TIRES OR TRACKS IN CANE TILLAGE

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ABSTRACT

Availability and price trends of tractor fuel encourage sugar cane producers to intensify their search for more efficient use of field tractor power. A simplified analysis of two-wheel drive (2-WD), four wheel drive (4-WD), and track type tractors (TTT) are currently best suited and is outlined by physical parameters determined by power, speed and weight. Tractor efficiency, power efficiency, matching implement loads, owning and operating cost considerations, plus the effects of tractor and implement weight on plant root development are discussed.

Wheel tractors are well adapted to tillage, transport, landforming, cultivation, weed control and other applications where drawbar loads are medium to light and their mobility is a requisite. Current direct drive tract-type tractors are well adapted to application requiring high drawbar pulls, maximum fuel efficiency, minimum surface compaction and long life. There is a great need for more careful matching of tractor power, weight, and speed with implement drafts to obtain higher production at lower costs to help alleviate the pressures from mounting fuel and equipment costs while sugar prices are depressed.

INTRODUCTION

Many sugarcane producing countries do not have their own source of fossil fuel and feel the adverse impact of high costs of imported oil. Those countries having an abundance of fuel can now receive such a favorable price by exporting their surplus fuel. It becomes expedient for all cane producers to intensify their search for more efficient use of field tractor power.

Tractor users are often confused by conflicting recommendations concerning the type and size of tractor for specific applications in agriculture. Much of this confusion results from the:

1. Efforts to extend practices common in temperate climates where shallow rooted crops dictate tillage speeds up to 10 km/h (6.2 mph) with light draw-
bar loads, to other areas where deep rooted crops need deep tillage which is most efficiently accomplished at lower speeds and higher drawbar pulls.

2. Use of different power ratings including maximum engine, flywheel, power takeoff, drawbar or concrete, without clearly identifying which power is used on what surface, at what speed.

3. Users' lack of information concerning implement loads including accurate owning and operating cost data.

Experience during the past decade indicates that two-wheel drive (2-WD), four-wheel drive (4-WD), and track-type tractors (TTT) all have their place in our search for improved efficiency in producing food and fiber.

DISCUSSION

Parameters

Under normal tractive conditions, agricultural drawbar pulls below 3000 kg (6600 lbs) can be efficiently supplied by 2-WD tractors. However, if compaction, traction, or flotation is critical, it may be advantageous to use a 4-WD or a TTT for these low drawbar pulls. Selection of 4-WD or TTT for drawbar loads over

![Figure 1. Speed and drawbar pull relationship of tired tractors.](image-url)
3000 kg (6600 lbs) are usually determined by the speed of the work. Speeds up to 7 km/h (4.4 mph) favor the TTT where speeds over 8 km/h (5.0 mph) favor the 4-WD.

Basic information from the Manitoba Traction Tests (Friesen et al.), Bowers Rule (Bowers), and years of field experience, were drawn upon for development of the following simplified analysis to be used as an aid in choosing the proper tractor for specific agricultural applications. Fig. 1 shows speed plotted on the horizontal scale and drawbar pull on the vertical scale. Arrow (1) is one parameter for rubber tired tractors operating at speeds down to 7 km/h (4.4 mph) at drawbar pulls not exceeding about 3000 kg (6600 lbs) to maintain reasonable service life. Arrow (2) indicates the lower practical limit of approximately 7 km/h (4.4 mph) where high drawbar loads can be maintained for a 4-WD tractor up to approximately 7000 kg (15,400 lbs). Today's 4-WD tractors capable of sustained drawbar pulls of 7000 kg must weigh over 16,500 kg (36,000 lbs) to produce these high pulls working on average ground conditions. Rubber tired tractors of this weight create compaction problems in many heavy soils.

Where deep tillage is required for deep rooted crops, the TTT is more efficient because in these applications, high drawbar pulls are developed as indicated by arrow (3). For these pulls, minimum tillage speed is about 3 km/h (1.9 mph).

![Figure 2. Work zones of 2-WD, 4-WD, and TTT.](image-url)
to a maximum of about 8 km/h (5 mph). The TTT can develop drawbar pulls from 3000 kg (6600 lbs) to pulls in excess of 16,000 kg (35,200 lbs) at speeds below 8 km/h (5 mph) as indicated by arrow (4). These four arrows identify the approximate physical parameters dictated by horsepower, traction, weight, and speed when choosing rubber tired or track type machines using current technology. The area bounded by the four arrows identifies a zone where application of 2-WD, 4-WD and TTT may overlap. In this zone, economic and convenience factors dominate the physical parameters.

Generally, it is impractical to own both rubber tired and TTT in sufficient quantity to perform every field application with maximum efficiency. To minimize capital investment, it becomes necessary to determine which type of tractor best fits the applications. In areas where traction and compaction are critical the TTT will dominate. Where speed and mobility are required, the rubber tired tractors will dominate. Drawbar power is a function of drawbar pull and speed. Practically all of today’s agricultural tillage applications fall under 150 kW (200 h.p.) drawbar power. By superimposing a 150 kW curve on Fig. 1, and shading the areas in accordance with the parameters outlined, we have identified the three work zones for 2-WD, 4-WD and TTT in Fig. 2.

With today’s technology, agricultural applications requiring an excess of 150 kW drawbar power are rare, require high return crops to justify the capital and operating costs.

**Performance**

Sugar cane growers are interested in the tons of sugar produced per unit area per month in relation to their investment over a period of years. Consequently, they desire a tractor that will provide the best tillage operations at the lowest cost over the life of the equipment. High performance for one or two seasons is inconclusive.

Ttractive efficiency is affected by both motion resistance (Chancellor and Avlani) and slip, making it imperative to use traction data for actual field conditions. In field applications, rubber tired wheel tractors can be expected to demonstrate a drawbar pull between 30% and 50% their weight at up to 16% slip without allowing a safety factor for service life. A major portion of motion resistance of an agricultural wheel tractor in tillage applications will be rolling resistance. A typical rolling resistance for a 10,000 kg (22,000 lbs) 4-WD is about 70 kg (155 lbs) for each short ton of operating weight in average tilled soil. By applying this rolling resistance to a 10,000 kg (22,000 lbs) tractor, we may calculate a drawbar pull of 770 kg (1,700 lbs) required to overcome rolling resistance only. This pull at 6 km/h (3.7 mph) requires about 13 kW (17 h.p.) drawbar power. Assuming the rolling resistance at 10 km/h (6.2 mph) becomes 21 kW (28 h.p.) drawbar power.
Demonstrable drawbar pulls in relation to tractor weight can be estimated by applying the traction factor listed below:

<table>
<thead>
<tr>
<th>Soil Condition</th>
<th>2-WD 14-16% Slip</th>
<th>4-WD 14-16% Slip</th>
<th>TTT 3-6% Slip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loose tilled or wet</td>
<td>0.29</td>
<td>0.37</td>
<td>0.52</td>
</tr>
<tr>
<td>Medium</td>
<td>0.40</td>
<td>0.43</td>
<td>0.54</td>
</tr>
<tr>
<td>Dry Firm</td>
<td>0.49</td>
<td>0.50</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Temptation is great to match big wheel tractors with the biggest implements they can pull and still perform satisfactory tillage. Remember that to conserve drive train components, today’s wheel tractors should not be counter-weighted so continuous maximum drawbar power can be attained at actual speeds below about 7 km/h (4.4 mph). Optimum tractor performance of wheel tractors requires proper use of weight to keep slippage within economic limits. Guidelines for weighting wheel tractors in relation to p.t.o. horsepower and speed for more efficient operation on firm and tilled soils are as follows:

<table>
<thead>
<tr>
<th>Draft</th>
<th>Speed</th>
<th>Weight per pto h.p.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>9.6 km/h (6 mph)</td>
<td>50-60 Kg (110-130 Pounds)</td>
</tr>
<tr>
<td>Average</td>
<td>8.0 km/h (5 mph)</td>
<td>60-70 Kg (130-155 Pounds)</td>
</tr>
<tr>
<td>Heavy</td>
<td>6.5 km/h (4 mph)</td>
<td>70-90 Kg (155-200 Pounds)</td>
</tr>
</tbody>
</table>

Slippage varies widely with soil conditions, but should be kept below 16% for economical performance of wheel tractors. Increased ground contact provides the TTT with superior tractive efficiency, making it less susceptible than wheel tractors to adverse soil conditions. The TTT sprocket drives the tractor on metal rails making rolling resistance minimal; but, in place of rolling resistance, drag losses are encountered. This drag loss increases with speed. A guide to probable speed and drawbar pull capabilities of a TTT in relation to its operating weight is as follows:

<table>
<thead>
<tr>
<th>Drawbar Pull</th>
<th>Probable Speed Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>70% of Tractor Weight</td>
<td>3.0-4 km/h (1.9-2.5 mph)</td>
</tr>
<tr>
<td>60% of Tractor Weight</td>
<td>4.0-4.8 km/h (2.5-3.0 mph)</td>
</tr>
<tr>
<td>50% of Tractor Weight</td>
<td>4.8-5 km/h (3.0-3.5 mph)</td>
</tr>
<tr>
<td>40% of Tractor Weight</td>
<td>5.6-6.4 km/h (3.5-4.0 mph)</td>
</tr>
<tr>
<td>30% of Tractor Weight</td>
<td>6.4-8.0 km/h (4.0-5.0 mph)</td>
</tr>
<tr>
<td>20% of Tractor Weight</td>
<td>Pulled at top speeds are rarely economical applications.</td>
</tr>
</tbody>
</table>
Power train components of direct drive TTTs withstand continuous pull at low tillage speeds without sacrificing life of drive train components. Therefore, economics dictate that TTTs be loaded as near capacity as terrain and soil conditions permit. It is relatively easy to match implement loads to a TTT by applying the drawer capability of the tractor in relation to its operating weight and desired tillage speed.

**Power Efficiency**

A practical guide for estimating wheel tractor drawbar power when matching implement loads has been developed by Wendell Bowers. This "86% Rule" deviates a little from the Nebraska Test Data, manufacturers estimates, and years of field tests. The following factors are applied when p.t.o. power is considered as 1.0 and slip between 10 and 12%:

<table>
<thead>
<tr>
<th>Power</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Engine Power</td>
<td>1.16</td>
</tr>
<tr>
<td>Maximum p.t.o. Power</td>
<td>1.00</td>
</tr>
<tr>
<td>Maximum drawbar power on concrete</td>
<td>0.86</td>
</tr>
<tr>
<td>Maximum drawbar power on firm soil</td>
<td>0.74</td>
</tr>
<tr>
<td>Usable drawbar power on firm soil</td>
<td>0.63</td>
</tr>
<tr>
<td>Usable drawbar power on tilled soil</td>
<td>0.55</td>
</tr>
<tr>
<td>Usable drawbar power on soft soil</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Using this rule to estimate usable drawbar power on firm dry soil, it would require about 275 kW (368 maximum engine) power in a 4-WD to deliver 150 kW (200 h.p.) usable drawbar power. A direct drive TTT can develop this same usable continuous drawbar power with about 200 kW (270 maximum engine) power through better traction and less rolling resistance.

**Speed** and its relation to timeliness is a major factor in selecting an agricultural tractor. In the haste to complete a tillage operation care must be exercised to assure that proper tillage is accomplished at reasonable costs. Selection of proper implement size is extremely important to utilize the optimum speed for the operation in an efficient power range for the tractor. Excessive speeds to achieve maximum area coverage often result in less depth of penetration producing a poor seed bed, less safe operation, more wear and tear on the implement and higher fuel consumption. Applying average power efficiency (drawbar power divided by p.t.o. power) for all three Manitoba Traction Tests field conditions of 67% for the 4-WD, compared to 75% for the TTT, a fuel efficiency advantage for the TTT becomes readily apparent. These tests were of short duration and did not apply a factor to estimate continuous usable power.
Since the effect of speed on draft is large, it is of practical importance. An increase in speed increases draft. This trend has been sufficiently consistent so that quantitative relationships between speed and draft have been obtained using the formula from USDA Agricultural Handbook, No. 316 entitled, "Soil Dynamic in Tillage and Traction" (4). An example of this relation using a heavy duty plowing harrow in a heavy clay loam soil is shown in Fig. 3.

For example a TRCH 10x36 heavy duty cane plowing harrow working in heavy clay soil requires approximately 4,500 Kg (10,000 lbs) drawbar pull at 4.8 km/h (3 mph) resulting in 60 kW (80 h.p.) drawbar power continuous. To pull this same implement in the same cane field at the same depth at 9.6 km/h (6 mph) will require about 6,800 kg (15,000 lbs) drawbar pounds pull resulting in 180 kW (240 h.p.) drawbar power. Is the extra production attained by doubling the speed worth tripling the drawbar power required? It will require 330 kW (440 h.p.) maximum engine power to deliver 180 kW (240 h.p.) usable drawbar power in a 4 WD tractor to pull the TRCH 10x36 at 9.6 km/h (6 mph) speed. An alternative
would be to use a 188 kW (250 h.p.) maximum engine drive TTT and pull a TRCH 20x36 plow at 4.8 km/h (3mph) speed to double the production through doubling the implement width rather than doubling the speed.

**Speed** in relation to implement wear is another factor to be considered in selecting a tractor and implement. Laws of motion and kinetic energy have been known for generations, but too few have related these basic laws with increased implement costs accompanying higher field speeds. An effect of speed on the energy input that results in abrasion and breakage is pictured in Fig. 4.

![Figure 4. Implement wear vs production through increased speed](image)

This adds credence to the following statements made by Larson⁶.

1. Raising implement speed from 4 to 5 mph has doubled implement repair costs, and
2. Normal tillage with sweeps require about 4 horsepower hours per acre, increasing the tractor speed by one gear often increased the energy input by as much as 50%. (Larson⁶).

Operating too slow can result in poor pulverization whereas operating too fast increases the energy input with excessive pulverization inviting wind erosion and making soils more susceptible to crusting and sealing, affecting aeration and evaporation. Clearly, speed must be considered from viewpoints other than area
covered per unit time.

Compaction

Ground pressures of TTTs equipped for tillage with between 41 and 55 Pa (6 and 8 psi) are recognized as creating minimum compaction. Fallacies exist in the belief that we can eliminate soil compaction problems by simply reducing unit surface pressures through increased tire or track size. Improper width track shoes or unbalanced loading of TTT (Chancellor) can double the computed average ground pressure, thus approximating surface ground pressures created by dual wheels on 4-WD tractors. However, with dual wheels, the 4-WD tractor usually compacts about twice the surface area as the TTT on each pass. Another factor often overlooked is the adverse effect on water infiltration and plant root development at greater soil depths. Increasing the area of contact to compensate for increasing the total load has not solved soil compaction problems at all depths. (Taylor et al.) Soil scientists are concerned about the irreversible field damage that may result from excessive compaction. Every precaution should be exercised to keep compaction at a minimum with all tractors, especially in heavy tropical soils.

Matching Tractor and Implement

As costs rise, fuel consumption will become more critical, as will the necessity of optimizing implement loads in relation to power, weight and speed. The basic relationships covered under tractive efficiency and power efficiency must be considered when matching a tractor and implement.

It is common to start with the implement that performs the tillage operation best suited for sugar cane production in your soil and climatic conditions. Actual measurement of the drawbar pull of the implement working at optimum speed and depth in your fields is the best way to determine drawbar pull requirements. Estimating implement draft is less accurate, but most often necessary. Manufacturers provide draft or drawbar pull guides for their implements. Agricultural Experimental Stations and University Extension Services have guides that estimate implement drafts at different speeds for soil conditions in their specific territories. The drawbar power required for pulling a tillage tool can be determined by using the following formula.

\[ kW \text{ (power)} = \frac{kN \text{ (Draft)} \times \text{ km/h (Speed)}}{3.6} \]

which is the SI version of the familiar

\[ hp \text{ (horsepower)} = \frac{\text{ pounds (draft)} \times \text{ mph (speed)}}{375} \]
Factors in Bowers “86% Rule” mentioned earlier need be applied to the resulting drawbar horsepower in field condition encountered to determine the p.t.o. or engine h.p. required in a wheel tractor. Weight of the wheel tractor can be determined by using the factors discussed under tractive efficiency derived from the Manitoba traction tests.

Matching an implement to a TTT is easier. When the drawbar pull is determined, compare it to the tractor specification sheet drawbar pulls to determine which tractor will pull the implement at the desired speed. Direct drive TTTs can be expected to deliver usable drawbar powers between 72% and 78% of their p.t.o. powers depending on soil conditions. The estimated weight requirement of a TTT can be determined from the weight speed relationship reviewed under slippage and drag loss. Matching a TTT to its load is more precise and simpler to accomplish than with a wheel tractor. There is a general tendency to underload TTTs and overload wheel tractors. The basic fundamentals outlined in this presentation can be used as guides to improve utilization of investment in tractor and implements which lead to the next important consideration.

Owning and Operating Cost Considerations

Hourly owning and operating costs can vary widely and must be determined with local cost inputs. The principal owning cost is depreciation determined by subtracting the re-sale value from the landed cost and dividing by the service life in hours. Interest, insurance and taxes added to depreciation make up owning costs. The service life and hours used per year are major factors determining hourly depreciation. When dealing with capital intensive equipment, the hourly depreciation rate and residual value become major items in determining owning costs.

Operating costs consist of expenditures for fuel, filters, lubricants, grease, repairs, tire or tract maintenance, and operators wages. Tire and track costs can, under adverse soil conditions or improper application, be a substantial portion of operating costs making it extremely important to carry out good maintenance practices. There is no substitute for good reliable cost records to compare with work done and tons of sugar produced to aid in determining which field applications can be best accomplished with tractor and implement.

CONCLUSION

Current wheel tractors are well adapted to light tillage, cane transport, land forming, cultivation, weed control and other applications requiring speed and mobility. Current direct drive TTTs are well adapted to applications requiring high drawbar pulls, maximum efficiency, minimum surface compaction and long life.

Energy costs and low commodity prices are forcing careful review of field costs worldwide. There are interesting challenges and beneficial opportunities facing
us today. I hope the comments in this presentation will aid in analyzing your field tractor requirements and matching those tractors with implements to provide more sugar per acre per month at a lower cost in future years.

REFERENCES


LLANTAS O CADENAS EN EL CULTIVO DE CAÑA

LyLyG. Reeser

RESUMEN

La disponibilidad y la tendencia del precio de combustible hace que el cafiero intensifique su búsqueda de uso eficiente del poder del tractor en el campo. Un análisis simplificado de cuando debe usarse un tractor de tracción en dos ruedas (2-WD), tracción en 4 ruedas (4-WD) o de tipo de oruga (TTT) es establecido por parámetros físicos determinados por la potencia, velocidad y peso. Se discute la eficiencia de tracción, eficiencia de potencia, el implemento con la carga requerida, costos de posesión y operación además de los afectos del peso del
Los tractores de ruedas se adaptan bien a la aradura, transporte, nivelación de terrenos, cultivo, control de maleza y otros usos donde las cargas en la barra son entre medianas y livianas y su movilidad es un requisito. Los actuales tractores de oruga de transmission directa se adaptan bien para aplicaciones en donde se require alto tiro a la barra, eficiencia maxima de combustible, minima compactacion el la superficie y larga vida. Existe una gran necesidad de igualar la potencia, peso y velocidad de tractores y los implementos con el fin de obtener una produccion alta a costos bajos que alivien la presion del aumento constante de costos de combustibles y equipo, mientras los precios del azúcar continuan en depresion.