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The Draft of Farm Wagons as Affected by Height of Wheel and Width of Tire

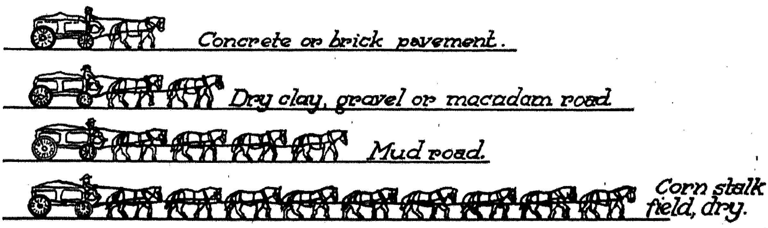

Fig. 1.—Horse power required to haul the same load on different roadways—each figure of a horse represents 1 horse power.

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UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE

Agricultural Experiment Station

The Draft of Farm Wagons as Affected by Height of Wheel and Width of Tire

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The Missouri Station was one of the first to make a study of the draft of farm wagons. In January of the year 1896, tests were conducted to determine the effect of width of tires on the draft, and the results of these tests were published in Bulletin 39 of the Missouri Experiment Station. In 1897, further tests were conducted for the purpose of measuring the effect of height of wheels on draft. A second publication, Bulletin 52, gives the results of these tests. In November, 1921, twenty-five years after the first tests were made, the Agricultural Engineering Department took up the project on the draft of wagons. The object of repeating these tests was two-fold; first, to secure more complete data on the project, and second, to secure information applicable to the standard wagon equipment of the present time.

The equipment for the tests consisted of one standard farm wagon equipped with six sets of wheels, three sets having 1½-inch tires and three

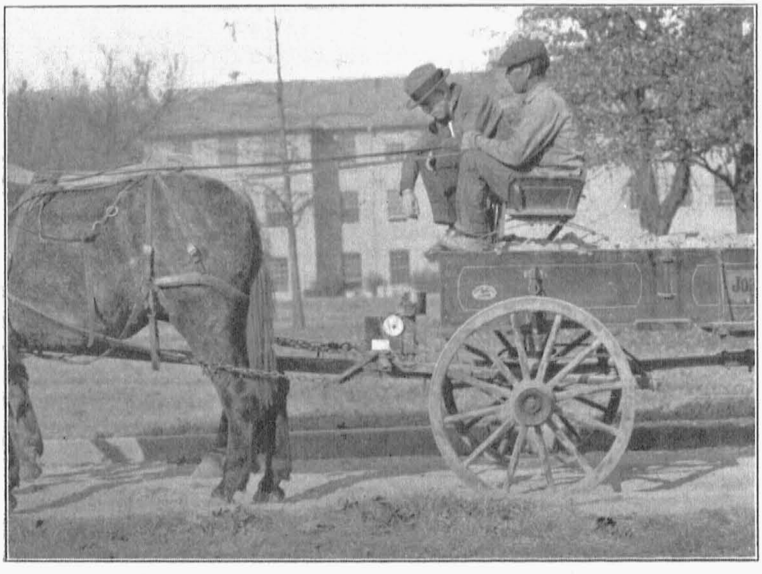


Fig. 2.—The type of equipment used in this experiment

sets having 4-inch tires. By using different combinations, the following wheel equipment could be obtained.

Low	1½-in. tires	36-in. front	40-in. rear.
Medium	1½-in. "	36-in. "	44-in. "
High	1½-in. "	40-in. "	44-in. "
Low	4-in. "	36-in. "	40-in. "
Medium	4-in. "	36-in. "	44-in. "
High	4-in. "	40-in. "	44-in. "

A net load of 3300 pounds was used in all the tests, any slight variation above or below this being taken into account in figuring the draft per ton load.

Total weight of wagon ready for test including driver and observer, was as follows:

Low narrow wheels	4509 pounds
Medium narrow wheels	4528 pounds
High narrow wheels	4532 pounds
Low wide wheels	4598 pounds
Medium wide wheels	4615 pounds
High wide wheels	4634 pounds

Creek gravel was used for the load and was placed to a uniform depth in the box of the standard wagon. With the driver and the observer on the wagon, the load on the front and rear axles was approximately the same.

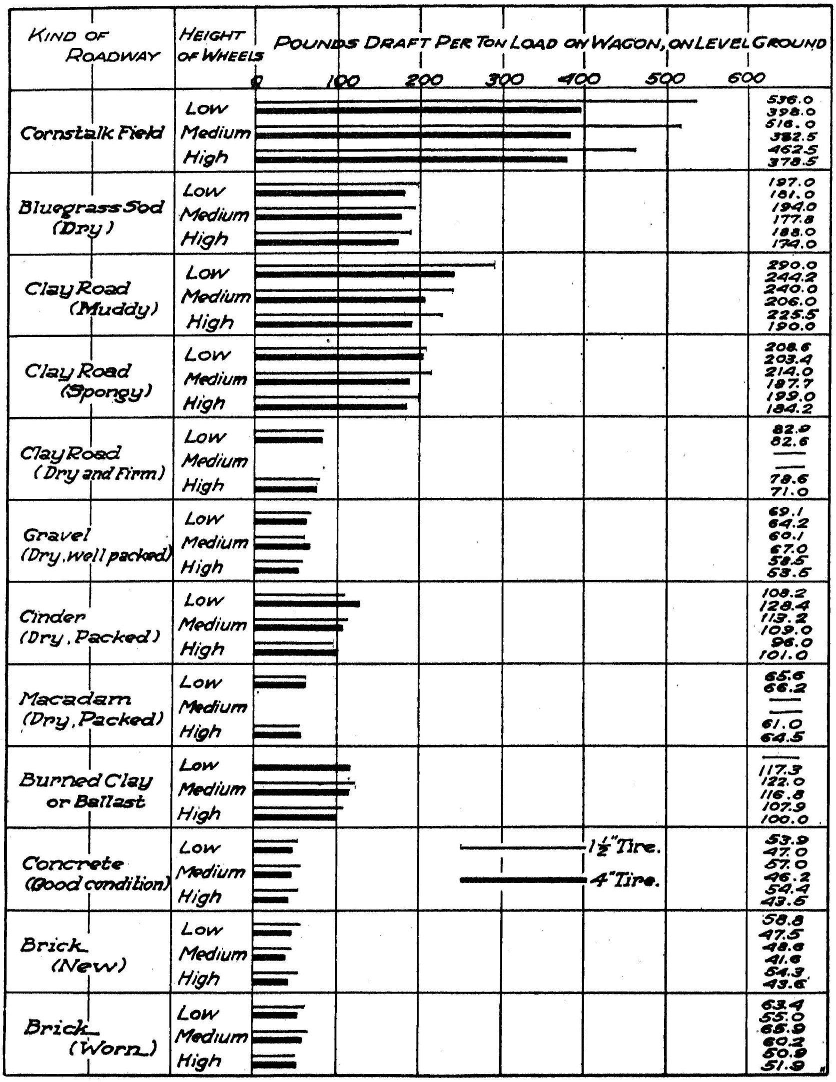
An Iowa integrating dynamometer was used in all the tests. By using a long hammer-strap and a closely coupled double-tree, the hitch for the team was not affected. Care was taken to keep the angle of hitch constant, as different teams were used.

In selecting testing places on each of the different road and field conditions and kinds of surfaces, it was not found possible to secure perfectly level areas on each of the types. To compensate for any difference in grade, a careful survey of each test road was made, and the percentage of grade up or down was computed. The observed draft was then corrected accordingly.

Six hundred twenty-nine tests are included in the reports which follow.

EXPERIMENTAL RESULTS

A study of Fig. 3 shows us that increasing the width of tire from 1½ to 4 inches was more effective in decreasing the draft than was the increase of height of wheel from 38 to 42 inches. For example: On cornstalk land, using low wheels, the wide tires caused 138 pounds decrease in draft, while increasing the height of the narrow wheels saved only 74 pounds, and in case of the wide wheels, only 19.5 pounds.



6Fig 3.—A graphic presentation of the difference in draft due to difference in width of tires.

Increasing height of wheel or width of tire becomes less effective as the density of the road surface is increased. On concrete roadway, there is very little difference in the draft with the different kinds of wheel equipment.

Table 1.—Summary of the Tests Reported in this Bulletin
(Figures Indicate Draft per Ton Load on Wagon on Level Ground)

Kind of roadway	Tire and wheels 1½", 36 x 40	Tire and wheels 1½", 36 x 44	Tire and wheels 1½", 40 x 44	Tire and wheels 4", 36 x 40	Tire and wheels 4", 36 x 44	Tire and wheels 4", 40 x 44	Avg. 1½"	Avg. 4"	Avg. All
I. Farm and Field Conditions.									
Corn stalk field	536.0	516.0	462.5	398.0	382.5	378.5	504.8	386.3	445.5
Bluegrass sod (dry)	197.0	194.0	188.0	181.0	177.8	174.0	193.0	177.6	185.3
Clay road (muddy)	290.0	240.0	225.5	244.2	206.0	190.0	251.8	213.4	232.6
Clay road (spongy)	208.6	214.0	199.0	203.4	187.7	184.2	207.2	191.7	199.4
II. Dry Clay, Gravel, Cinder Macadam, and Burned Clay Roads.									
Clay road (dry and firm)	82.9	....	78.6	82.6	....	71.	80 .7	76.8	78.7
Gravel (dry, well packed)	69.1	60.1	58.5	64.2	67.0	53.5	62.6	61.6	62.1
Cinder (dry, packed)	108.2	113.2	96.0	128.4	109.0	101.0	105.8	112.8	109.3
Macadam (dry, packed)	65.6	....	61.0	66.2	....	64.5	63.3	65.3	64.3
Burned clay or ballast	....	112.0	107.9	117.3	116.8	100.0	114.9	111.3	113.1
III. Brick and Concrete Pavement									
Concrete (good condition)	53.9	57.0	54.4	47.0	46.2	43.5	55.1	45.5	50.3
Brick (new)	58.8	48.6	54.3	47.5	41.6	43.6	53.9	44.2	49.0
Brick (worn)	63.4	65.9	50.9	55.0	60.2	51.9	60.0	55.7	57.8

The vertical space between any pair of curves in Fig. 4 denotes the difference in draft of wide and narrow tires, and the amount of drop in the curves from left to right denotes the advantages of increased diameter of wheels. The position of the curves, curve for wide tires under that for

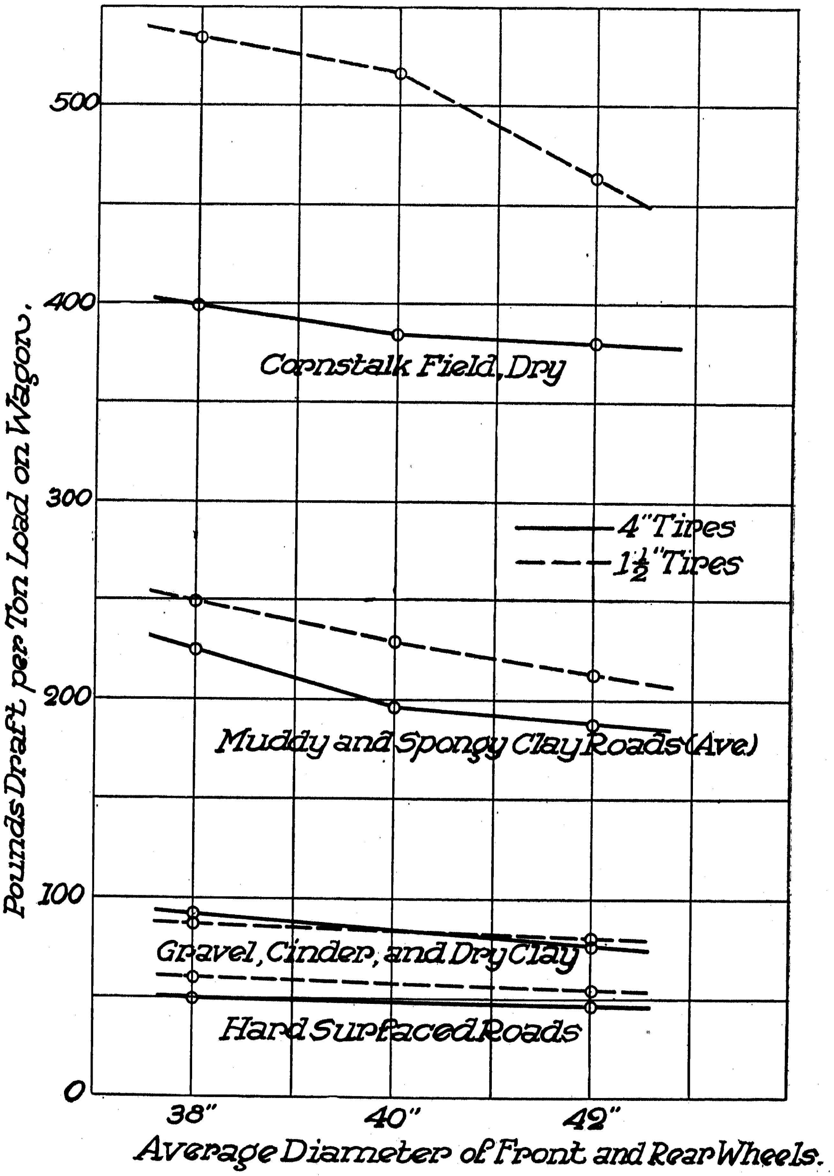


Fig. 4.—Curves illustrating the effect of height of wheel and width of tire on draft of wagons. (Tests of 1921 to 1925.)

narrow, indicates the advantage of wide tires in three conditions out of four, the advantage being negligible on pavement or dry hard roads. For farm or field conditions, the advantage of the wide tire is more pronounced.

The tests conducted in previous years could not be figured in with the tests of recent date because it was not possible to determine the condition of the roadways on which the tests were made, but these tests shown graphically in Fig. 5 show practically the same results.

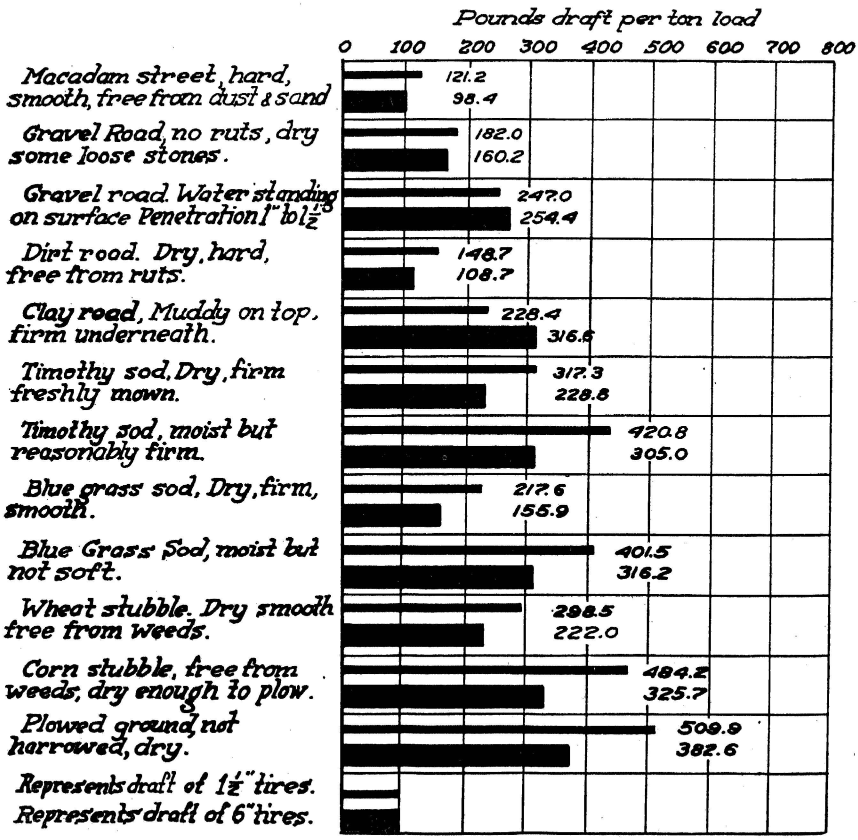


Fig. 5.—Results of tests conducted in 1896 and 1897 to determine effect of width of tire on draft. The narrow black band in each section represents draft of 1½-inch tires; the wide band that of 6-inch tires.

The 6-inch tires caused a decrease in draft on each of the roadways shown, being greatest on plowed ground where the draft was reduced 127.3 pounds by use of the wide tires.

The tests conducted from 1897 to 1901 show the advantage of high over low wheels to be 9.4 pounds on a macadam street and 153 pounds on freshly plowed land. The advantage of high over low wheels in all cases averaged ogether was 42.5 pounds.

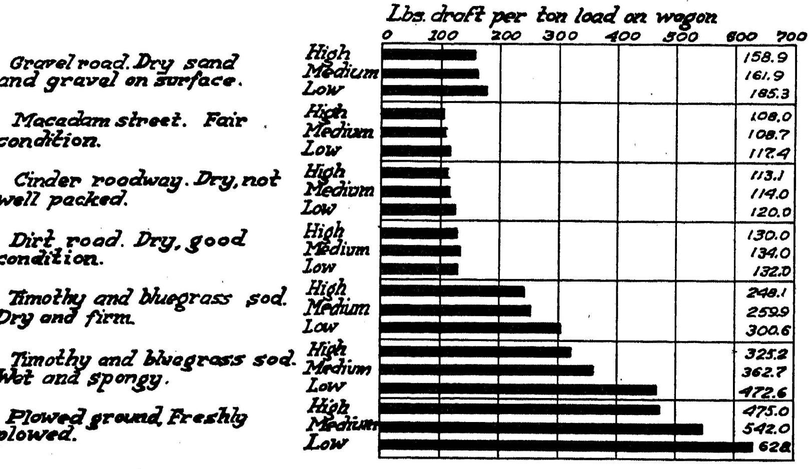


Fig. 6.—Results of tests conducted from 1897 to 1901 to determine the effect of height of wheel on draft. Average height of high, medium and low wheels referred to above was as follows: 49½-in., 38-in. and 26-in. respectively.

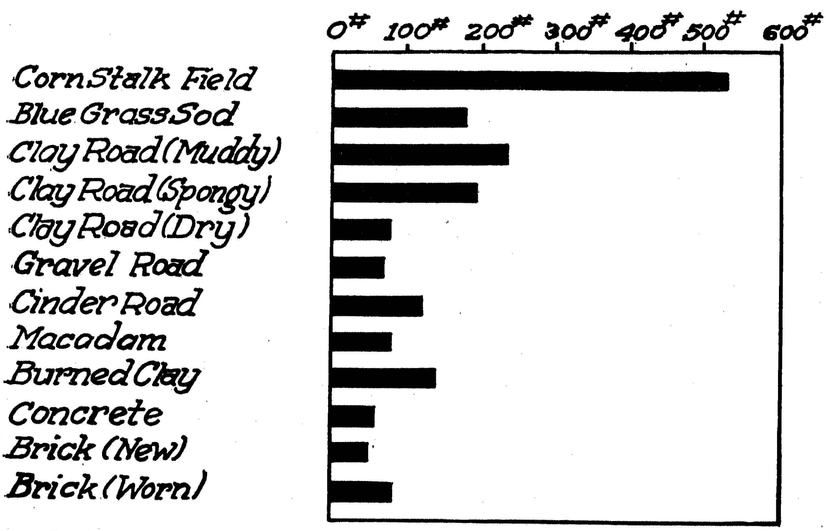


Fig. 7.—Draft per ton load on different roadways. These values include averages of all tests with different heights of wheels and widths of tires.

Numerous questions come to the Station concerning the comparative draft on different kinds of roads. The chart shown in Fig. 7 was made up by averaging an equal number of tests with each kind of wheel equipment and on each kind of roadway, so that the results show the comparative efficiency and give a very good idea as to the comparative cost of transportation on the different types of roadways.

ANALYSIS OF DRAFT OF A FARM WAGON

The draft of a wagon is made up of three separate components. The first is axle friction; the second, resistance due to grade; and the third is rolling resistance.

Axle Friction.—Axle friction, which increases the draft of a wagon by very little, varies with the load on the wheels, the radius of the spindle, the efficiency of lubrication, and with the materials used in the wearing surfaces. The coefficient of axle friction is defined as that number (determined by experiment) which when multiplied by the total load on the wheels will give the resistance to rotation due to axle friction. Professor I. O. Baker, in his "Roads and Pavements", states that the ordinary thimble-skein American wagon, when loaded and well lubricated, has a coefficient of axle friction of about .012, and that the coefficient runs up to from two to six times this value if lubrication is deficient.

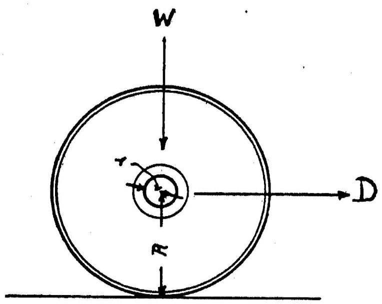


Fig. 8.—The factors involved in axle friction.

The tractive pull required to overcome axle friction varies with the radius of the spindle and inversely with the radius of the wheel, as is seen from the following consideration.

In Fig. 8 let D represent the force required to overcome the resistance due to axle friction, R the radius of the wheel, r the radius of the spindle, and Wc the resistance due to axle friction (W being the weight on the wheel and c the coefficient of axle friction). Then, from the principle of the wheel and axle or the principle of moments of forces.

$$D \times R = Wc \times r, \text{ or } D = \frac{Wc \times r}{R}$$

The draft due to axle friction in the tests reported in this bulletin, as calculated from the above formula, are given in the following table. The coefficient of axle friction is taken as .012 and W is taken as 4055 lbs., which is the gross weight of the wagon including the driver and observer, less the weight of the wheels.

Height of Wheels	Draft due to axle friction (in lbs. per ton load on wagon)
Low	2.3
Medium	2.2
High	2.1

It is seen, therefore, that the axle friction for our tests is a very small fraction of the total draft, and for many considerations is negligible. Some manufacturers have furnished roller bearings for their wagons, but since axle friction is such a small part of the total draft, the reduction in draft due to roller bearings cannot be a large factor. There are certain other advantages of roller bearings, however, such as ease of lubrication which may justify their use on a farm wagon.

Grade Resistance.—The second component of the draft of a wagon is grade resistance, or the draft due to the steepness of the roadway. Grade resistance is independent of the size of the wheel, etc., and depends only upon the load and the grade. For all practical purposes, the grade resistance is equal to the weight times the percentage of grade, or 20 lbs. per ton load for each one per cent of grade, as is shown below. (The steepness of a grade is expressed in percentage, or the number of feet of vertical rise in 100 feet of horizontal run. Thus, a 1 per cent grade would be a rise of one foot per hundred feet of run.)

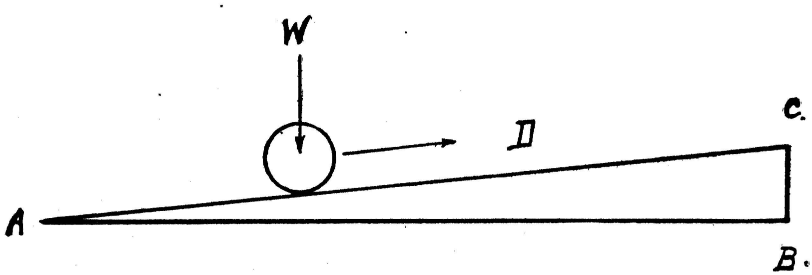


Fig. 9.—The factors involved in grade resistance.

In Fig. 9 let W represent the weight of the load, D = the force necessary to move it up the incline, AB the horizontal run, and BC the vertical rise. (The percentage of grade would then be $\frac{BC}{AB}$. From the principle of the inclined plane, we may state that

$$D = W\frac{BC}{AC}$$

Since on most roadways, AC is practically equal to AB, we may say

$$D = W\frac{BC}{AB}.$$

or $$D = W \times \text{the percentage of grade.}$$

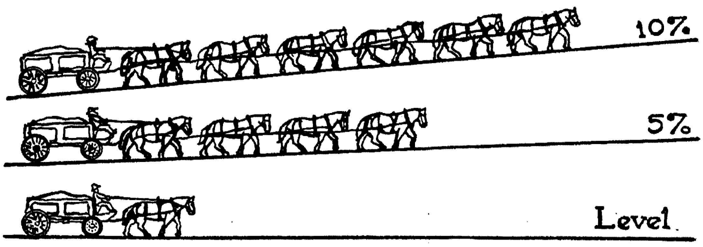


Fig 10.—Effect of grade on the draft of a wagon.

From our tests, it is found that it requires one horsepower to draw a net load of 7454 pounds on a level concrete roadway at the rate of two miles per hour. (Weight of wagon taken at 1200 pounds and the weight of the driver at 150 pounds.) (Pulling with a force of 187½ pounds at the rate of 2 miles per hour constitutes one horse power). On a 5 per cent grade, 3.34 horse power would be needed to draw the load at 2 miles per hour; and on a 10 per cent grade, 5.68 horse power would be required.

Rolling Resistance.—A third component of the draft of a wagon is that due to rolling resistance, or the resistance caused by the wheels sinking into the surface over which it is moving or by the surface piling up ahead of the wheel as shown in Fig. 11. The dynamometer used in the tests, of course, measured the total draft. By subtracting the draft due to axle friction and that due to grade resistance from the total draft, we have left the draft due to rolling resistance.

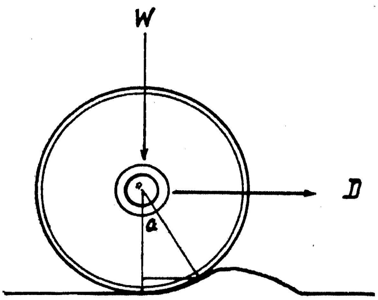


Fig. 11.—The factors involved in rolling resistance

The formula which has been used in the past to determine rolling resistance was stated as follows:

$$C = \frac{D \times R}{W}$$

or transposing

$$D = \frac{W \times C}{R}$$

but C/R = sine of angle A, the angle between the resultant at rest and in motion.

Therefore, $D = W \times \text{sine angle } A.$

C = the distance bd, the perpendicular distance from the point of application of the resultant of W and D when motion is impending.

D = pounds draft to overcome rolling resistance.

R = Radius of wheel.

W = Gross load.

This formula is in error in that it assumes the work arm of D to be R when in reality the work arm is od. With steel wheels on steel rails, the difference between od and R is too small to be reckoned with, but under field conditions where the penetration is great, the difference is greatly increased. To take care of this error, the formula should be as follows.

$$d \times od = W \times db$$

Then $$D = \frac{W \times db}{od}$$

but $$\frac{db}{oD} = \text{tan. angle } A.$$

Therefore $$D = W \times \text{tan. angle } A.$$

SELECTION OF A FARM WAGON

If lightness of draft were the only factor to be considered in selecting a farm wagon, then wide tires and high wheels would, no doubt, be the choice; but since there are other important factors to be considered some sacrifice along this line may be justified. A high wheel with wide tires causes some difficulty in turning, due to the small clearance between the wheel and the wagon box. It is difficult to load a high wagon with many of our heavy or bulky crops. Therefore, for farm conditions, a low wagon is desirable. The tests have shown that under farm and field conditions the low wheel and the wide tire result in about the same draft as the high wheel and the narrow tire. Since the low wheels are so much more convenient for farm work, they would no doubt be the best selection for average conditions.

Four-inch tires seem to be about as wide as can be used well in practice. It is true that the 6-inch width will result in some decrease in draft, but since they offer more difficulty in turning and since they cause the tongue to whip more in crossing rough ground, due to the fact that the tread is necessarily widened, they are not often selected by teamsters. The 36-inch front and 40-inch rear wheels equipped with 4-inch tires would seem to be the logical choice for a wagon to meet the needs of the average farm.

HORSE POWER DEVELOPED BY FARM TEAMS

In hauling a load of 3000 lbs. in corn stubble at the rate of two miles per hour, a team will develop 2.4 H. P. During the tests the greatest horse power developed was on corn stubble. The team in this test developed 7.38 H. P. for a period of 15 seconds. This ability of the horse to take care of an overload for a short period increases his usefulness as a farm power unit.

Table 2.—Showing Values of Tan. Angle A or Coefficient of Rolling Resistance.

Roadway	Average radius (inches)	Narrow wheels (1½ in.) Tan. Angle A	Narrow wheels (1½ in.) Angle A	Wide wheels (4 in.) Tan. Angle A	Wide wheels (4 in.) Angle A
Corn Stubble (dry)	19	0.1864	10.56°	0.1432	8.25°
" " "	20	0.1836	10.4°	0.1372	7.66°
" " "	21	0.1716	9.73°	0.1368	7.83°
Blue Grass Sod	19	0.0720	4.11°	0.0652	3.75°
" " "	20	0.0688	3.93°	0.0632	3.66°
" " "	21	0.0672	3.84°	0.0620	3.57°
Clay Road (muddy)	19	0.1060	6.05°	0.0876	5.03°
" " "	20	0.0856	4.90°	0.0732	4.20°
" " "	21	0.0600	3.45°	0.0672	3.87°
Clay Road (spongy)	19	0.0768	4.40°	0.0732	4.20°
" " "	20	0.0776	4.43°	0.0528	3.03°
" " "	21	0.0716	4.10°	0.0656	3.75°
Clay Road (dry)	19	0.0300	1.72°	0.0296	1.70°
" " "	20	----------	----------	----------	----------
" " "	21	0.0288	1.65°	0.0248	1.42°
Gravel Road (dry)	19	0.0284	1.63°	0.0244	1.40°
" " "	20	----------	----------	----------	----------
" " "	21	0.0284	1.63°	0.0232	1.33°
Cinder Road (dry)	19	0.0396	2.25°	0.0424	2.43°
" " "	20	----------	----------	----------	----------
" " "	21	0.0288	1.65°	0.0352	2.03°
Macadam Road	19	0.0240	1.38°	0.0252	1.45°
" "	19	----------	----------	----------	----------
" "	21	0.0224	1.258°	0.0236	1.35°
Burned Clay	19	----------	----------	0.0376	2.15°
" "	20	----------	----------	----------	----------
" "	21	0.0376	2.16°	0.0356	2.05°
Concrete	19	0.0232	1.33°	0.0196	1.36°
"	20	0.0208	1.20°	0.0164	0.95°
"	21	0.0192	1.10°	0.0144	0.82°
New Brick	19	0.0228	1.3°	0.0160	0.92°
" "	21	0.0180	1.02°	0.0164	0.95°
Worn Brick	19	0.0228	1.3 ·	0.0212	1.22°
" "	21	0.0184	1.05	0.0180	1.0332°