THE EFFECT OF LOAD AND TRACTOR SIZE ON TRACTOR TRAILER FUEL CONSUMPTION

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Abstract

The South African sugar industry moves 74% of the annual crop by road transport. As fuel prices continue to rise there is therefore a need to investigate the effects of load size and tractor size on the fuel consumption and the productivity of transport units. Tests have been carried out to evaluate the effects of these parameters for the tractor sizes most common in the sugar industry. Results indicated that fuel consumption could decrease at the rate of 1,08 *l*/t per 100 km per ton of increase in payload for 50 kW tractors, and fuel consumption could increase at the rate of 0,17 *l*/t per 100 km for each kilowatt increase in tractor size.

Introduction

As a result of the recent increase in the price of diesel fuel and because 74 percent of the sugar industry's cane is hauled by road transport, it was decided to investigate the effect on fuel consumption of increases in load sizes and also to assess the effect that tractor size has on the amount of fuel consumed.

A selection of tractor sizes was chosen and tested on a standard route from Mount Edgecombe to La Mercy for loads which varied from 3,6 tons to 18,6 tons gross load. (The term "load" in this paper implies gross load, i.e. mass of trailer and payload).

Tests were also carried out on a dirt road route but the data from these tests are of such a nature that they require more sophisticated analysis than the data from the tar road tests, and they will therefore not be discussed in this paper.

Materials and Methods

In order to evaluate the effect of payload and tractor power on fuel consumption and on productivity it was decided to test a range of tractor sizes along a common route, pulling a representative range of loads. Tractors of 55, 50, 39 and 31 kW were chosen from various makes that are represented in the sugar industry.

The route chosen was on a tar road surface from Mount Edgecombe to La Mercy, being 11,62 km long with slopes ranging up to 8%.

Each section of continuous slope on each route was marked with pegs at beginning and end and its length measured. Most of the information that was required to mark the route on tar was available from the Natal Roads Department. To determine fuel consumption and productivity it was necessary to measure both the fuel consumed and the time it took to travel between markers.

An electronic Romess fuel flow meter was used initially to measure fuel consumption, but unfortunately the instrument gave a considerable amount of trouble and was finally dispensed with in favour of a home-made batch type fuel flow meter, the details and fitting of which are illustrated in Figure 1.

The batch type fuel flow meter consisted of two calibrated reservoirs to which the tractor fuel supply line was connected at a point before the injector and fuel pump bleed lines

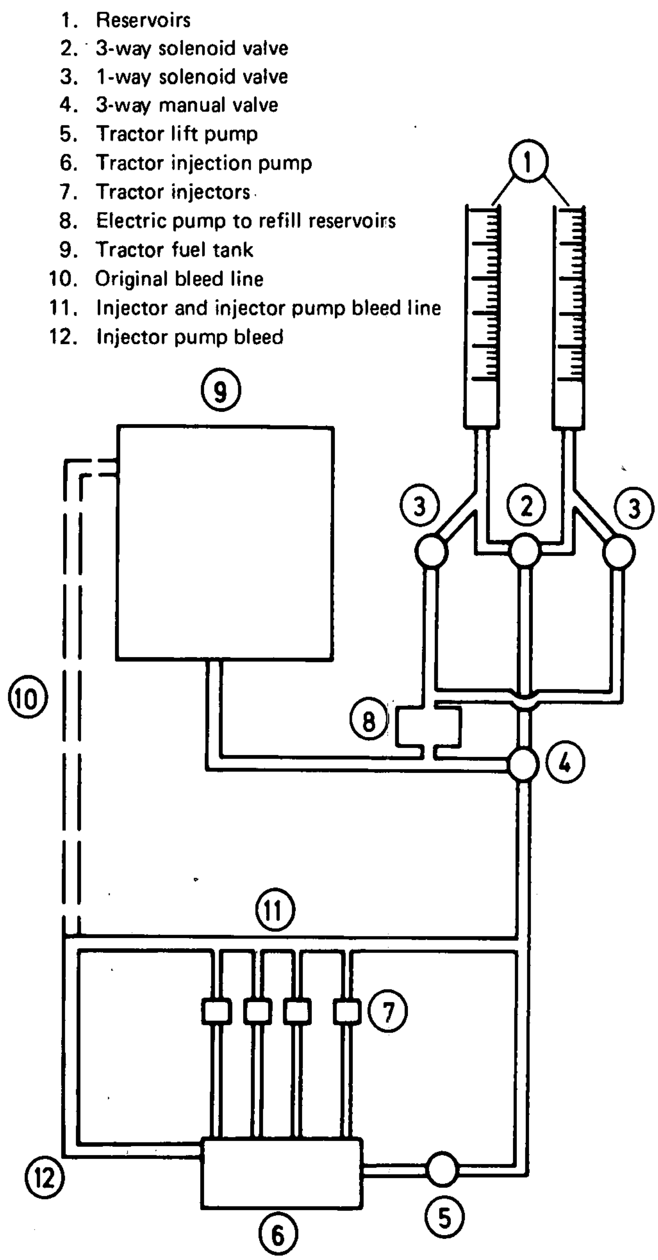

FIGURE 1 A diagrammatic representation of the layout of the batch type fuel flow meter showing how it was attached to the machines being tested.

returned, the connection being made by a 3-way solenoid valve. This valve made it possible to draw fuel from the two reservoirs alternately. An electric pump was installed to refill the reservoirs. (Initially a gravity feed was used for the purpose of refilling the reservoirs but this proved to be inadequate when full power was being used by some of the tractors).

The operation of the flow meter was as follows. A journey was started with both reservoirs full and when the tractor passed the first peg of the marked route the fuel supply was switched from the tractor fuel tank to the flow meter. Fuel would then be drawn initially from one of the reservoirs, and on passing the next peg the supply was alternated so that fuel would be drawn from the second reservoir, allowing a direct measurement of the amount of fuel used between the pegs. The reservoir not in use was refilled after the reading had been taken, in preparation for measurement over the next section.

The time to cover the distance between pegs was measured with a stop watch having a lap time facility, the time taken to travel from one peg to the next being obtained by subtraction. Knowing the amount of fuel consumed and the time taken to cover the distance between every two pegs on the route, it was possible to calculate the fuel consumption and speed on each section of the route.

Each tractor was tested along the route measuring fuel consumed and speed on every stage of the route in both directions, i.e. from La Mercy to Mount Edgecombe and back again. The total drawn load ranged from 3,60 tons to 18,65 tons, and there were seven loads altogether. Unfortunately no loads greater than 11,75 tons could be carried on one trailer because the position of the hitchpoint caused the tractor to be unstable. Consequently the higher loads were achieved by pulling two trailers in tandem. The 31 kW tractor (D) did not manage to pull more than 16,65 tons.

Both trailers were fitted with failsafe air brakes and consequently a compressor had to be mounted on each tractor. This was facilitated by means of a quick-couple arrangement to fit the compressor onto the tractor power take-off shaft. For the small tractor, however, it was necessary to build a hydraulic drive for the compressor and this, in fact, turned out a far more acceptable arrangement than did the pto-mounted system.

The performance of each tractor was compared with the specifications obtainable from official test reports compiled according to OECD standards. The tractors were tested over the full range of full throttle engine speeds by means of a pto dynamometer. On most occasions when the power being generated was measured, fuel consumption was also measured. The specific fuel consumption could then be calculated and checked against official test report data when these were available. Once each tractor had been tested and brought as close as possible to the official test specifications, the road tests were carried out. Unfortunately tractors C and D were on loan from a dealer and there was not enough time to bring tractor C as close to the specifications as would have been preferred.

Results

The results of the dynamometer tests on tractor performance are given in Table 1, where measured maximum pto power and specific fuel consumption at maximum power are listed together with the expected maximum indicated by the official test reports. The performance of tractor A was of particular interest because, when tested initially, it produced only 70% of is expected maximum power. It was nevertheless a very new tractor, still under guarantee, and the dealers took the fuel injection pump off and had it recalibrated. The performance improved considerably, but was still 14% less than maximum power, as can be seen from Figure 2. After further investigation it was observed that the tractor had been fitted with a fuel injection pump that had been derated for altitude. Once this had been corrected the tractor performed according to specification. The specific fuel consumption of the engine was slightly higher when it was uprated than when it was derated, but this was probably a characteristic of the particular engine in the make and model of tractor being used.

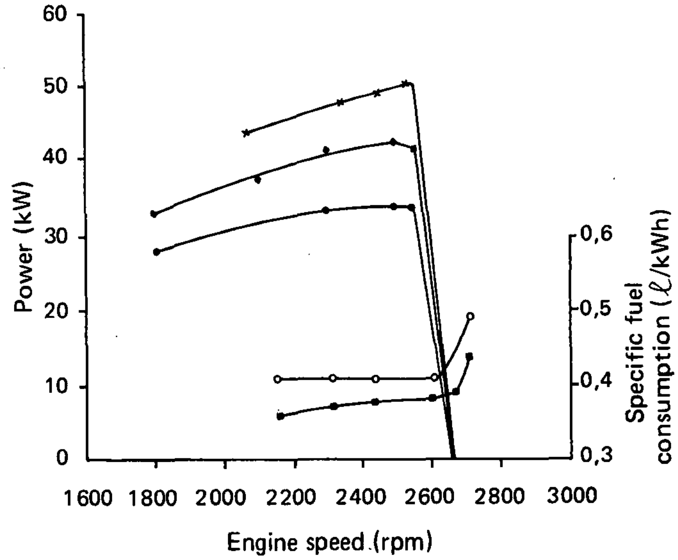

FIGURE 2 The relationship between "full throttle" power (kW) and specific fuel consumption (ℓ/kWh) and engine speed characteristics of tractor A as measured on the p.t.o. dynamometer.

Tractor B was close enough to specification that it did not require adjustment (see Table 1 . As already mentioned, tractors C and D were on loan, and after correcting some mechanical problems on tractor C there was not enough time to investigate its fairly low performance (see Table 1). Tractor D performed according to expectations and required no adjustment.

TABLE 1

Dynamometer test results showing measured results and deviation of measurement from official test specifications

Tractor	Official test maximum pto power (kW)	Measured maximum pto power (kW)	Deviation of measured power from official maximum, %	Official test specific fuel consumption at max. power ℓ/kWh	Measured specific fuel consumption at max. power ℓ/kWh	Deviation of measured specific fuel consumption from specific fuel consumption, %
A	49,7	50,3	+ 1	0,33	0,38	+ 15
B	39,2	36,4	− 7	0,33	0,36	+ 8
C	53,0*	48,4	− 9	0,30	0,34	+ 13
D	31,5*	31,0	− 2	0,30	0,34	+ 13

* Estimated assuming pto transmission efficiency of 0,95 (Kolazsi and McCarthy[1])

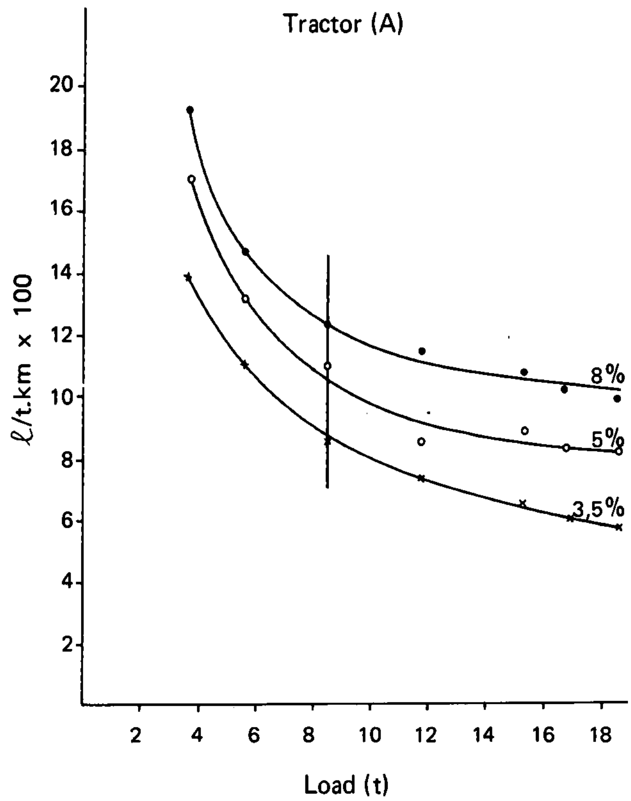

FIGURE 3 The relationship between specific fuel consumption (ℓ/tkm) and trailed load (t) for tractor A on three gradients.

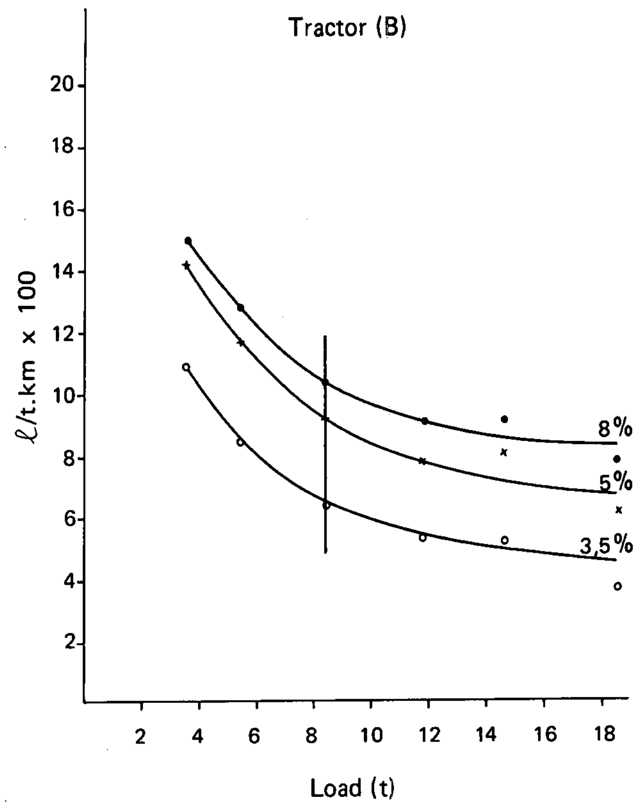

FIGURE 4 The relationship between specific fuel consumption (ℓ/tkm) and trailed load (t) for tractor B.

TABLE 2

Regression equations for calculating specific fuel consumption from load size for two tractor sizes and three road gradients

Road gradient %	Tractor power (kW)	Load range 0-8,5 t: regression equation	Load range 0-8,5 t: R	Load range 8,5 t-18,5 t: regression equation	Load range 8,5 t-18,5 t: R
8	50	y = 21,97-1,17 (x)	0,94	y = 13,95-0,20 (x)	0,93
5	50	y = 20,19-1,17 (x)	0,87	y = 12,71-0,25 (x)	0,85
3,5	50	y = 16,33-0,91 (x)	0,83	y = 11,13-0,30 (x)	0,98
Mean regression coefficient		− 1,08		− 0,25	
8	36	y = 17,44-0,85 (x)	0,92	y = 11,67-0,19 (x)	0,84
5	36	y = 16,68-0,89 (x)	0,92	y = 11,05-0,25 (x)	0,89
3,5	36	y = 13,09-0,79 (x)	0,93	y = 7,78-0,18 (x)	0,90
Mean regression coefficient		− 0,84		− 0,21	
Mean regression coefficient for both powers		—		− 0,23	

y = specific fuel consumption (ℓ/t km x 100) x = load (tons) R = correlation coefficient

Because the tractors were not all up to specification, a good spread of available power was not obtained. The two large tractors, A and C, were rated at 50 and 48 kW respectively, and the two small tractors were certainly closer in performance than would have been preferred.

Results of tests on the roads

The test procedure was such that the specific fuel consumption in terms of l/t km could be calculated for conditions of varying load and gradient. Figures 3 and 4 show the variation in specific fuel consumption (l/t km) as load was varied on three slected gradients. Figure 3 represents the data for tractor A (50 kW) and Figure 4 the data for tractor B (36 kW). The smaller tractor was obviously more fuel efficient on all gradients, but the slope of the curves in Figures 3 and 4 are all reasonably similar for loads greater than 8,5 t, indicating that the effect of load increase above 8,5 t on specific fuel consumption was no greater for a large tractor than it was for a small tractor.

Each of the curves in Figures 3 and 4 can be approximated by two straight lines, one for loads less than 8,5 t and another for heavier loads. It can be seen from Table 2 that the regression coefficients for large and small tractors in the range of loads from 8,5 t to 18,5 t varied from -0,18 to -0,30. The average values for 30 kW and 50kW tractors indicate that the effect of increase in load was relatively independent of tractor size and could be approximated by -0,23 l/t per 100 km for each ton of load increase over the range from 8,5 to 18,5 t.

For loads less than 8,5 t, however, the larger tractors became more inefficient with light loads than did the smaller tractor, the average regression coefficients being -1,08 and -0,84 l/t per 100 km per ton of load increase respectively. This highlights the need for large tractors to pull fairly big loads if they are to be economic.

The effects of tractor power on fuel consumption are illustrated in Figures 5 and 6, which relate l/t km to available tractor power for fixed conditions of gradient and load. The regression equations for calculating l/t km from tractor power and the respective correlation coefficients (R) are given in Table 3. The average value of the regression coefficients for both 8% and 5% gradients was 0,17. This implies that the specific fuel consumption worsens at a rate of 0,17 l/t per 100 km per kilowatt increase in tractor power.

TABLE 3

Regression equations for calculating specific fuel consumption from available tractor power for two road gradients and three load sizes

Gradient %	Load tons	Regression equation	R
8	5	$y = 5{,}6 + 0{,}20\,(x)$	0,93
	10	$y = 4{,}2 + 0{,}15\,(x)$	1,00
	15	$y = 2{,}74 + 0{,}15\,(x)$	1,00
5	5	$y = 2{,}25 + 0{,}25\,(x)$	0,92
	10	$y = 3{,}54 + 0{,}12\,(x)$	0,97
	15	$y = 2{,}16 + 0{,}13\,(x)$	0,99
Mean coefficient of regression for both gradients		0,17	

y = specific fuel consumption (ℓ/t km x 100)
x = tractor power (kW)
R = correlation coefficient

TABLE 4

Regression equations for calculating speed from load size for two sizes of tractor and three road gradients

Road gradient %	Tractor power (kW)	Load range 0-8,5 t: regression equation	0-8,5 t: R	8,5 t-18,5 t: regression equation	8,5 t-18,5 t: R
8	50	$y = 28{,}73\text{-}1{,}66\,(x)$	0,94	$y = 18{,}5\text{-}0{,}49\,(x)$	0,94
5	50	$y = 36{,}60\text{-}1{,}95\,(x)$	0,87	$y = 24{,}25\text{-}0{,}74\,(x)$	0,96
3,5	50	$y = 35{,}73\text{-}1{,}88\,(x)$	0,83	$y = 24{,}62\text{-}0{,}57\,(x)$	0,97
8	36	$y = 29{,}4\text{-}1{,}94\,(x)$	0,92	$y = 17{,}42\text{-}0{,}58\,(x)$	0,94
5	36	$y = 31{,}70\text{-}1{,}70\,(x)$	0,92	$y = 22{,}77\text{-}0{,}70\,(x)$	0,94
3,5	36	$y = 33{,}69\text{-}1{,}66\,(x)$	0,93	$y = 25{,}03\text{-}0{,}69\,(x)$	0,95
Mean coefficient of regression for both tractors		− 1,80		− 0,63	

y = road speed (km/h) x = load (t) R = correlation coefficient

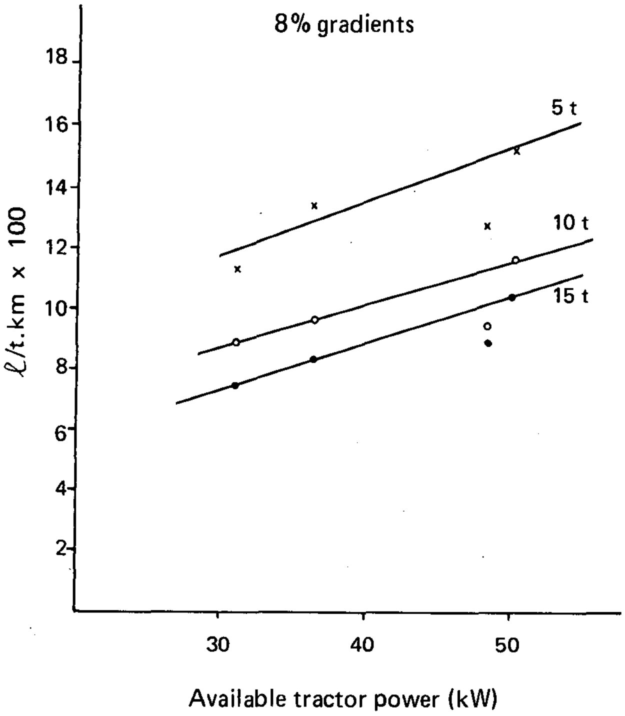

FIGURE 5 The relationship between specific fuel consumption (ℓ/tkm) and available p.t.o. power (kW) for 5, 10 and 15 t loads on an 8% gradient.

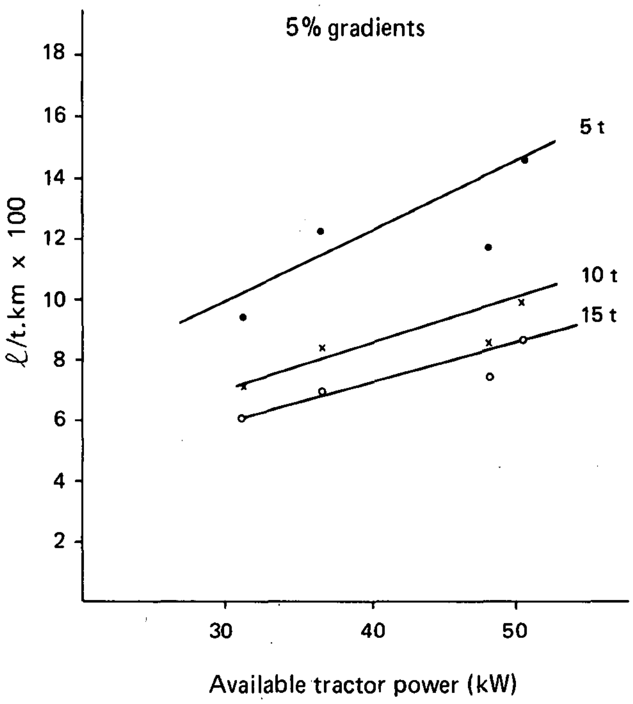

FIGURE 6 The relationship between specific fuel consumption (ℓ/tkm) and available p.t.o. power (kW) for 5, 10 and 15 t loads on a 5% gradient.

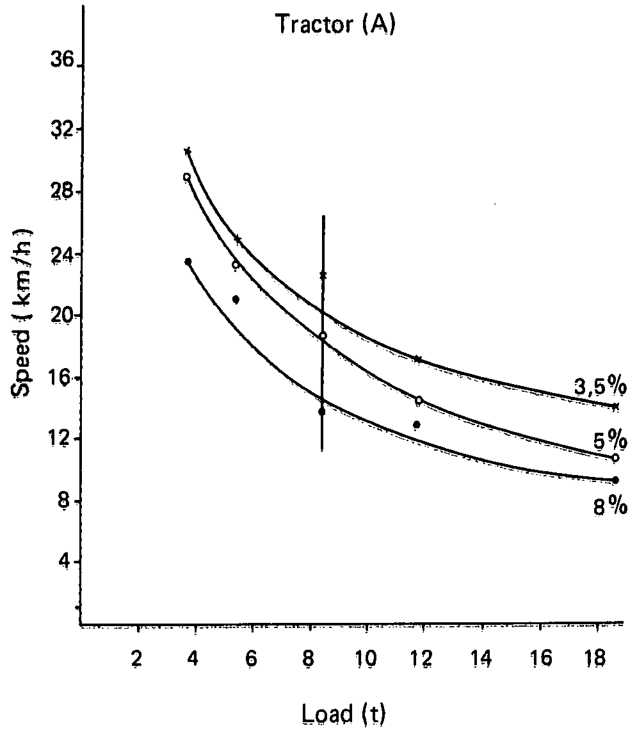

FIGURE 7 The relationship between speed (km/h) and load (t) for tractor A on gradients of 3,5, 5 and 8%.

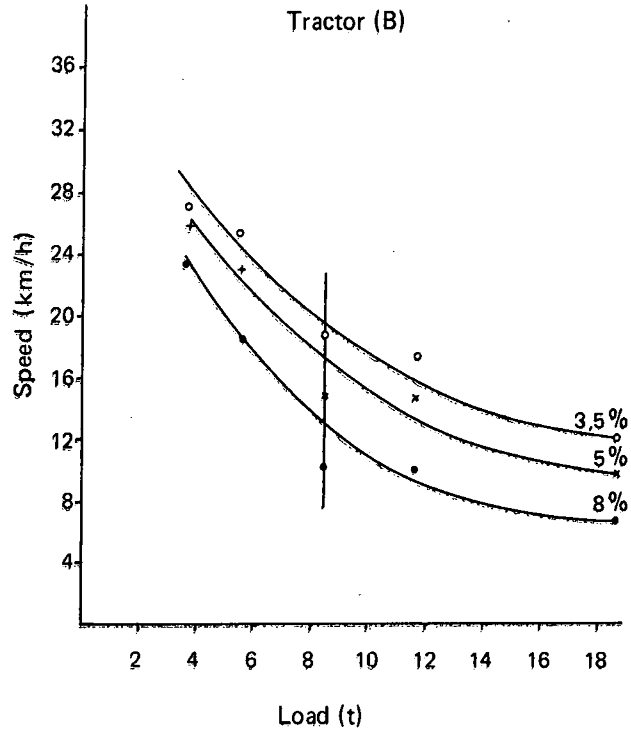

FIGURE 9 The relationship between speed (km/h) and available tractor p.t.o. power (kW) for 5, 10 and 15 ton loads on an 8% gradient.

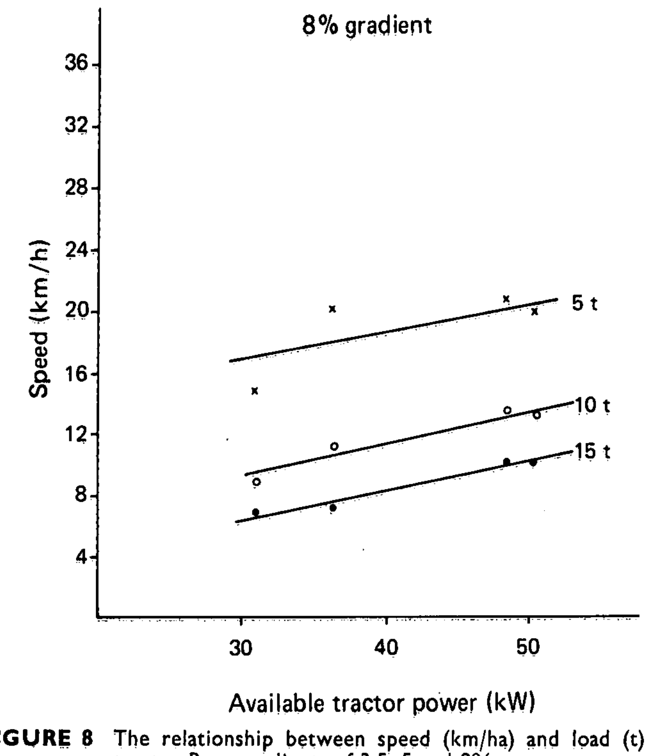

FIGURE 8 The relationship between speed (km/ha) and load (t) for tractor B on gradients of 3,5, 5 and 8%.

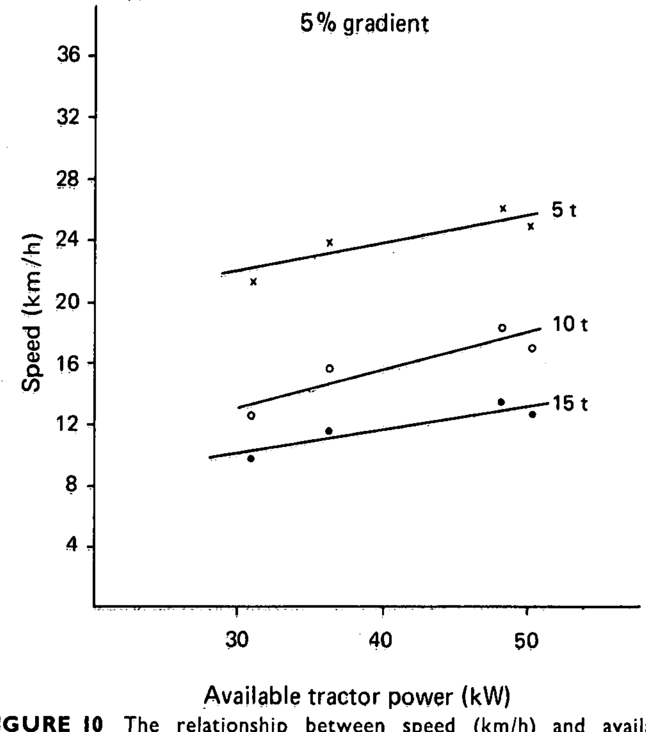

FIGURE 10 The relationship between speed (km/h) and available tractor p.t.o. (kW) for 5, 10 and 15 ton loads on a 5% gradient.

The converse to the specific fuel consumption is the productivity of the tractors of various sizes when the size of the load is varied. Figures 7 and 8 show the reduction in speed which can be expected as the size of the load increases.

If loads less than and greater than 8,5 tons are considered separately, then straight lines can be substituted for the two parts of the curve, and the respective regression coefficients for the 50 and 36 kW tractors, as shown in Table 4, are not significantly different. The mean for both tractors is –0,63 km/h per ton of load for loads of 8,5 to 18,5 t and –1,8 km/h per ton for loads less than 8,5 t.

The effect that the available power of the tractor had on speed is illustrated in Figures 9 and 10 for fixed conditions of gradient and load. The straight lines are approximately parallel because the coefficients of regression for the different tractor sizes and gradients, as shown in Table 5, are not very different. This indicates that the effect of increase in available power on speed was relatively independent of both load and gradient, and is approximately 0,20 km/h increase in speed for each kW increase in available power.

Conclusion

The main conclusion to be drawn from the results of the tests carried out on a tar road surface is that the amount of fuel used will decrease at the rate of 1,08 l/t per 100 km

TABLE 5

Regression equations for calculating road speed from available tractor power for two road gradients and three load sizes

Gradient %	Load, tons	Regression equation	R
8	5	$y = 9{,}79 + 0{,}22\ (x)$ . .	0,61
	10	$y = 2{,}44 + 0{,}22\ (x)$ . .	0,93
	15	$y = 0{,}85 + 0{,}19\ (x)$ . .	0,99
5	5	$y = 15{,}77 + 0{,}19\ (x)$.	0,81
	10	$y = 6{,}07 + 0{,}23\ (x)$ . .	0,81
	15	$y = 5{,}23 + 0{,}15\ (x)$ . .	0,90
Mean regression coefficient:		0,20	

y = speed (km/h)
x = maximum available power (kW)
R = correlation coefficient

for each ton increase in load up to 8,5 t for tractors in the 50 kW power range. For tractors in the 36 kW range the fuel consumption will decrease at a rate of 0,84 l/t per 100 km for loads less than 8,5 t. The improvement in fuel consumption for loads from 8,5 to 18,5 t will take place at the rate of 0,22 l/t per 100 km per ton increase in load for tractors delivering 36 to 50 kW pto power. For a given load on the other hand, fuel consumption will increase at a rate of 0,17 l/t per 100 km per kilowatt increase in available power.

Productivity, which is proportional to speed for a given load, increases in proportion to the increase in speed at a rate of 0,20 km/h per kW increase of available pto power.

These data should only be used to calculate the change in expected cycle times and fuel consumption that may arise due to proposed changes in tractor or trailer sizes.

Future work

The scope of the work described here will be extended by testing lorries ranging in power from 50 kW to 250 kW, pulling loads up to 35 tons. More detailed and intensive studies will be made of fuel consumption infield and on dirt roads, and the results of these studies should lead to a better understanding of the factors that influence the fuel consumption and productivity of road transport vehicles.

Acknowledgements

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1. Kolozsi A. and McCarthy, T. T. (1974). The measurement of tractor transmission losses. *J Agric Engineering Res* **19**: 71-75.