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Improvement of Tractor Performance

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IMPROVEMENT OF TRACTOR PERFORMANCE

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ABSTRACT. *Improvement of agricultural tractor performance was analyzed using the data from 926 diesel tractors tested at the Nebraska Tractor Test Laboratory from 1959 through 2002. The performance analysis included the specific volumetric fuel consumption, power per unit weight, traction coefficient, maximum torque rise, and sound level. They were evaluated based on the PTO power level and chassis type of tractor. Some of the results are: (1) The average specific volumetric fuel consumptions for the maximum PTO and drawbar powers increased by 20.5% and 23.4% to 3.47 kW·h/L and 3.01 kW·h/L, respectively, from 1959 through 2002. (2) The average maximum PTO and drawbar powers per unit weight of ballasted tractors increased 72.1% and 66.2% to 1.48 and 1.28 kW/kN from 1959 through 2002. (3) The traction coefficient increased 24.4% for 4WD tractors and 27.4% for standard tractors from 1959 through 2002, resulting in 1.02 and 0.94 for 2001-2002 respectively. In the 2001-2002 period, the average torque rise of the tractors in a PTO power range of 37-75 kW was 27.7%, which was 18.4% increase from 1992 through 2002. The tractors with greater PTO power than 187 kW had an average torque rise of 50.8%, which was 30.9% increase over the same period. The maximum sound level within the cab in the early 1970's ranged from 83.0 to 93.6 dBA and reduced to 73.5 to 88.5 dBA in the 2001-2002 period, which was about 9.3% to 21.5% reduction from 1972 through 2002.*

Keywords. *Tractor performance, Nebraska tractor test.*

In the 82 years from when the first test was conducted on the 18.6-kW (25-hp) Waterloo Boy manufactured by the Waterloo Gasoline Engine Co. in 1920 until 2002, the Nebraska Tractor Test Laboratory (NTTL) has tested a total of 1795 tractors, which is an average of 22 tractors per year. The NTTL is the only active tractor test station in North America and provides up-to-date tractor performance information which helps farmers and dealers make good marketing decisions. A performance test is required for current tractor models over 29.8 kW (40 hp) sold in Nebraska.

This paper reviewed the tractor performance evaluations of the NTTL and analyzed the performance enhancement achieved for the 43 years from 1959 through 2002. The fuel consumption, PTO power, drawbar power, torque rise and sound level were considered. This information provides state of the art performance level of agricultural tractors, which can serve as a target that less technically developed tractor manufacturers may aim at. The information is also useful for tractor manufacturers to compare the performance of their products with those of up-to-date tractors.

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NEBRASKA TRACTOR TEST

The Nebraska Tractor Test evaluated the power outlet and drawbar performance of agricultural tractors. From 1920 to 1958, belt tests were used to determine maximum, rated, and varying powers of tractor engines at the belt pulley and to measure fuel consumption at each power level. The belt test was replaced by PTO performance tests in 1959. Rated PTO power was measured at the tractor standard PTO speed of 540 or 1000 rpm and a maximum PTO power test was also conducted. The test method for the drawbar performance was also changed in 1959. The former maximum drawbar power measured at the gear known as the plow gear was changed to the maximum power measured at manufacturer's specified engine speed in each gear of the tractor. Tests for the varying drawbar performance remained the same. The NTTL expanded its testing capacity by including sound level measurement in 1970, three-point hitch performance in 1988, and replacement of the lugging ability test by the maximum torque rise test in 1992.

In 1988, the NTTL adopted a new numbering system called the Nebraska Summary Number. The earlier numbering system was used from 1920 for tractors tested at Nebraska under the Nebraska Test Code. Numbers under the new system were assigned to tractors tested at Nebraska under the OECD Test Code and also to tractors tested elsewhere and submitted for sale in Nebraska. Tractors tested at Nebraska under the Nebraska and OECD Test Codes were given both a Nebraska Test Number and a Nebraska Summary Number. Between 1988 and 2002, a total of 179 test reports carried both numbers.

PERFORMANCE ANALYSIS

The tests considered in this study included all 1113 tests conducted at the NTTL from 1959 through 2002 (Univ. of Nebraska, 1960-68, 1969-79, 1980-87, 1988-2002). Since

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Table 1. Number of tested tractors used for the performance enhancement analysis.

Tractor	Total No. of Tractors	Fuel Type			Chassis Type				
		Diesel	Gasoline	LPG	4WD	FWA	STD	Crawler	Tricycle
Tested tractors (1959-2002)	1113	926	149	38	151	245	601	58	58
Analyzed tractors (1959-2002)	926	926	–	–	149	245	458	49	25

the test methods changed in 1959 as mentioned earlier, it was impractical to compare the test results before and after 1959.

Of the 1113 tractors considered (table 1), 926 were diesel tractors, 149 were gasoline tractors, and 38 were LPG tractors. No LPG tractors were tested after 1969 and no gasoline tractors after 1979. For comparison purposes, five chassis types were considered: four-wheel drive (4WD), front-wheel assisted (FWA), standard (STD), crawler, and tricycle. The rear-wheel drive tractors with smaller front and larger rear wheels were classified as STD. Tractors having front and rear wheels of the same size or constant-mesh front axle were classified as 4WD. Tractors where the front-wheel drive can be engaged or disengaged from the operator's station were classified as FWA. Tracked and three-wheeled tractors were classified as crawler and tricycle, respectively

All 926 diesel tractors were considered as fully ballasted. The front-wheel drive was considered engaged for FWA tractors.

Tractors were compared for fuel consumption, power per unit weight, tractive coefficient, maximum torque rise, and sound level.

Fuel Consumption

Fuel consumption was compared using specific volumetric consumption, defined as the ratio between the measured power and the corresponding volume of fuel consumed per unit of time (*ASAE Standards*, 2003). Figure 1 presents 5-year average specific volumetric fuel consumption data for the PTO and drawbar tests, illustrating the trends from 1959 through 2002. The data indicated increasing fuel economy as the technology advanced.

From 1959 to 2000, fuel economy improved 20.5% for the PTO test and 23.4% for the drawbar test. As shown in figure 1, no significant improvement in fuel economy was observed in the 1960s and '70s. But, steady improvement was made since 1980. Figures 2 and 3 show that fuel economy increased slightly with tractor size. Since 1990, tractors with more than 187 kW exhibited the greatest fuel economy. Missing data in the figures indicated that no tractors in that particular power range were tested during that particular period of time.

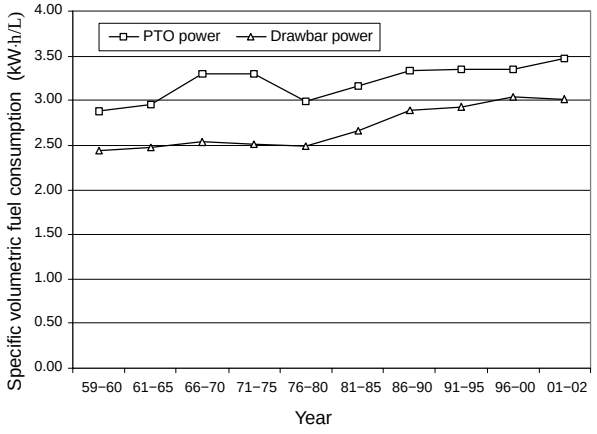

Figure 1. Trends in specific volumetric fuel consumption.

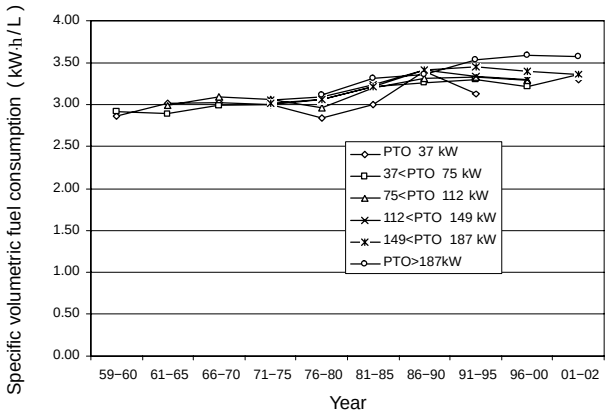

Figure 2. Specific volumetric fuel consumption for PTO power by PTO power level.

Figures 4 and 5 give the 5-year average specific volumetric fuel consumption data by chassis type. Since 1971, no tricycle tractors were tested. Tests of FWA tractors started in 1981. Since 1990, the 4WD tractor had the greatest fuel economy, then crawlers, and next the FWA. The rubber-tracked crawlers of the 1990s had better fuel economy than the steel-tracked tractors of the 1960s. The fuel economy of all tractors types increased steadily since 1970.

Power Per Unit Weight

From a traction standpoint, heavier tractors yield more traction. However, heavier tractors consume more fuel and cause compaction. Therefore, tractor weight must be heavy enough to generate the necessary traction force while minimizing the fuel consumption. The average power per unit weight of ballasted tractors increased 72.1% to 1.48kW/kN for the PTO power and 66.2% to 1.28kN/kW for the drawbar power from 1959 through 2002 (fig. 6).

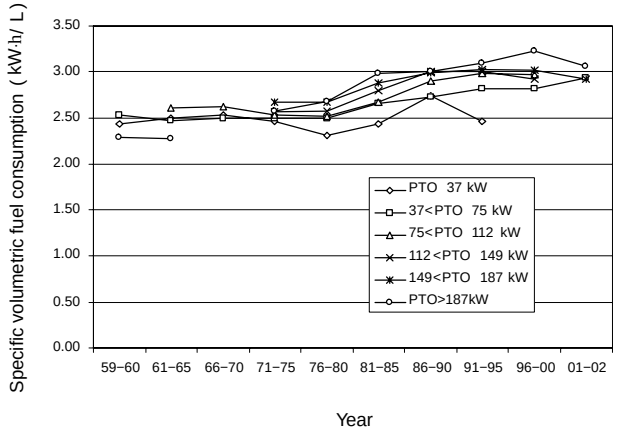

Figure 3. Specific volumetric fuel consumption for drawbar power by PTO power level.

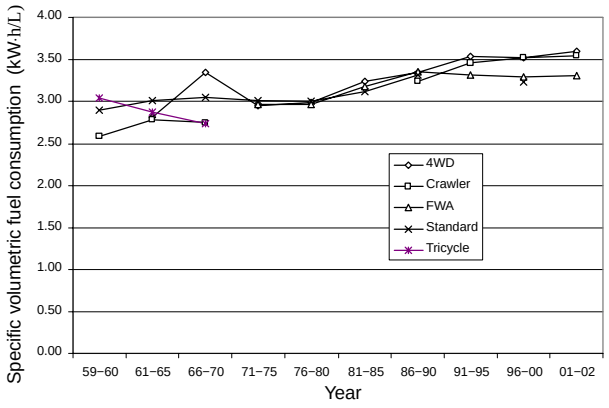

Figure 4. Specific volumetric fuel consumption for PTO power by chassis type.

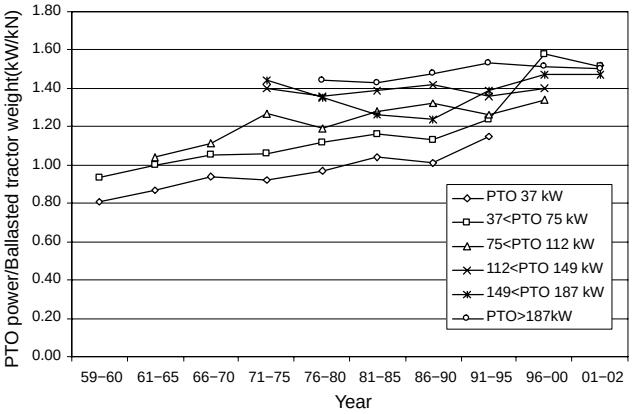

Figure 7. Average PTO power per unit weight of ballasted tractors by PTO power level.

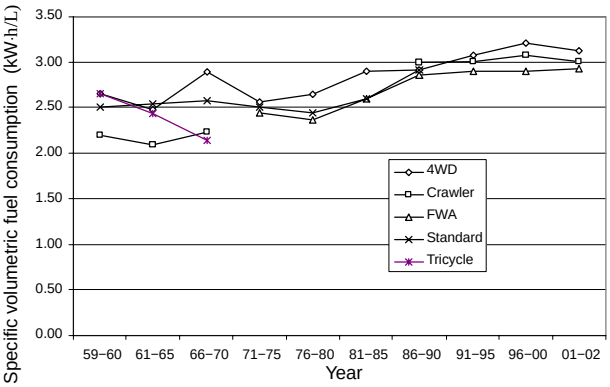

Figure 5. Specific volumetric fuel consumption for drawbar power by chassis type.

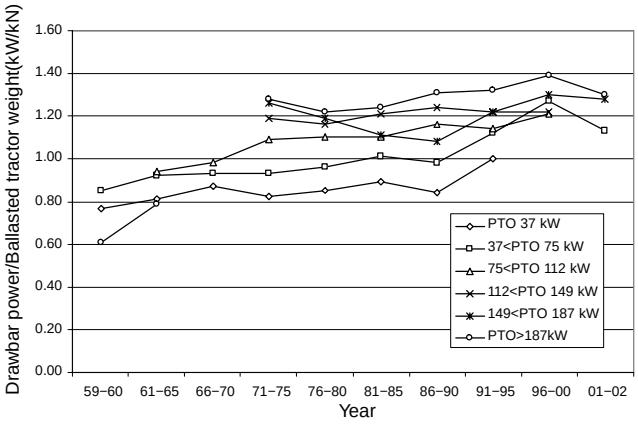

Figure 8. Average drawbar power per unit weight of ballasted tractors by PTO power level.

Figures 7 and 8 show the 5-year average PTO and drawbar power produced by unit weight of ballasted tractors in different PTO power ranges from 1959 through 2002. The power per unit weight of ballasted tractors was generally greater for tractors with higher PTO power. However, for tractors smaller than 112 kW, the power per unit weight increased more rapidly over time. Tractors in the PTO power range of 149 to 187 kW had a dip in power per unit weight between 1970 and 1996.

Over most of the years studied, 4WD and STD tractors produced more power per unit weight than other chassis types. However, after 2000, FWA tractors produced 1% to 3% more power per unit weight than the 4WD and crawler tractors as shown in figures 9 and 10. For FWA tractors, average power per unit ballasted weight increased by 27.7% for the PTO power and 34.0% for the drawbar power from 1972 through 2002. From 1959 through 2002, the power per unit weight increased steadily also for the STD tractors. 4WD tractors experienced a dip in power/weight ratio in the mid-1970s but then an upward trend occurred. From 1959

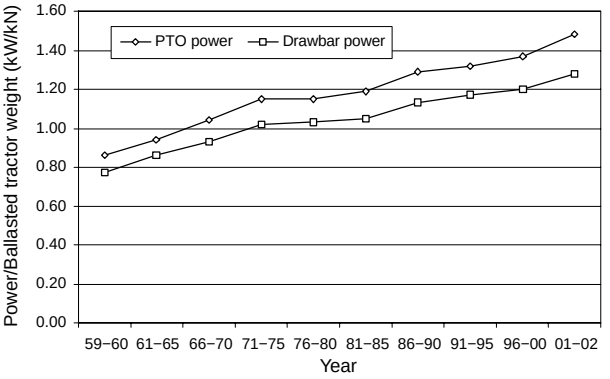

Figure 6. Changes in power produced per unit weight of ballasted tractor.

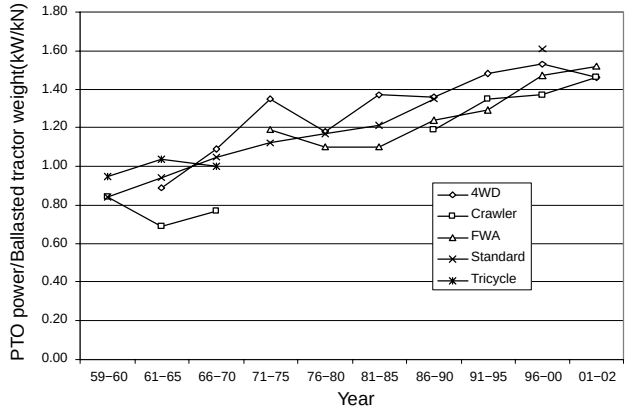

Figure 9. Average PTO power per unit weight of ballasted tractors by chassis type.

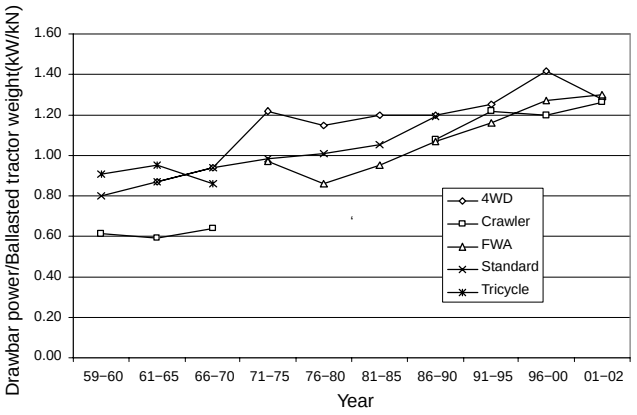

Figure 10. Average drawbar power per unit weight of ballasted tractors by chassis type.

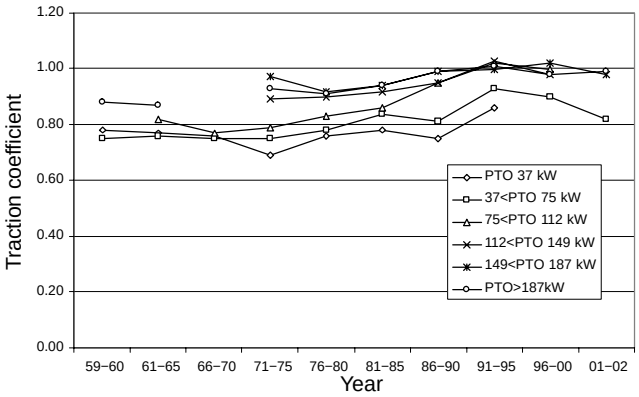

Figure 12. Average traction coefficient by PTO power level.

through 2002, the PTO power per unit weight of ballasted tractors increased by 64% for 4WD, 73.8% for crawlers, and 91.7% for STD tractors. For the drawbar power, the increase over the same period was 47.1% for 4WD, 106.6% for crawler, and 48.8% for STD tractors. The rubber-tracked tractors in the 1990s generated more power per unit weight of ballasted tractors than the steel-tracked ones in the 1960s.

Traction Coefficient

Figure 11 shows the improvement of average traction coefficient achieved from 1959 through 2002. The average traction coefficient increased by 24.1%, to 0.98 in 2002. Many tractors were evaluated in 2002 with a traction coefficient greater than 1.0 on the test track. The highest traction coefficient was found to be 1.07. The recent high traction coefficient may be a result of replacing bias ply tires with radial tires in most tractors. The concrete test track of the NTTL is 150 m long and has two180 degree turns with a radius of 15 m. In the 1960s and ’70s, little progress was made on traction performance. Since 1980, the average traction coefficient increased steadily and remained constant in a range of 0.96 to 0.98 after 1990 (fig. 11).

The greatest increase in average traction coefficient was for tractors of 75- to 112-kW PTO power (fig. 12). After the mid-90s, many tractors with the PTO power greater than 75 kW had average traction coefficients about 20% to 25% greater than those with less than 75 kW. In the 1990s, the traction performance of the tractors in a PTO power range of 37 to 75 kW decreased.

Before the mid 1980s, there was a significant difference in the average traction coefficient among the tractors of different chassis types (fig. 13). The highest traction coefficient was found to be 1.0 for crawler tractors and the lowest was 0.71 for tricycle tractors. The 4WD and STD tractors had ranges of 0.82-0.93 and 0.73-0.78, respectively. However, after 1990, the difference was reduced and the average traction coefficient increased to values greater than 0.95 regardless of the chassis type. From 2001, the 4WD tractors had an average traction coefficient greater than 1.0 possibly due to advanced technology and radial tires. The traction coefficient increased from 1960 through 2002 by 24.4% for 4WD tractors and 27.4% for STD tractors. The average traction coefficient of FWA tractors was 0.83 in 1971 and increased by 13.3% to a value of 0.94 in 2001. After 1996, the highest traction coefficient was obtained with 4WD tractors, followed by the crawler and FWA tractors.

Maximum Torque Rise

Since 1988, tractors were tested according to the OECD Test Code. The OECD Test Code required the evaluation of torque rise of the tractor engine. Before the OECD Test at the NTTL, all tractors were tested only to the Nebraska Test Code that required evaluation of the lugging ability of tractor by measuring power at 80% of the rated engine speed. During

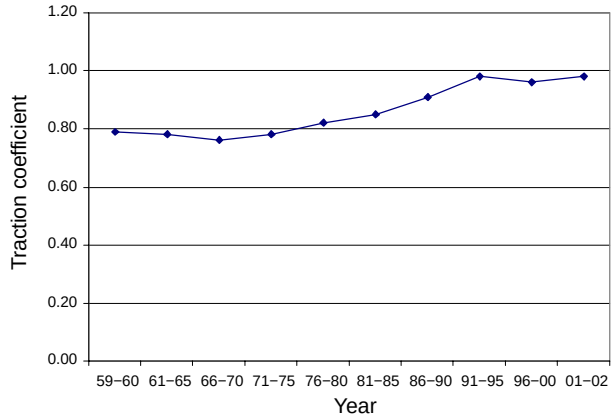

Figure 11. Average traction coefficient.

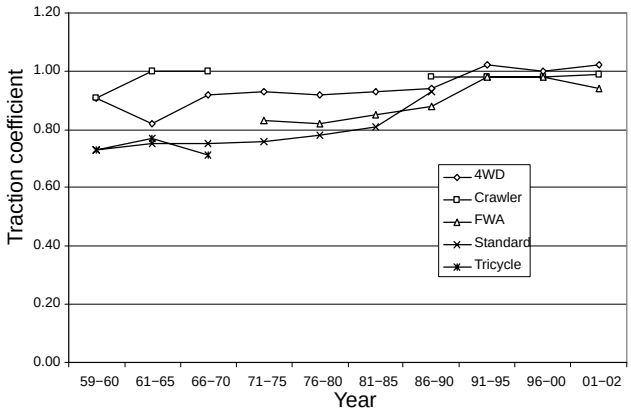

Figure 13. Average traction coefficient by chassis type.

the 1986-1990 period, tractors were subjected to either lugging ability or torque rise tests depending upon the test code requested by the tractor manufacturers. In general, the tractors of greater PTO power had larger lugging ability or torque rise. The largest difference in the torque rise between the tractors of the PTO power greater and less than 75 kW was approximately 32.8%.

The lugging ability and torque rise also increased steadily from 1972-2002 although they experienced a partial up-and down trend (fig. 14). For the 2001-2002 period, the average torque rise of the tractors in a PTO power range of 37 to 75 kW was 27.7%, which was an 18.4% increase in10 years. The tractors with PTO power greater than 187 kW had an average torque rise of 50.8%, up 30.9% over the same time period. A similar enhancement was also made on the tractors in other PTO power ranges. However, in the 2001-2002 period, average torque rise of the tractors with the PTO power less than 75 kW and of 149- to 187-kW range decreased.

Sound Level

The maximum sound level was measured at the operator's ear position inside the cab of the tractor while pulling the maximum drawbar load. Figure 15 shows the average maximum sound level with cab by the PTO power range from 1959 through 2002. The maximum sound level of 83.0 to 93.6 dBA in the early 1970s was reduced to 73.5 to 88.5 dBA in 2001-2002. The maximum sound level of the tractors with PTO power greater than 75 kW was 75 dBA in 2001-2002 and 88.5 dBA for the tractors less than 75 kW. However, the difference in the maximum sound level between the tractors of different PTO power ranges was not significant. For smaller tractors, the maximum sound level with cab was often greater than the sound level at the bystander's position outside the cab. The maximum sound levels decreased by 8% to 15% from 1972 through 2002. However, after 1990, the maximum sound level of the tractors less than 75 kW increased.

Summary and Conclusions

Agricultural tractor performance was analyzed using data from 926 diesel tractors tested at the Nebraska Tractor Test Laboratory from 1959 through 2002. Specific volumetric fuel consumption, power per unit weight of ballasted tractors, traction coefficient, maximum torque rise, and sound level were evaluated based on the PTO power level and chassis type of tractor. The following conclusions were made from the analysis.

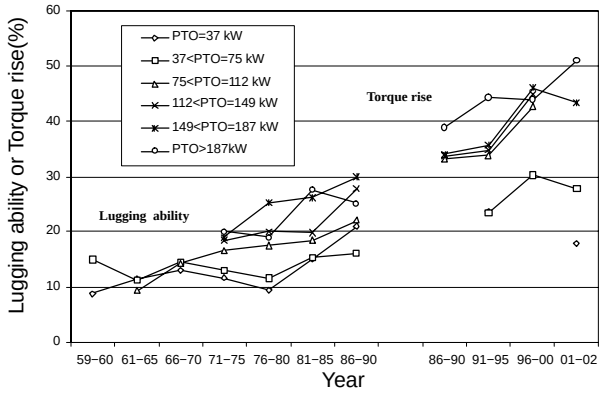

Figure 14. Lugging ability and torque rise by PTO power level.

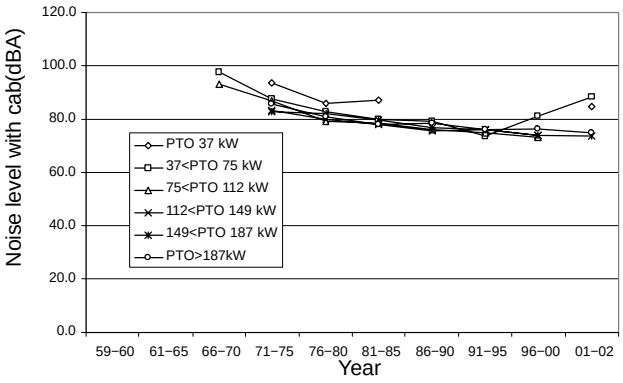

Figure 15. Maximum sound level within the cab.

Fuel Consumption

The average specific volumetric fuel consumptions for the maximum PTO and drawbar powers improved by 20.5% and 23.4% to 3.47 and 3.01 kW·h/L, respectively. Better specific volumetric fuel consumption was observed in tractors with higher PTO power levels. The 4WD and crawler tractors exhibited better specific volumetric fuel consumption for PTO power than the FWA tractors. The improvement was slow in the 1960s and '70s, and rapid after 1980.

Power Per Unit Weight

The average maximum PTO and drawbar power per unit weight of ballasted tractors increased 72.1% and 66.2% to 1.48 and 1.28 kW/kN from 1959 through 2002. As the PTO power increased, the power per unit weight of ballasted tractor increased. However, the rate of increase was greater in tractors with PTO power less than 112 kW. Until the 1990s, the tractors in a PTO power range of 149 to 187 kW experienced a decline in the average PTO power per unit weight. In the 1990s, an increase was observed in the tractors with a PTO power range of 37 to 75 kW. A similar trend was also exhibited on the average maximum drawbar power.

The 4WD and STD tractors have more power per unit ballasted-weight than any other chassis types except recent FWA tractors. In the 2001-2002 period, the FWA tractors produced 1.52 kW/kN of ballasted tractor weight while both the 4WD and crawler tractors produced 1.46 kW/kN. A similar trend was also observed in the drawbar power. Over the same period, the FWA tractors produced 1% to 3% more power than the 4WD and crawler tractors. In general, the increase in the PTO power per unit ballasted tractor weight was 64% for 4WD, 73.8% for crawlers, and 91.7% for STD tractors from 1959 through 2002. For the drawbar power, the increase was 47.1% for 4WD, 106.6% for crawlers, and 48.8% for STD tractors. The large increase in the crawler tractors may be attributable to rubber tracks. The FWA tractors also exhibited an increase in power per unit weight of ballasted tractor: 27.7% for the PTO power and 34.0% for the drawbar power from 1972 through 2002.

Traction Coefficient

From 1959 through 2002, the traction coefficient increased 24.4% for 4WD tractors and 27.4% for STD tractors, resulting in 1.02 and 0.94 for 2001 and 2002, respectively. The average traction coefficient of the FWA tractors was 0.83 in 1971 and increased 10.6% to 0.94 in 2000.

Most significant increase in the average traction coefficient was observed in the tractors with a PTO power level of 75-112 kW. The average traction coefficient of the tractors with the PTO power greater than 75 kW was 1.0.

The highest traction coefficient was observed with the crawler tractors followed by 4WD and STD tractors. However, from 1990, the traction coefficient increased to the values more than 95% regardless of the chassis type. In the 2000's, the 4WD tractors had an average traction coefficient greater than 1.0 on the test track. The increase in the traction coefficient may be a result of replacing the bias ply tires by the radial tires.

Torque Rise

Tractors of greater PTO power had larger lugging ability or torque rise. The lugging ability and torque rise increased steadily for the 30-year period from 1972 through 2002. In the 2001-2002 period, the average torque rise of the tractors in a PTO power range of 37 to 75 kW was 27.7%, which was 18.4% increase in 10 years. The tractors with greater PTO power than 187 kW had an average torque rise of 50.8%, being 30.9% increase over the same period.

Sound Level

In the early 1970s the maximum sound level ranged from 83.0 to 93.6 dBA. Over the next 30 years, the range of the maximum sound level decreased to 73.5 to 88.5 dBA for the 2001-2002 period.

Acknowledgement

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