very low pressure, the lower mounting carrying slightly more pressure than the upper. A diagramatic view of this mounting is shown in Figure 9. The tubes are held between the recorder and the frame by retainers made from 1-inch strips of sheet iron and rounded to fit the tube. These retaining arcs are so spaced and limited in number that sufficient room is allowed for tube expansion and no metallic contact occurs between the recorder and the frame. The recorder is mounted with the top tilted back approximately 10 degrees from the vertical so as to insure a good contact between the pen and the chart at all times. The framework is constructed from 1-inch angles made from 18-gauge galvanized sheet iron. The total weight of the framework and recorder is 22 pounds. The pneumatic recorder may be conveniently carried along during the test run, or it may be strapped to the implement or tractor in any convenient place.

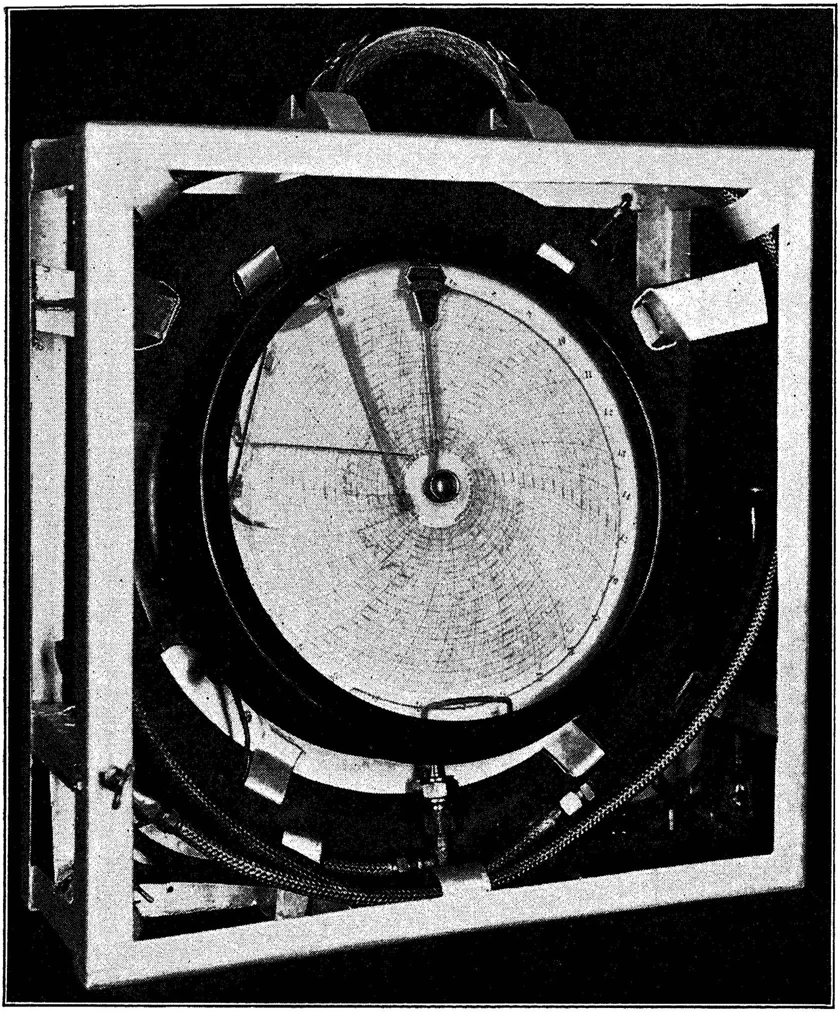

Figure 8.—Pneumatic Mounted Recorder Ready for Transportation to the Field

The effectiveness of the mounting in protecting the recorder for mechanical shock was determined by placing the dynamometer, with cylinder and piston clamped for a constant pressure, on a tractor equipped with 5-inch spade lugs and driven at 3¼ miles per hour over a hard-surfaced road. This severe condition will never be met in the field. As a comparison, a similar record was secured with the recorder mounted on springs. Figure 10 shows a photographic reproduction of the records secured.

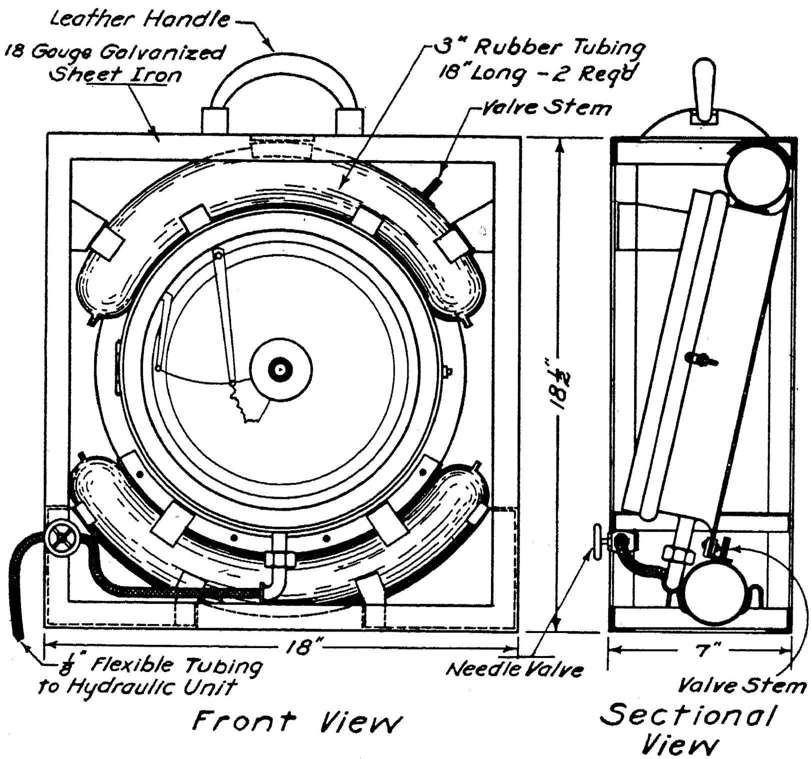

Figure 9.—Diagrammatic Drawing of Pneumatic Mounted Recorder.

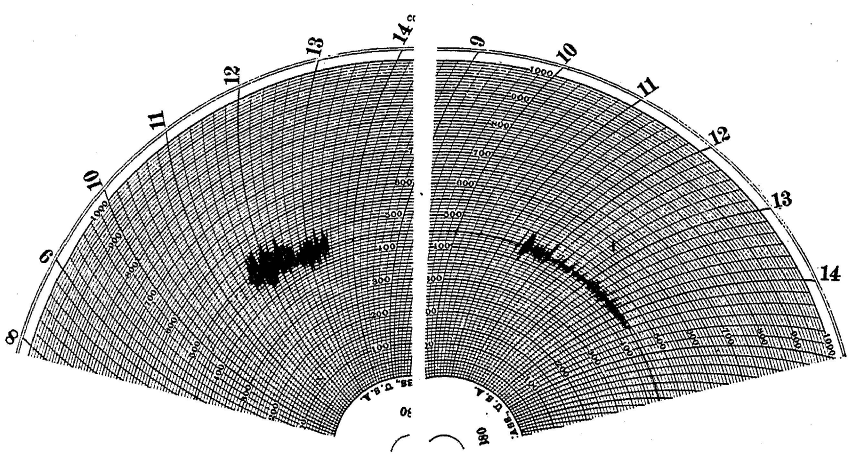

Figure 10.—(Left) Record Secured with Recorder Spring Mounted and Hydraulic Unit Clamped for Constant Pressure and Placed on a Tractor Equipped with 5-inch Spade Lugs and Driven at Three and One-Fourth Miles per Hour over a Hard Surfaced Road.

(Right) Record Secured Under Same Conditions as Left Except Recorder was Pneumatic Mounted.

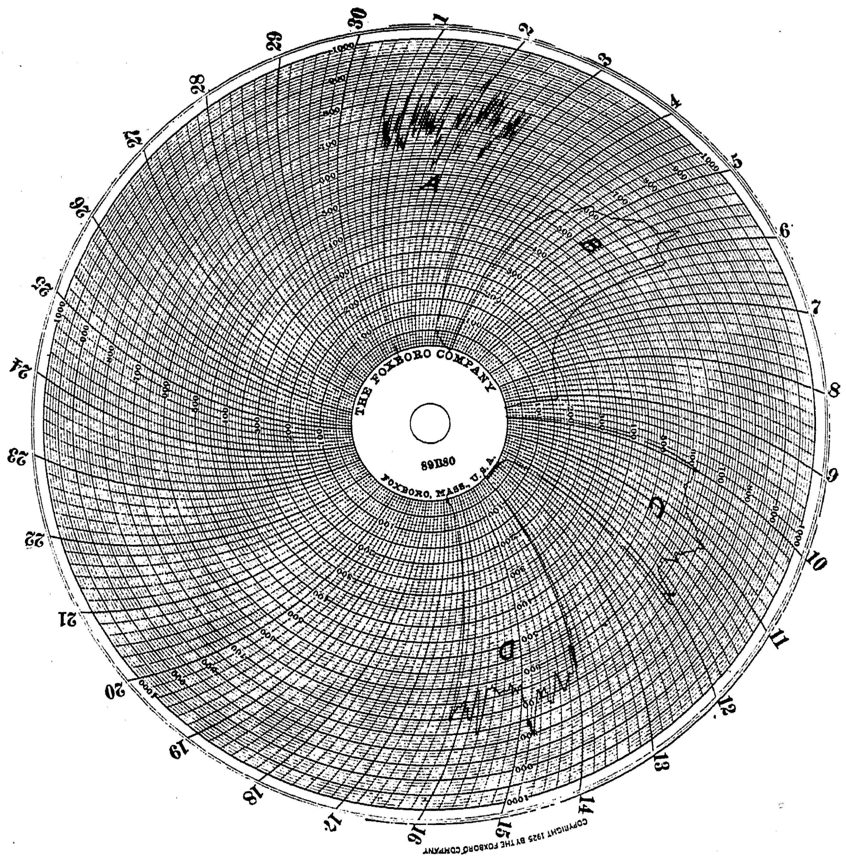

Figure 11.—Traces Secured by Four Different Degrees of Throttling.

Throttling, to get a smoothing-out of the trace to any desired degree, is secured by a small needle valve located in the oil line and mounted on the recorder frame. Figure 11 is a photographic reproduction of a chart showing four different degrees of throttling. Record D is the ideal since minor fluctuations are ironed out. This results in a readable chart. It is necessary to open the valve wide at the start to prevent delay between entry of the implement into the ground and attainment of the full record, and then to throttle to the desired degree. Record A, secured with the valve wide open, is very accurate but very difficult to evaluate. Where it is necessary to secure recorded resistance for each increment of field travel this wide valve opening may be desirable. For any given opening the character of the trace will depend upon the soil type. A light sandy soil will give a smoother trace than that obtained in heavy stony soil.

PRESSURE TRANSMISSION LINE

The oil-pressure transmission line is a ⅛-inch flexible all-metal tubing, designed to stand a pressure well in excess of 350 pounds per square inch.

CALIBRATION

The entire dynamometer system for the two larger cylinders, was calibrated for accuracy with the use of an Olsen testing machine of 5000 pounds capacity. Direct loading by use of known weights was used in calibrating the instrument with the small cylinder. The resulting curves, prepared by taking small load increments, showed that at all points the indicated load values needed no correction.

DETERMINATION OF AVERAGE DRAFT

The average draft of a record, such as is shown in Figure 12, may be secured by the use of a planimeter. However, experience indicates that the following method will give results which, for all practical purposes, are just as accurate as the planimeter method. Average values are read from the chart for equal intervals, such as ten seconds, during the length of the trace and these values are in turn averaged. This is a much simpler and quicker method and does not require the purchase of a special planimeter for circular charts.

DETERMINATION OF POWER

With the average draft determined as stated above, we need only the element of time in order to determine the power. Each test is run over a measured distance. The time required to travel this measured distance is obtained in either of two ways: (1) by the use of a stop watch, and (2) by use of the electric pen which marks on the dynamometer chart.

SOIL RESISTANCE

In the design of the tillage experiment the land has been divided into long parallel strips or plots, each of which is allotted to certain tillage methods. Since the tillage machinery used for these methods will be directly compared by their draft records, it is necessary to know whether the physical properties of the soil which govern the drawbar pull are the same on the various plots. A physical analysis of the soil may be made at regular intervals over the plots but this would involve a great amount of labor. The drawbar pull is the sum total of all these physical reactions of the soil to force. Therefore, if a tillage implement may be operated over the plot areas at a constant mechanical setting then the recorded drawbar pull will be a measure of the degree of uniformity of the soil. A common moldboard plow is best suited to determine this soil resistance

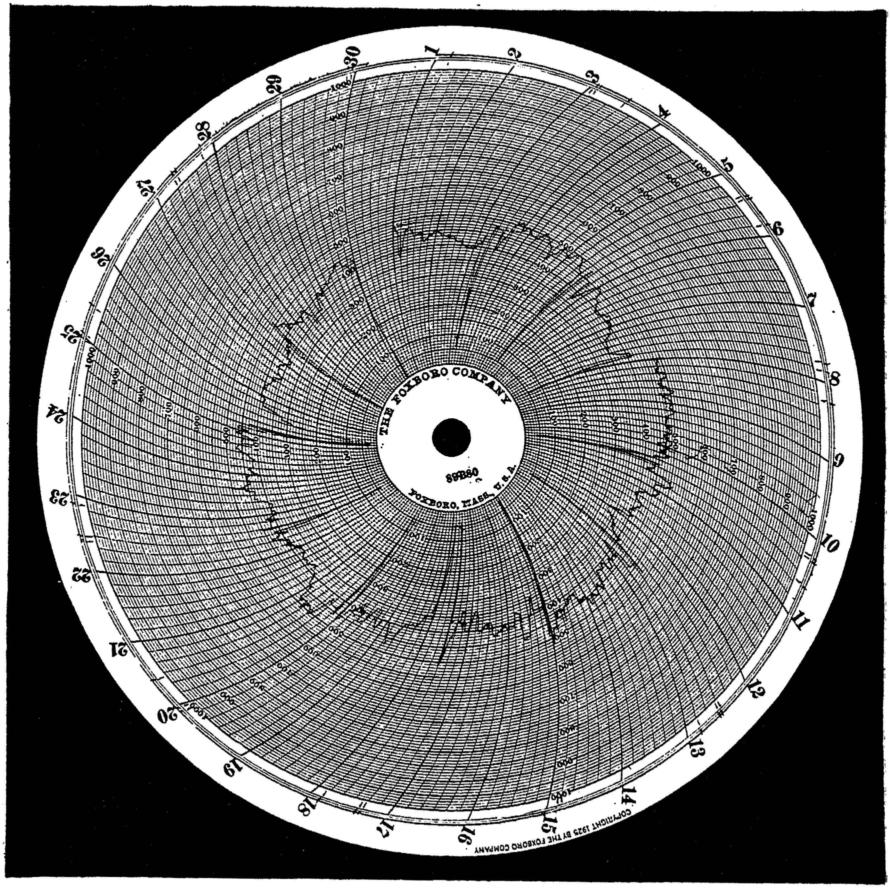

Figure 12.—A Typical Draft Record of a Series of Plowing Tests.

for it exerts a force over the entire cross sectional area of the surface and the amount of cut can be kept more constant than other types of tillage implements. In addition, this measurement must be made at the start of the season before the various methods of tillage affect the structure of the soil. The soil resistance, therefore, may be taken in conjunction with the operation of breaking the soil in preparation for the crop.

The arrangement of the tillage plots is such that all variations in the method of seedbed preparation and cultivation lie side by side and when taken as a group form a range. Twenty-two plots (4 corn rows wide and 125 feet long) form the range. There is one replication of this range. Two other ranges are used to complete the two-year rotation of corn, oats and lespedeza, that is practiced on the experimental field.

In the spring of 1934 all the plots within Ranges 1 and 3 were plowed with a one-bottom 18-inch Oliver plow (No. 134—general purpose). The ranges were plowed lengthwise or across the plots, and values of soil resistance in pounds were secured by measuring the draft with the use of the dynamometer developed. A draft record was taken on the average of every other furrow. Tables 1 and 2 show the values of soil resistance

TABLE 1.—VALUES OF SOIL RESISTANCE (POUNDS), RANGE 1.

Plot	A	B	C	D	E	F	G	H	I	Average
1	538	520	596	557	617	634	596	629	567	584
2	546	568	602	567	598	636	585	598	563	585
3	553	596	612	598	581	635	575	570	559	586
4	553	517	631	603	586	619	576	582	555	580
5	568	529	621	594	586	608	578	579	552	579
6	583	542	611	586	585	597	579	585	550	580
7	584	543	613	589	581	595	560	609	550	580
8	607	546	610	590	574	595	570	607	537	582
9	610	545	611	595	573	589	572	599	538	581
10	563	539	619	607	577	572	569	576	558	576
11	557	512	623	590	572	563	562	570	574	569
12	548	500	622	572	567	562	558	566	587	565
13	528	491	618	536	557	567	551	560	600	556
14	533	506	523	552	555	561	564	596	600	554
15	534	502	622	555	547	548	553	570	613	560
16	534	492	618	552	538	527	540	542	625	552
17	569	508	602	556	532	532	537	528	550	546
18	597	503	591	559	529	546	538	522	539	547
19	625	497	582	561	528	558	539	515	524	548
20	635	510	588	558	560	558	541	506	499	551
21	636	517	593	559	546	541	522	503	503	547
22	636	523	598	561	530	525	503	500	508	543

TABLE 2.—VALUES OF SOIL RESISTANCE (POUNDS), RANGE 3.

Plot	A	B	C	D	E	F	G	H	I	Average
1	920	485	447	435	450	434	440	427	370	492
2	870	484	455	457	440	431	440	434	370	487
3	722	480	478	460	412	424	442	452	369	471
4	734	482	474	455	409	428	442	444	380	472
5	749	485	468	447	406	433	443	436	393	473
6	698	472	463	439	407	433	445	439	392	465
7	647	460	457	432	409	433	447	442	390	457
8	610	463	456	438	411	431	451	445	393	455
9	580	466	456	443	412	431	455	446	398	454
10	547	470	461	445	417	431	459	443	416	454
11	536	472	459	444	417	431	457	445	421	453
12	540	472	451	440	412	433	449	450	415	451
13	550	462	445	436	402	432	441	450	423	449
14	565	455	443	430	398	431	435	446	436	449
15	584	460	440	418	394	434	438	446	434	450
16	600	476	435	407	391	438	443	447	432	452
17	608	463	432	408	397	439	446	443	430	452
18	616	450	429	409	401	441	450	440	429	452
19	602	454	430	411	402	439	459	441	432	452
20	585	456	430	412	403	436	470	495	438	453
21	574	453	429	417	407	435	472	450	442	453
22	562	450	429	419	409	434	475	452	446	453

in pounds for Ranges 1 and 3 respectively. These tables were constructed by dividing the range lengthwise into nine sections (A to I). These section lines and the plot boundaries formed square regions, within which all draft values were averaged to secure a mean drawbar pull value for the region. This ironed out all minor variations. The maps shown in Figures 13 and 14 were constructed from the tables by plotting in the center of each region the average draft value for that region. Then points having equal values were joined by a smooth line. Each line shows a region where the draft is constant. These lines are called isodynes. These values of resistance are relative since they represent the draft for a one-bottom plow. A map which will give the same character of lines may be constructed with draft values in pounds per square inch.

A probable-error determination was made by comparing the gradient of soil resistance, from one line to the next, to individual furrow records. These errors ranged from zero to a maximum of 25 per cent. The average was 7.5 per cent.

It will be observed that the isodynes have a tendency to run in the direction in which the plowing was done. Random measurements of the depth of plowing showed that there may be a variation of as much as 1 inch in any row. When plowing 6 inches deep this would mean a 16 per cent variation in the draft. This may result in greater variation in draft from row to row as compared with actual soil variation in the direction of travel. When securing soil resistance maps on a small scale it is necessary therefore that a very accurate record be taken of the depth. By very careful driving the width of the plow may be kept constant. The average depth over the length of the plot is fairly constant and so the average draft of each plot may be directly compared.

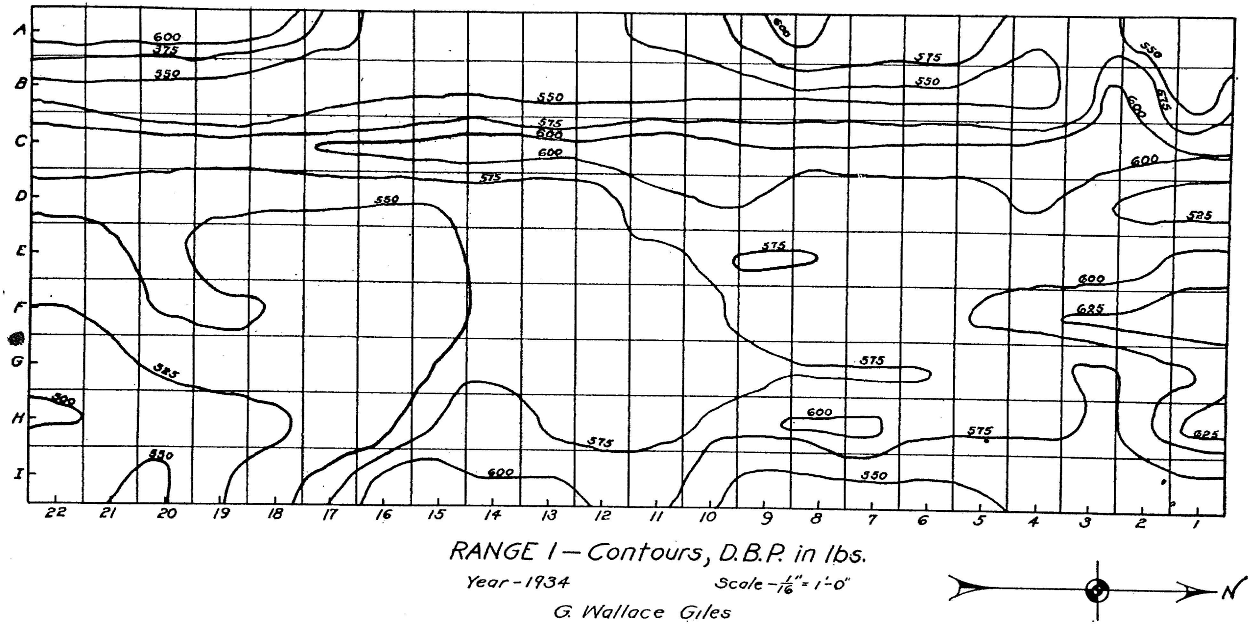

Figure 13.—Isodyne Map of Range 1.

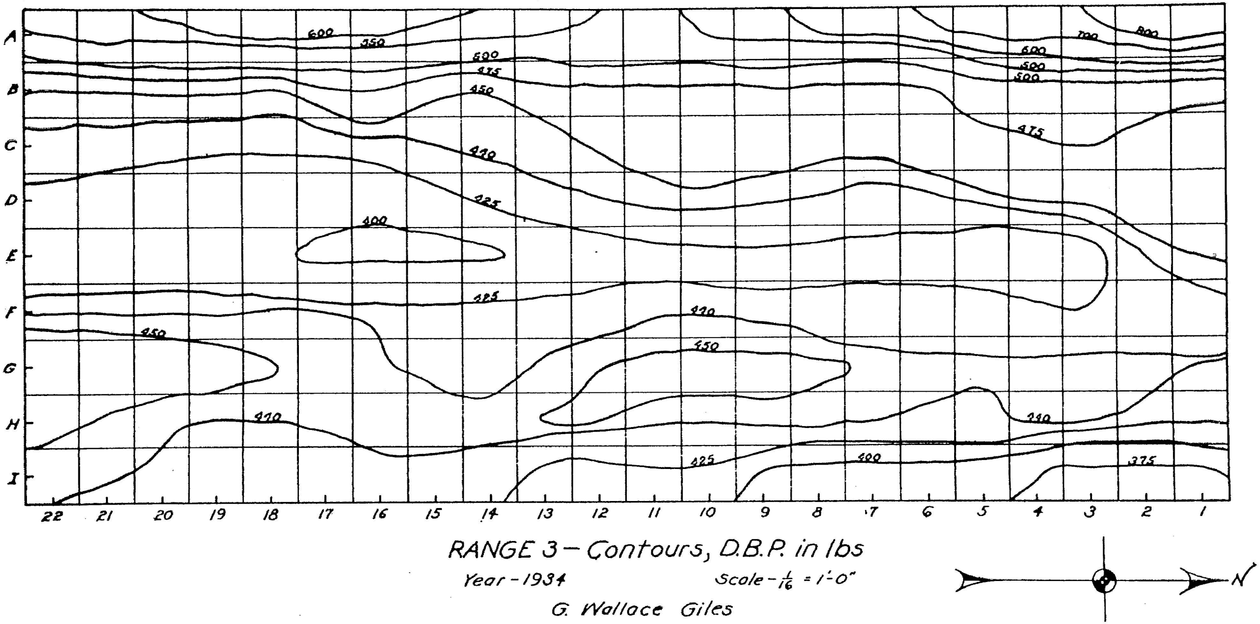

Figure 14.—Isodyne Map of Range 3.