ESTIMATING WAGON DRAFT[1]

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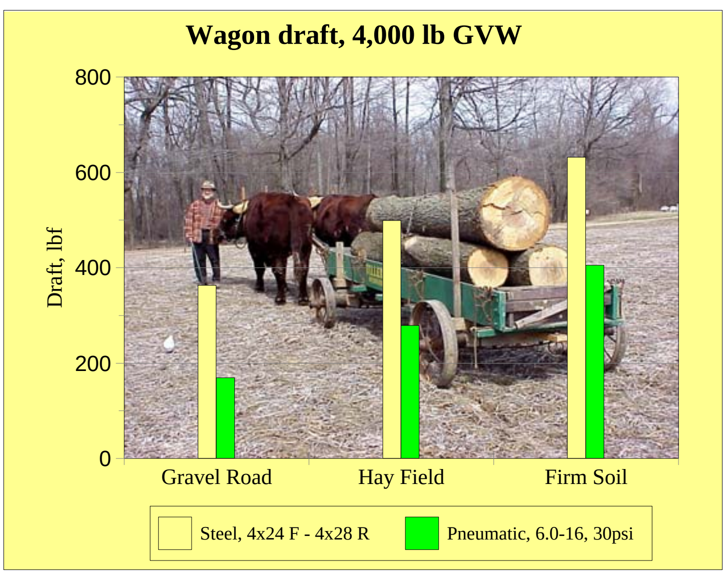
Measurements of draft as tension (pounds-force, lbf) in the towing chain were made while pulling wagons over a range of tractive surfaces. Wagon draft ranged from about 4% of GVW with pneumatic tires on a gravel road to 16% of GVW when using steel tires on firm soil. Compared to pneumatic tires, the use of steel tires increased draft 50% to 100%. The use of wider or taller tires increased bearing area, improved flotation in soft soils and reduced draft.

INTRODUCTION

An ability to estimate wagon draft is important in working draft animals. A well-matched wagon and team allow efficient use of time for fieldwork. A convenient rule-of-thumb for estimating the working ability of oxen is that a well-conditioned team can handle draft loads measured as tension in the draft chain equal to 10-12% of their body weight throughout the day and greater loads for short periods of time. In training, young animals can become discouraged if forced to draw too heavy a load. Mature animals may also refuse to pull their best if frequently confronted with a heavy draft load they are unprepared for or cannot move. The purpose of this bulletin is to help you estimate the draft loads created by wagons with steel and pneumatic tires.



WAGONS

Draft for wagons and carts on level ground is largely the force needed to overcome the rolling resistance of transport wheels. Rolling resistance is the force needed to keep an implement moving at a constant speed while compressing or moving soil and overcoming wheel and axle-bearing friction.

Rolling resistance is largely a function of the road surface. A hard surface offers little rolling resistance while a soft surface offers considerable resistance.

Tire selection influences wagon draft. Small or overinflated tires provide a small bearing surface, allow greater tire sinkage and increase rolling resistance. Larger tires provide more bearing surface and thereby reduce tire sinkage and draft in soft and tilled soils. And, depending upon the load, larger tires can often be used at a lower inflation pressure which further increases their bearing surface and reduces draft.

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Our Need to Know . . .

In writing a series of articles on implement draft, we at ***Tillers International*** are seeking to improve the relationship of people with their working animals. We are committed to easing the burden of animals as they help meet the energy needs of small farms.

If we lack an understanding of what we ask of our animals, we have limited means of knowing why they may act up in particular ways. If a teamster mistakenly thinks a load is light, he or she may become overly demanding. Underestimating a load may lead to a heavy whip and frustrate the animals into becoming nervous and unpredictable. Repeatedly overloading a team will discourage them and reduce their willingness to pull. Our goal is to enhance the teamsters ability to match the ability of the team with the demand of the load.

Calculating a load will take a little practice and attention. But you will be rewarded with a more productive relationship with your animals. They trust us to attend to such details and their trust grows as we demonstrate our trustworthiness to them. Those who have not worked oxen or draft horses may think this overestimates their perceptiveness and memory; nonetheless, experience clearly teaches the perceptive teamster that oxen and horses develop differing levels of trust and respect for variations among drivers. There are real benefits to be gained by understanding the loads you are asking your animals to move. We hope this article will help all teamsters empathize with the tasks they are presenting to their animals.

A major component of wagon draft is from slope or grade. A slope can be described as either a percentage calculated as a ratio of a rise to run or an angle measured in degrees. A 10% slope indicates a 10-foot vertical rise in 100 feet of horizontal run. A 100% slope equals a 45° angle. The relationship between percent slope and angle is provided in Table 1.

Table 1. Relationship between slope and angle.

Slope	Angle	Slope	Angle
10%	6°	60%	31°
20%	11°	70%	35°
30%	17°	80%	39°
40%	22°	90%	42°
50%	27°	100%	45°

Pulling up a slope increases draft. In estimating the draft added from the slope it is more convenient to refer to the slope as a percentage rather than an angle. When pulling up a 10% slope you lift the load vertically one-foot for each 10-foot of linear pull. The slope component of the draft is approximately equal to the slope percentage multiplied by the gross vehicle weight. For instance, if draft for a wagon (3,000 lb GVW) on level ground is 200 lbf, the added draft from a 10% grade would be 300 lbf (3,000 lb GVW * 0.10 = 300 lbf). Therefore, the total

Pneumatic tires provide a large bearing surface and cushion the impact of stones and other obstructions.

draft would be 500 lbf. For a 20% slope, add 20% of the load.

Table 2 provides an estimate of draft for wagons with pneumatic tires over a range of surfaces from concrete to freshly plowed ground. These estimates for draft on level ground range from about 3% to 38% of GVW with the 6.00-16 tires and are based on equations and functional relationships for machinery management provided by the American Society of Agricultural Engineers (ASAE, 2000). Selection of the larger 11.00-15 tires (11.00 refers to the tire section width in inches, 15 to the rim diameter) inflated to 20 psi rather than 6.00-16 tires at 30 psi decreased draft as much as 33% on tilled soils. Tire size and pressure had less of an effect when on concrete or hard ground.

Table 2. Predicted wagon draft per 1,000 lb GVW for a range of surfaces, slopes and tires.

	Draft, lbf/1000 lb GVW		
	6.00-16 Tires (30 psi)		
Surface	Level	10 %	20 %
Concrete	32	132	227
Hard pasture	57	157	252
Firm soil	118	217	312
Tilled, settled	194	293	386
Freshly plowed	378	476	567
	11.00-15 Tires (20psi)		
Concrete	32	132	227
Hard pasture	50	150	245
Firm soil	89	189	283
Tilled, settled	143	242	336
Freshly plowed	264	363	455

Based on: *Hunt, D. 1995. Farm Power and Machinery Management, 9th edition*.

While the ASAE Standards provide convenient guidelines for estimating the rolling resistance of pneumatic tires, such guidance is not provided for wagons with the steel tires favored by many teamsters. In order to better define the draft relationship between steel and pneumatic tires, we at Tillers International measured wagon draft on a gravel road, an alfalfa/grass hay sod and the firm soil of a harvested soybean field.

Draft measurements were made using a simple hydraulic pull meter--a closed-circuit fluid system that consisted of a hydraulic cylinder and a pressure gauge. The pull meter was placed in the towing chain and the reaction force was measured by the pressure gauge on the discharge side of the cylinder. This device allowed instantaneous measurements of draft (lbf), and when combined with time and distance, power output (hp).

4x24 front steel tires.

The steel-tired wagon had front tires measuring four inches in width by twenty-four inches in diameter (4x24), the rear tires were 4x28. The pneumatic-tired wagon had 6.00-16 bias ply tires inflated to 30 psi. Each wagon was loaded with logs to 4,000 lb GVW. Lewis and Clark, Tillers' 3,850 lb ox team was used to pull the load. In measuring draft, several observations were recorded over a known distance. A comparison of an average draft and power output for each tire and surface condition are provided in Table 3.

Table 3. Draft and power output for a 3,850 lb ox team drawing a 4,000 lb wagon for a range of tire and surface conditions.

	Draft				
	Lbf	% GVW	% Body Wt	MPH	HP
Gravel road					
Steel	363	9.1	9.4	2.3	2.2
Pneumatic	169	4.2	4.4	2.6	1.2
Hay sod					
Steel	499	12.5	13.0	2.2	2.9
Pneumatic	279	7.0	7.2	3.1	2.3
Firm soil					
Steel	632	15.8	16.4	2.1	3.6
Pneumatic	405	10.1	10.5	2.2	2.3

Based on research at Tillers International, 2001.

Compared to steel tires, pneumatic tires cushion the impact of stones and other obstructions. This is particularly helpful on a hard surface such as a gravel road. Pneumatic tires also deflect under a load. As the load increases, tire deflection increases the tire/soil contact area. This provides a larger bearing surface, improves flotation, and reduces tire sinkage and rolling resistance. In Tillers' wagon draft trials an average draft using pneumatic tires ranged from about 4% to 10% of GVW. When using steel tires draft ranged from 9% to 16% of GVW.

How did the ASAE guidelines for wagon draft using pneumatic tires compare with Tillers' measurements of wagon draft? ASAE estimated draft with 6.00-16 tires at 30 psi on concrete at 32 lbf per 1,000 lb GVW (Table 3). We at Tillers measured 42 lbf on a gravel road. ASAE predicted 57 lbf per 1,000 lb on hard pasture ground, we measured 70 lbf on an alfalfa/grass hay sod. ASAE suggested 118 lbf on firm soil, we recorded an average draft of 101 lbf on firm soybean ground. The ASAE guidelines were a suitable predictor of wagon draft when using pneumatic tires. Compared to pneumatic tires, use of steel tires increased draft 50 to 100%.

EFFECTS OF TIRE WIDTH AND DIAMETER

The spokes of a wheel form a continuous, rotating lever. Wheel height affects draft by altering the length of the lever arm available for lifting the load over obstructions. Taller wheels provide a longer lever arm and greater mechanical advantage. Equally important, taller wheels provide a larger bearing surface. A larger bearing surface improves flotation, reduces tire sinkage and reduces rolling resistance.

A wheel will sink in the ground until the resistance offered by the soil equals the pressure applied by the tire. Wheel sinkage increases a tire's contact area and bearing surface. Tire contact area is directly related to wheel height. In other words, doubling wheel height doubles the tires contact area. In a uniform soil and under similar loads a 48-inch wheel will sink to only one-half the depth but will have the same contact area as a 24-inch wheel.

In many cases, wagon or implement design limits our ability to use taller wheels to improve flotation. And, taller wheels may not be desirable when loading or unloading a wagon by hand since a higher reach will be needed.

Table 4. Draft per 1000 lb of gross vehicle weight (GVW) for a wagon with steel tires six inches wide and wheel diameters high (44" front x 56" rear), medium (36" front x 44" rear) or low (24" front x 28" rear).

		Draft, lbf per 1000 lb GVW [1]			
Surface	**Tire**	**Level ground**	**% change**	**10% slope**	**20% slope**
Hard top, slightly worn, clean, fair condition					
	high	54	---	154	254
	medium	54	---	154	254
	low	59	+9	159	259
Soil, dry, hard, no dust					
	high	65	---	165	265
	medium	67	+3	167	267
	low	66	+2	166	266
Gravel, dry with 1 inch of sand and small loose stones					
	high	80	---	180	280
	medium	81	+1	181	281
	low	93	+16	193	293
Soil, frozen, ½ inch sticky on top					
	high	95	---	195	295
	medium	107	+13	207	307
	low	117	+23	216	312
Grass pasture, firm and dry					
	high	124	—	223	319
	medium	130	+5	229	325
	low	150	+21	249	344
Grass pasture [2] wet and spongy					
	high	163	---	262	357
	medium	182	+12	281	375
	low	237	+45	336	429
Plowed ground, dry and cloddy					
	high	238	---	337	430
	medium	271	+14	370	464
	low	314	+32	413	506

[1] Adapted from Ramsower (1917). Draft on level ground was measured, draft on sloping ground was estimated by the authors as the draft on level ground plus an estimated draft from slope.

[2] Low wheels cut ruts 3- to 4-inches deep.

Comparisons of wagon draft while using steel wheels of varying diameter were made in Missouri in the early 1900's (Ramsower, 1917). Their work compared wagon draft when using high (44" front x 56" rear), medium (36" front x 44" rear) and low (24" front x 28" rear) diameter wheels over a range of surfaces. Steel tires six inches wide were used. The lowest draft was on hard and smooth surfaces (Table 4). There was little difference in draft due to wheel height on the hard surfaces. Draft increased on the gravel surface since the steel tires did not cushion the impact of stones and other obstructions. Draft increased as the wagon moved to softer road surfaces. The advantage provided by the taller tires also increased in soft ground, partially due to the longer lever arm and partially due to better flotation and less tire sinkage.

Table 5. Comparison of draft for wagons with pneumatic tires (6.00-16, 30 psi) or four-inch steel tires (24 inch front, 28 inch rear)[1].

	Draft, lbf/1000 lb GVW			
Surface	**Level ground**	**% change**	**10% slope**	**20% slope**
Gravel road				
Pneumatic	42	—	142	238
Steel	91	+117	191	285
Hay sod				
Pneumatic	70	---	170	264
Steel	125	+79	224	320
Firm soil				
Pneumatic	101	---	200	295
Steel	158	+56	257	352

[1] Based on research at Tillers International.

Taller tires increase bearing area and reduce draft.

The wagon draft measured at Tillers (Table 5) compares favorably with that from Missouri when similar tires were used. Each group measured draft on a gravel road at about 90 lbf/1000 lb GVW. Our measurement of draft on firm soil (158 lbf) was similar to their findings on a firm and dry grass pasture (150 lbf/1000 lb GVW).

An efficient way to increase tire/soil contact area is to use wider tires. We expect less tire sinkage and rutting with wider tires. Ground contact increases in direct proportion to tire width. Increasing tire width from 4 inches to 6 inches increases ground contact area by 50%.

Table 6. Draft per 1000 lb of gross vehicle weight (GVW) for a wagon with narrow (1½ inch) or wide (6-inch) steel tires.

		Draft, lbf per 1000 lb GVW [1]			
Surface	**Tire**	**Level ground**	**% change**	**10% slope**	**20% slope**
Soil, dry, hard, no ruts					
	wide	53	—	153	253
	narrow	69	+30	169	269
Gravel, dry, dusty					
	wide	79	---	179	279
	narrow	120	+52	219	314
Gravel, dry, no ruts					
	wide	82	---	182	282
	narrow	109	+33	209	309
Soil, sticky on top, firm underneath					
	wide	154	---	253	348
	narrow	103	-33	202	297
Meadow [2], soft					
	wide	153	---	252	345
	narrow	210	+37	309	404
Meadow [3], moist					
	wide	162	—	261	355
	narrow	285	+76	384	476

[1] Adapted from Ramsower (1917). Draft on level ground was measured, draft on sloping ground was estimated by the authors as the draft on level ground plus an estimated draft from slope.

[2] Narrow tires cut ruts 3½ inches deep, wide tires cut ruts ¼ to 1 inch deep.

[3] Narrow tire cut ruts 5 to 6 inches deep, wide tires cut ruts 1½ to 2 inches deep.

The Missouri group also evaluated the impact of tire width on wagon draft (Ramsower, 1917). The greatest advantage

A wagon loaded with loose hay weighs about 3,500 lb.

when using wider tires was on the softer road surfaces. Notice that on the meadow ground, increasing steel tire width from 1½ to 6 inches (4x) reduced tire sinkage to roughly one-fourth that of the narrow tires (Table 6).

Wide tires and tall wheels provided the greatest benefit on soft ground, but there was an exception to this rule. Narrow tires provided a lower draft than wide tires in soil that was sticky on top and firm underneath. Perhaps the sticky soil covered the inner portion of the wide tire and served as unneeded ballast while the narrow tires simply cut through the mud to the firm soil below without accumulating and lifting much debris.

SUMMARY

A wide range of wheels and tires are available for farm wagons. The use of steel tires increases draft 50% to 100% compared to pneumatic tires, but choosing taller wheels or wider tires can increase bearing area, reduce tire sinkage and rutting, and reduce wagon draft. Selecting the best wagon for the conditions at hand can ease the burden of your working animals.

REFERENCES

ASAE Standards 2000. D497, Agricultural machinery management data. ASAE: St. Joseph, MI.

Hunt, D. 1995. Farm Power and Machinery Management, 9th edition. Iowa State University Press, Ames, IA.

Ramsower, H.C. 1917. Farm Equipment and How to Use It. Reprinted in 2001: The Lyons Press.

SUGGESTED READING

Conroy, D. 1995. Advanced Training Techniques for Oxen. Tillers International, Kalamazoo, MI.

Conroy, D. 1999. Oxen--A Teamsters Guide. Rural Heritage, Gainesboro, TN

Harrigan, T.M. and R.J. Roosenberg. 2002. Estimating Tillage Draft. TechGuide 2G-210. Tillers International, Kalamazoo, MI.

Harrigan, T.M., R. Roosenberg, D. Perkins and J. Sarge. 2002. Estimating Sled and Stoneboat Draft. TechGuide 2G-211. Tillers International, Kalamazoo, MI.

Harrigan, T.M., R. Roosenberg, D. Perkins and J. Sarge. 2002. Estimating Logging Draft. TechGuide 2G-212. Tillers International, Kalamazoo, MI.

Harrigan, T.M., R. Roosenberg, D. Perkins and J. Sarge. 2002. Estimating Sicklebar Mower Draft. TechGuide 2G-214. Tillers International, Kalamazoo, MI.

Harrigan, T.M., R.J. Roosenberg, D. Perkins and J. Sarge. 2002. Estimating Manure Spreader Draft. TechGuide 2G-215. Tillers International, Kalamazoo, MI.

Keith, M. 1992. Training Young Steers. Tillers International, Kalamazoo, MI.

Ludwig, R. 1995. The Pride and Joy of Working Cattle. Pine Island Press, Westhampton, MA.

Roosenberg, R. 1992. Neck Yoke Design and Fit: Ideas from Dropped Hitch Point Traditions. Tillers International, Kalamazoo, MI.

Roosenberg, R. 1997. Yoking and Harnessing Single Cattle. Tillers International, Kalamazoo, MI.