ESTIMATING OX-DRAWN IMPLEMENT DRAFT

by

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Well-conditioned oxen are capable of working draft loads equal to 10-12% of their body weight throughout the day and greater loads for short periods of time. This bulletin provides a range of normal draft requirements for tillage implements, wagons, sleds, stoneboats and some commonly used logging implements. This information can help the teamster plan fieldwork, match implements with the power available and establish realistic guidelines for animal performance.

INTRODUCTION

An ability to estimate implement draft is important in working draft animals. A well-matched team and implement allow efficient use of time for fieldwork. 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.

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. The draft load that

Our Need to Know . . .

In writing this article 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 power 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. ***Tillers*** hopes this article will help all teamsters empathize with the tasks they are presenting to their animals.

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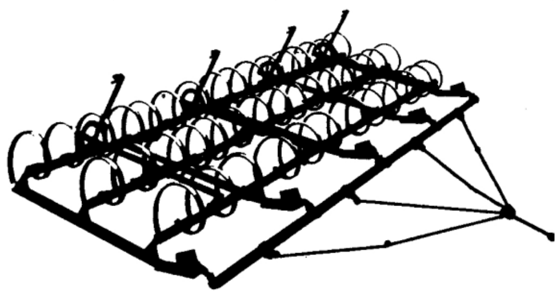
the team feels as tension in the towing chain varies with the implement or tools used and the tractive surface over which they are drawn. It is not generally well understood how the selection of tools and implements can influence draft.

POWER MEASUREMENT

Draft power is often described in units of horsepower (hp). The horsepower unit was first described by James Watt in England in the late eighteenth century. Watt found that an average horse could lift 366 lb of coal out of a mine at the rate of one foot per second (366 ft-lb/sec). In seeking to rate his steam engines in terms of the competition of the day--the horse--but not wanting to overstate the ability of his engines, Watt arbitrarily



inflated the power delivered by a horse to 550 ft-lb/sec. The ability to move 550 lb with a velocity of one foot per second has been used ever since as the unit of horsepower.

Power delivery is a measure of the work accomplished. It is not always a suitable measure of a team's effort. In equation form:

Hp = (force, lb. X distance, ft) / time, sec

Power delivery is increased by increasing force (draft, lbf), or speed (ft/sec). In pulling competitions victory means power delivery. But a team may struggle mightily to move a heavy load and if the load does not move, no power is delivered. For most teamsters, draft alone is more descriptive and meaningful than power delivery in managing and training draft animals. Draft measured as tension in the towing chain is independent of time and distance.

TILLAGE DRAFT

Draft is the force (pounds-force, lbf) required to move an implement in the direction of travel. Total draft of most tillage implements is primarily resistance to soil and crop residues. Under normal conditions wide variations in draft of tillage tools are common both within and between soil textural groups due to soil moisture, soil strength, residue cover and other physical characteristics. Dry, consolidated soil generally provides greater resistance to tillage tools than the same soil when moist and friable.

The tractive surface in the field can vary from firm and compact to soft or muddy. Loose soil increases rolling resistance of wagon wheels and increases slippage of the animal's hooves. And, draft increases when moving up a slope. These are normal variations in field conditions that can greatly vary the demand on working animals.

Table 1. Expected range in draft for shallow tillage tools.

		Expected Draft		
Implement	**Unit**	Low	Avg	High
Spike-Tooth Harrow	lbf/ft	30	40	50
Roller-Packer	lbf/ft	20	40	60

Source: *ASAE Standards, D497, Agricultural machinery management data.*

In estimating tillage draft, soils can be conveniently categorized as fine, medium or coarse rather than using the traditional but more confusing classifications such as clay, sandy-loam or silty-clay-loam. Fine textured soils can be considered as high in silt and clay, medium textured are loamy soils and coarse textured soils are sandy soils. Implement draft generally increases in going from coarse to fine textured soils.

Tillage draft standards published by the American Society of Agricultural Engineers (ASAE) can be used to predict draft for common ox-drawn tillage tools when adjusted for soil texture, speed and depth of operation. Typical draft per foot of implement width for a few such implements is provided in Table 1. These values can be adjusted within the range given based upon local experience or when conditions are likely to cause a substantial change from the normal draft requirements.

Draft also depends upon the depth of tillage. Expected draft (lbf/ft of implement width or lbf/row) for a range of tillage tools operating in various soils at about two miles per hour is listed in Table 2. Some tillage tools are used for both primary and seedbed tillage. Primary tillage is an initial soil working operation designed to shatter consolidated soil and bury crop residue. Seedbed tillage generally follows primary tillage. Some goals of seedbed tillage are to level and firm the soil, incorporate fertilizer and control weed growth.

Table 2. Expected range in draft for common tillage tools in a range of soils.

	Draft, lbf/ft machine width		
	Coarse	Medium	Fine
Moldboard Plow			
6-inch depth	320	490	740
8-inch depth	420	650	990
Disk, Tandem			
3- to 4-inch depth	140	160	180
Disk, Single Gang			
3- to 4-inch depth	55	65	75
Spring-Tooth Harrow			
2-inch depth	90	115	135
3-inch depth	130	170	195
	Draft, lbf/row		
	Coarse	Medium	Fine
Row Crop Cultivator			
2.5-inch depth	85	115	135
Disk Bedder-Ridger			
3-inch depth	90	100	110
5-inch depth	145	165	190

Based upon: *ASAE Standards, D497, Agricultural machinery management data.*

Moldboard plowing is a high draft primary tillage operation. When plowing one acre to a depth of six-inches, a plow will cut, lift and turn more than two million pounds of soil. A normal draft for a moldboard plow ranges from 320 to 990 lbf per foot of plow width.

Disk draft can be variable and difficult to predict. Draft is largely dependent upon depth of tillage, but depth varies with disk weight, disk angle, blade spacing and diameter, soil strength, crop residue cover and many other factors. Light tandem disks typically have a blade spacing of 7.5 to 9 inches, a gang angle of 16 to 20 degrees, and weigh about 200 lb per foot of machine width. A normal draft for a tandem disk varies from about 140 to 180 lbf per foot of width.

Single disk gangs are generally lighter and carry a less aggressive cutting angle than tandem disks. A normal draft ranges from 55 to 75 lbf per foot of cutting width.

These tillage draft guidelines can be used to help teamsters select and match implements with the draft power available.

Example 1**:** Select a moldboard plow and spring-tooth harrow suitable for a 3,600 lb team on a coarse (sandy) soil.

Answer: A normal working draft (10% to 12% of body weight) ranges from 360 to 430 lbf (3,600 lb * .10 = 360 lbf; 3,600 lb * .12

= 430 lbf). Implement draft within this range allows reserve power to overcome

Moldboard plow: A normal working depth for a moldboard plow is one-half the width of cut. Referring to Table 2, a normal draft for a 12-inch moldboard plow at a six-inch depth in a coarse soil is 320 lbf. This level of draft is well within the normal working range for a 3,600 lb team. In medium or fine textured soils a teamster can reduce draft by decreasing depth or width of cut.

Spring-tooth harrow: Referring to Table 2, an average draft for a spring-tooth harrow in a coarse soil is 90 to 130 lbf per foot of implement width. Assuming a mid-range draft of 110 lbf per foot, a working draft of 430 lbf will allow selection of a 4-ft harrow (430 lbf / 110 lbf/ft = 3.9 ft).

SLED AND STONEBOAT DRAFT

Most teamsters have a sled or stoneboat. They are easily built, inexpensive, and great tools for hauling stones, firewood, feed and most everything else around the farmstead. And, since they are small, maneuverable and capable of carrying both light and heavy loads, they are excellent implements for use in training and conditioning draft animals. But how large a load should a sled or stoneboat carry for efficient training and conditioning? How much of the load does the team feel as tension in the towing chain? And how do ground conditions affect draft?

Research was done at Tillers' training center to compare sled and stoneboat draft over a range of surfaces. Specific objectives were to measure an average draft and develop rules-of-thumb for estimating draft of sleds and stoneboats on: 1) a gravel road, 2) an alfalfa-grass sod, 3) a firm soil, and 4) a tilled, settled soil.

Draft measurements were made using a simple hydraulic pull meter--a closed-circuit fluid system that consisted of a hydraulic

normal variations in draft.

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).

Measurements of draft were made with both a sled and a stoneboat over a range of ground conditions. The gravel road was firm and compact with little exposed aggregate. The alfalfa-grass sod was firm but moist. The firm soil was a loamy soil covered with soybean stubble from the previous cropping season. The tilled, settled soil was a loam soil recently spring plowed, fit and seeded to oats.

Stoneboats are typically about three-feet wide and six- to eight-feet long. Their low profile makes them ideal for loading heavy stones by rolling them onboard rather than having to lift them off the ground. Their large contact area minimizes ground pressure which improves flotation in soft and tilled soil.

A sled consists of an elevated platform on two parallel skids or runners. Carrying the load on narrow skids increases the ground pressure at the skid/soil interface. This helps prevent sideslip when moving

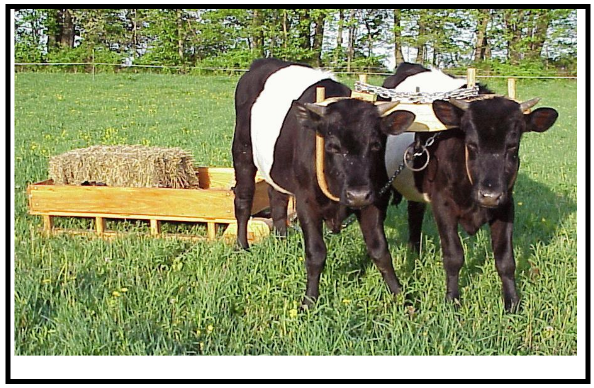
across a slope and improves tracking in snow. But concentrating the load on skids can also increase sinkage, motion resistance and draft in soft and tilled soils.

In our draft trials the combined weight of the sled or stoneboat plus the load was 1,000 lb. The sled had skids measuring nine-feet long by four-inches wide. This contact area provided for an average ground pressure of 1.2 lb/in^2. The stoneboat measured thirty-five inches wide by eight-feet long for an average ground pressure of 0.3 lb/in^2.

There was little difference in draft between the sled and stoneboat when

Differences in draft between the sled and stoneboat increased as we moved to softer surfaces. On firm soybean ground the sled runners cut in a small amount but the stoneboat caused little disturbance. In moving and compressing soil the sinkage of the skids increased motion resistance and sled draft to 576 lbf compared to 459 lbf for the stoneboat. An average draft was about 46% of the load for the stoneboat and about 58% for the sled.

hauling the load over a gravel road. An average draft was 382 lbf for the stoneboat and 379 lbf for the sled (Table 3). On this hard surface about 38% of the total load was transferred to the team as tension in the towing chain.



On the alfalfa-grass sod an average stoneboat draft was 460 lbf while an average sled draft was 419 lbf. The hay field was firm enough so that neither implement formed ruts or noticeable depressions in the soil. On this firm surface the motion resistance of the concentrated load on the sled runners was less than the resistance offered by the low/pressure, large contact area of the stoneboat. In the hay field, 42% of the sled load and 46% of the stoneboat load were transferred to the team as tension in the towing chain.

The greatest difference in draft between the sled and stoneboat was on the tilled, settled soil of a freshly seeded oat field. The sled runners cut in about an inch while the stoneboat was able to float on the soil surface with little disturbance. The average stoneboat draft was 485 lbf. Draft was about 30% higher (635 lbf) when using the sled.

Concentrating the load on sled runners increased sinkage and motion resistance on soft and tilled soils. The team experienced a 68% increase in draft in going from the gravel road to the oat field. The greater flotation of the stoneboat lead to only a 27% increase in draft as the team moved from the gravel road to the tilled soil.

Table 3. Draft and power output for a 3,850 lb ox team drawing a 1,000 lb load.

	Draft				
	Lbf	% Load	% Body Wt	MPH	HP
Sled					
Gravel Road	379	38	10	2.3	2.3
Hay Field	419	42	11	1.8	2.1
Firm Soil	576	58	15	2.2	3.4
Tilled, Settled	635	64	16	2.0	3.4
Stoneboat					
Gravel Road	382	38	10	2.2	2.2
Hay Field	460	46	12	2.1	2.6
Firm Soil	459	46	12	2.0	2.4
Tilled, Settled	485	49	13	2.0	2.6

These sled and stoneboat draft measurements can be used as guidelines in matching a load with the power available:

Example 2: In training and conditioning a young team of working steers a teamster seeks to load a stoneboat to achieve a load measured as tension in the towing chain equal to 12% of the team's body weight. Each steer weighs about 400 lb. The load will be hauled over level pasture and hay ground. Estimate a combined weight for the load and stoneboat to achieve this level of draft.

Answer: 209 lbs.

Solution: The team weighs 800 lb. Twelve percent of the teams body weight equals 96 lb (800 lb*.12 = 96 lb). Referring to Table 3, stoneboat draft (lbf) on hay ground will be about 46% of the weight of the stoneboat. In order to achieve the desired draft, the total weight of the stoneboat plus the load should be 209 lb (96 lbf/0.46 = 209 lb).

Example 3: Estimate a representative draft for a 750 lb sled on tilled, settled ground.

Answer: 480 lbf.

Solution: Referring to Table 3, sled draft on tilled, settled ground will be about 64% of the total load. Sled draft measured as tension in the towing chain will be about 480 lbf (750 lb*0.64 = 480 lb).

LOGGING DRAFT

Many teamsters enjoy working in the wood lot. Logging is a great activity for training and conditioning draft animals as they learn to maneuver and haul large and small loads over changing conditions. Commercial loggers are able to remove logs with little damage to the forest floor or standing timber when using draft animals. Noncommercial logging of small wood lots provides firewood and vigorous exercise for the team and teamster.

Estimating logging draft requires a knowledge of the weight of logs and an understanding of how logging tools and implements can influence draft. Logs are heavier than they appear. A freshly cut hickory log 12 feet in length and 18 inches in diameter weighs about 1,500 lbs. The draft load that the team feels as tension in the towing chain varies with the implement or tools used and the tractive surface over which the logs are drawn. It is not generally well understood how the selection of logging implements can influence draft.

Research was done at Tillers' training center to compare logging draft using common tools and implements over both bare and snow-covered ground. Specific objectives were to measure an average draft and develop rules-of-thumb for estimating logging draft using: 1) tongs, 2) a go-devil, and 3) an arch. Timber varies in density (lb/ft^3) based on wood species and moisture content. Freshly cut timber contains considerable moisture and can weight twice as much fresh as when air-dry (<20% moisture). Typical densities for several species of timber common throughout the Northeast and upper Midwest are provided in Table 4. Since uncut logs dry slowly, the green density is generally most representative of recently sawn or down timber.

Table 4. Typical densities of green and air-dry timber.

	Density, lb/ft^3	
Wood	Green	Air-Dry
Beech	54	46
Cherry	46	36
Cottonwood	60	29
Elm	56	36
Hickory	70	54
Sugar Maple	58	46
Red Oak	63	46
White Oak	61	49
Red Pine	34	33

Based on: Forest Products Laboratory. *Wood Handbook: Wood as an Engineering Material*. Agric. Handbook 72. Washington DC:USDA; rev. 1987.

Logging has long been a winter activity for farmers in the upper Midwest and Northeast. It is a productive activity that does not conflict with other farming operations, cold weather is suitable for the strenuous effort required, insects are not a problem in the cold, and frozen and snow-covered ground facilitates the movement of heavy loads over uneven ground. While many implements were available for transporting logs, we tested two in mid-February on snow-covered ground: 1) logging tongs, and 2) a go-devil, also known as a logging lizard.

A logging tong is a simple device used

to grasp the log and hold it fast in skidding over the ground. Tongs are often used in skidding logs a short distance to a staging area for loading on a wagon or sled. Tongs are a quick-hitch option compared to wrapping a chain around the circumference of the log. A go-devil consists of two angled skids and an elevated platform to carry the hitch end of the log. The angled skids allow the implement to deflect off stumps and other obstructions. Elevating the hitch end of the log reduces ground contact, friction and motion resistance, prevents the butt of the log from catching on roots or stumps, and helps keep the log clean.

When using the logging tongs to skid a 1,475 lb oak log, we used a beveled cut on the leading edge of the butt of the log to help keep it from catching on roots and other obstructions. The ground was frozen, level, and covered with three to five inches of settled snow. An average draft with logging tongs was 845 lbf, 57% of the weight of the log. Considerable effort was needed to pull the log as tension in the

towing chain was 22% of the team's body weight. Power delivery was 4.6 hp (Table 5).

How heavy is that log?

Logs vary according to size, species and moisture content. In order to calculate the weight of a log, first calculate it's volume (ft^3) and then multiply the volume by the density (lb/ft^3, from Table 4).

Example: Estimate the weight of a freshly cut Hickory log measuring 12 ft long and 18 inches in diameter.

Answer: The radius is one-half the diameter. Units are feet:

$$\text{Radius (ft)} = 9 \text{ in.}/12 \text{ in. per ft} = .75 \text{ ft}$$

$$\text{Vol } (ft^3) = 3.14 * \text{rad } (ft)^2 * \text{length (ft)}$$

$$\text{Vol } (ft^3) = 3.14 * (.75)^2 \text{ ft} * 12 \text{ ft}$$

$$21.2 \text{ ft}^3 = 3.14 * .56 \text{ ft}^2 * 12 \text{ ft}$$

$$\text{Volume} = 21.2 \text{ ft}^3$$

Log weight is volume (ft^3) multiplied by the density (lb/ft^3) of freshly cut (green) Hickory

$$\text{Weight (lb)} = \text{vol } (ft^3) * \text{density } (lb/ft^3)$$

$$\text{Weight (lb)} = 21.2 \text{ ft}^3 * 70 \text{ lb/ft}^3$$

$$\text{Weight} = 1{,}484 \text{ lb}$$

Elevating the hitch end of the log on a go-devil reduced ground contact, friction, and motion resistance. An average draft was 724 lbf, a 14% reduction compared to using the tongs. Draft as tension in the towing chain was 49% of the weight of the load, an effort equal to 19% of the body weight of the team.

Table 5. Logging draft and power delivery with a 1,475 lb oak log.

	Draft lbf	% Load	% BW	mph	hp
Go-devil					
Hardpack	284	19	7	3.4	2.6
Snow	724	49	19	2.1	4.1
Arch					
Gravel road	590	40	15	2.2	2.2
Hay ground	592	40	15	2.1	2.1
Tongs					
Hay ground	806	55	21	2.1	4.5
Snow	845	57	22	1.9	4.2

We also used the go-devil to draw the log over a hard-pack snow surface. This was packed snow over a gravel road, not quite as hard as ice but much harder than the settled snow in the field and wood lot. An average draft was 284 lbf. Tension in the towing chain was equal to 19% of the weight of the log, 7% of the team's body weight. Draft increased 155% in going from the hard-packed snow on the road to the settled snow in the field. It is no wonder why loggers were willing to spend considerable time and effort in packing and icing down winter logging trails.

In late April we measured draft using logging tongs on bare alfalfa-grass hay ground. We also used a logging arch to draw the 1,475 lb log over hay ground and a gravel road. A logging arch is a wheeled implement with a raised hitch point that allows the arch to straddle the log and raise the hitch end of the log off the ground for transport. Raising the hitch end of the log reduces ground contact, friction, and motion resistance. This reduces draft, keeps the log cleaner than when ground skidding and reduces rutting and ground disturbance.

The logging arch we used was built by Fred Herr, a local horse logger. The arch weighed about 750 lb, the hitch point was 26 inches above the axle, and the tongue weight was 90 lb. Logging tongs were used to

grasp the hitch end of the log for transport. Under a load the tongue weight came off the yoke as it counterbalanced the rearward torque of the log.

When drawing the log with the logging arch there was little difference in draft when traveling on a gravel road or on the alfalfa-grass hay ground. An average draft was 592 lbf on the gravel road and 590 lbf on the hay ground. This includes the draft of the arch plus the log. Draft as tension in the towing chain was 40% of the weight of the log. This was a draft load equal to 15% of the team's body weight.

We also used the tongs to draw the log over an alfalfa-grass sod. The ground was firm but moist. Tension in the towing chain was 806 lbf, a draft load equal to 55% of the

Example 5: Compare draft for an 1,800 lb log when using logging tongs and a logging arch. The log will be hauled across a level, firm sod.

Answer: 720 lbf with the logging arch, 990 lbf with the logging tongs.

Solution: Referring to Table 5, about 40% of the weight of the load is transferred to the team as tension in the towing chain when

weight of the load and 21% of the team's body weight. Surprisingly, draft in the snow (846 lbf) was about 5% higher than on bare hay ground. The sod likely provided more friction per unit area, but the log sank in the snow and contacted a much larger area. Even though we made a beveled cut on the butt of the log, it still plowed and compressed snow in cutting a path. Motion resistance was greater in the snow than on the hay sod.

In comparing draft on the hay sod when using the logging arch (590 lbf) with draft when using the tongs (806 lbf), it appears that one could increase the weight (lb) of the load by 36% when using an arch and achieve the same draft load (lbf) as when using tongs. Use of an arch could increase productivity by one-third with no additional effort required of the team.

These logging draft measurements can be used as guidelines in matching a load with the power available:

Example 4: In training a young team, a teamster seeks to limit an average draft measured as tension in the draft chain to 300 lbf. Logs will be hauled across a level snow surface using a go-devil. Estimate the weight of the largest log allowable.

Answer: About 600 lb.

Solution: Referring to Table 5, about 49% of the weight of the load is transferred to the team as tension in the towing chain when using a go-devil on a level, snow-covered surface. 300 lbf divided by .49 equals 612 lb.

using a logging arch, 55% when using logging tongs. 1,800 lb * .40 = 720 lbf (logging arch), 1,800 lb * .55 = 990 lbf (logging tongs).

WAGON DRAFT

Logs are often hauled a short distance to a staging area and then loaded on a wagon for transport. 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 will increase considerably when going from a hard surface to tilled soil.

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.

Pulling up an incline increases draft. A slope is often described as a percentage and is calculated as the ratio of rise to run. A 10% slope indicates a one foot vertical climb for each ten foot of horizontal run. Total draft for a hay wagon pulled up a 10% slope is approximately equal to the force needed to overcome rolling resistance plus about 10% of the gross vehicle weight (GVW, weight of the wagon plus the weight of the load). Uphill draft can quickly exceed the ability of a team.

Table 6 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 ASAE. 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.

Table 6. Predicted wagon draft per 1,000 lb GVW with a range of surface, slope 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 provides 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.

Table 7. Draft and power output for a 3,850 lb ox team drawing a 4,000 lb wagon over 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

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. Tillers' 3,850 lb team of oxen, Lewis and Clark, 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 7.

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, reduces tire sinkage and reduces 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 6). 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%.

These tillage and wagon draft guidelines can be used to help teamsters select and match implements with the draft power available:

***Example 6*:** Estimate draft for a 1,500 lb wagon with 6.00-15 tires loaded with 2,500 lb of hay (4,000 lb GVW) on level hay ground.

Answer: About 360 lbf

Solution: Referring to Table 6, an average draft on hay ground will likely vary between 57 lbf (hard pasture) and 118 lbf (firm soil) per 1,000 lb GVW. Assuming a mid-range draft of 90 lbf, wagon draft (4,000 lb GVW) will be about 360 lbf (4 * 90 lbf).

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