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Full Length Research Paper

Empirical determination of the motion resistance of pneumatic bicycle wheels for on and off-road performance

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Four pneumatic bicycle wheels of diameters 405 mm (16"), 510 mm (20"), 610 mm (24") and 660 mm (26") were tested on three different test surfaces (paved surface, grass field and tilled (sandy-clay loam) soil at selected tyre inflation pressures of 276 kPa (40 psi), 337.5 kPa (50 psi) and 414 kPa (60 psi) with varied (added) dynamic loads of 98.1 N (10 kg), 196.2 N (20 kg), 392.4 N (40 kg) and 588.6 N(60 kg) respectively. The motion resistances of these wheels at various dynamic loads and the selected inflation pressures were compared, to identify the wheel with the lowest motion resistance. On all the test surfaces, the 660 mm diameter recorded the lowest motion resistance measured with an average of 16 out of the 36 total number of test outcomes. The 660 mm diameter wheel, if used, has the potential to increase the pull (draft) and can be used in the development of simple, easy to maintain and low-cost agricultural machines with narrow wheels; as traction member for the low-income farmers and the rural dwellers to boost their agricultural productivity.

Key words: Motion resistance, test surfaces, pneumatic bicycle wheel, narrow wheel, inflation pressure, dynamic loads.

INTRODUCTION

Agricultural mechanisation is the bedrock of any developing and the underdeveloped countries' economy, to take care of their teeming population in terms of food production and to provide employment in the rural areas where the largest population resides. However, the agricultural mechanisation strategies of developing and the developed countries are not identical and the adoption of such by the developing nations has failed because of the misplaced strategies and wrong adoption processes. Some of the reasons are unavailability of funds to procure agricultural equipment, land fragmentation and lack of technical know-how on maintenance and repair of such equipment. Therefore, simple and low-cost appropriate machines will help to increase the agricultural productivity of the agricultural mechanisation development in developing countries is a key solution to increased agricultural productivity and economic survival (Akande et al., 2008).

Narrow wheels are defined as wheels with sectional width ranging from 35 mm to 100 mm. These include bicycle wheels, motorcycle wheels and motor scooter wheels. These narrow wheels could be pneumatic, rigid, pneumatic-lug, rigid lug or the non-lug rigid and pneumatic wheels within the category. In the tractive performance of off- road vehicles, motion resistance otherwise called rolling resistance is a major factor in the determination of the drawbar pull of agricultural vehicles. Therefore, vehicle designers will like to minimise the motion resistance, in order to reduce the energy wasted to overcome the motion resistance with a view to achieving higher pull according to Equation 1 (Macmillan, 2002) (Macmillan, 2002):

$$P = H - R \quad (1)$$

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P is the drawbar pull (N), H is the tractive force (N) and R is the motion resistance (N).

Motion resistance is defined as the force opposing the motion of a free rolling wheel in contact with a surface. Motion resistance also refers to the resistance to motion of a wheel caused by the absorption of energy in the contacting surfaces of the wheel and the soil upon which the wheel rolls (Plackett, 1985; Macmillan, 2002). Motion resistance may be described as, the total drag opposite to the steady motion of a free rolling wheel across a horizontal surface. Usually, the motion resistance is expressed in terms of motion resistance ratio. Thus, mathematically, the motion resistance ratio is as expressed in Equation 2 (Arregoces, 1985)

$$\tau = \frac{R}{Q} \quad (2)$$

R is the motion resistance force suffered by the wheel and Q is the normal (dynamic) load on the wheel. The performance characteristics of a towed wheel are described usually by a towing force (motion resistance), sinkage and skid. The most pertinent parameter of the towed pneumatic wheel is the rolling (motion) resistance, which is influenced by the tyre design, system parameters and terrain characteristics. In studying the soil-wheel interaction, the behaviour of the soil and the most important design parameters of the wheel form the basic inputs and need to be quantitatively defined (Pandey and Tiwari, 2006).

Traditionally, design parameters of the tyre include overall diameter of the wheel, section width, section height, tyre inflation pressure and load-deflection relationship. All these are considered to have varying degrees of influence on the tyre-soil interaction (Wong, 1984). The terrain characteristics include the type of soil, soil moisture content and its compaction level. The system parameters comprise the dynamic load on the wheel and the forward velocity (Tiwari and Pandey, 2008).

This paper is aimed at identifying the wheel with the lowest motion resistance out of the four test wheels on all the test surfaces under consideration when all the wheels are subjected to the same conditions of inflation pressures and dynamic loads. It will also suggest the best inflation pressures and dynamic loads at which the minimum motion resistance can be achieved on all the test surfaces, and which of the surfaces has the lowest motion resistance.

The rolling (motion) resistance test rig

A motion resistance test rig for traction studies on towed narrow wheel has been developed to investigate the off- and on- road performances of narrow wheels with emphasis on motion resistance. The test rig is relatively simple, portable and suitable for both laboratory and field motion resistance studies for narrow wheels. It has the following features:

1. It is portable and collapsible (assembling and dismantling) for ease of movement to the field and in the laboratory.
2. It is made from readily available materials such as hollow pipe, angle iron and mild steel that make it simple to construct, repair or replace.
3. It can accommodate various narrow wheels in the specified categories without any modification.
4. The data acquisition system can easily and readily be powered by batteries which can last for 48 runs (tractor travels) before being recharged.

The motion resistance rig was designed to measure the towing force of a single test wheel when towed by a tractor. The towing force is equal to the motion resistance of the wheel. The motion resistance of different narrow wheels can easily be measured with this device on various terrains to obtain new design information for narrow wheels especially the non-lug type under the specified categories.

The test rig (Figure 1) is hitched to the tractor via the three-point hitch connecting links and the tractor towed the test rig over the selected test surface at a predetermined velocity of 4.44 km/h. This velocity is assumed to be the optimum velocity at which bicycle can be operated in off-road condition and this was used throughout the tests.

The test rig comprises the frames and the data acquisition systems. The frame is divided into two parts, the first part holds the test wheel and the second part is hitched to the tractor three-point hitch on top of which is placed the Mecmesin Basic Force Gauge (model BFG 2500) (Newton House, Spring Copse Business park, Stane Street, Slinford, West Sussex, RH 13 7SZ) for data acquisition for onward signal transfer to the notebook PC.

The data acquisition system

The data acquisition system for the test facility comprised the Basic Force Gauge (BFG) that is RS-232 interfaced to Hewlett Packard (HP) dv6000 notebook personal computer with installed Mecmesin data plot software. The complete data plot software is capable in real time to record the measured compression or tension forces per unit time as specified and a plot of the graph showing the forces measured in desired units against time intervals.

The average towing force over time is read from the

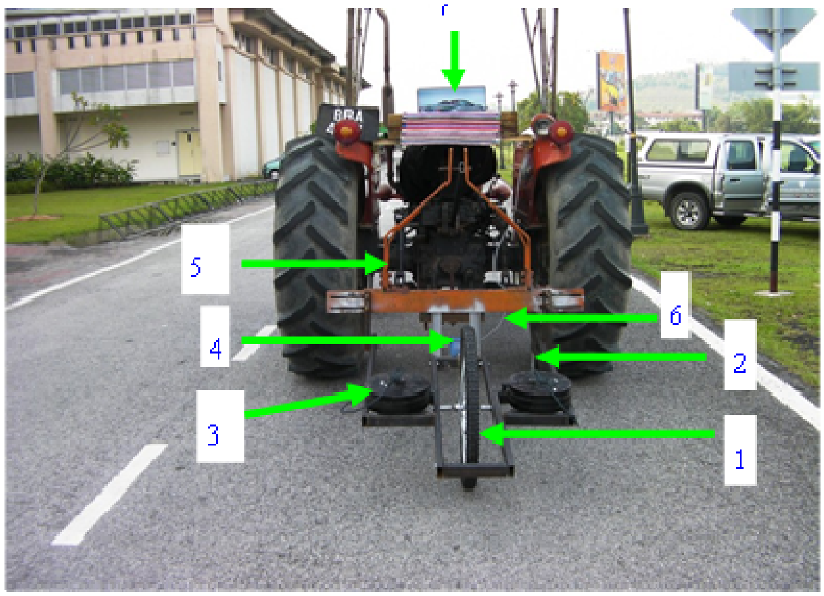

Figure 1. The complete test rig with the data acquisition system on paved surface. 1-Test wheel, 2-Load hanger, 3- Added load, 4- The basic force gauge, 5- Three-point hitch frame, **6**- Connecting cable and 7- Notebook PC.

Table 1. Specifications of pneumatic bicycle wheels.

Tyre size designation	Overall diameter mm (in.)	Sectional width mm (in.)
26" x 1.9"	660 (26)	48 (1.9)
24" x 1.9"	610 (24)	48 (1.9)
20" x 1.9"	510 (20)	48 (1.9)
16" x 1.9"	405 (16)	48 (1.9)

graph (plot).

MATERIALS AND METHODS

Tyre selection/tyre parameters

Four pneumatic bicycle wheels of different sizes were selected for this study. The tyre dimensions are as shown in Table 1. The inflation pressure range according to the manufacturer's specification is between 240 kPa (35 psi) to 450 kPa (65 psi).

Test surfaces

The test surfaces considered in this study were the paved road (Figure 1), grass field (Figure 2) and the tilled sandy-clay soil (Figure 3). The first two test surfaces represent the available road for rural dwellers and farmers, for the transportation of their farm produce from the farm to the house or directly from the farm to the market. The tilled sandy- clay- loam soil is considered for the off-road performance to obtain design information for simple agricultural machinery and or equipment with these narrow wheels at affordable price for low- income farmers to boost their agricultural productivity. The three test surfaces were located within the premises of the Universiti Putra Malaysia (UPM).

Figure 2. Test on grass field.

Figure 3. Test on tilled sandy- clay-loam soil.

Table 2. Analysis of total dynamic loads.

Wheel diameter inches (mm)	Weight of wheel and the frame (N)	Dynamic loads levels (N)				Total vertical loads (N)			
16" (405)	21.88 (214.64)	98.1	196.2	392.4	588.6	312.74	410.84	607.84	803.24
20" (510)	22.18 (217.59)					315.69	413.79	609.99	806.19
24" (610)	22.50 (220.73)					318.83	416.93	613.13	809.33
26" (660)	22.52 (220.92)					319.02	417.12	613.32	809.52

Table 3. Test treatments on each surface.

D_1	D_2	D_3	D_4
$D_1P_1L_1$	$D_2P_1L_1$	$D_3P_1L_1$	$D_4P_1L_1$
$D_1P_1L_2$	$D_2P_1L_2$	$D_3P_1L_2$	$D_4P_1L_2$
$D_1P_1L_3$	$D_2P_1L_3$	$D_3P_1L_3$	$D_4P_1L_3$
$D_1P_1L_4$	$D_2P_1L_4$	$D_3P_1L_4$	$D_4P_1L_4$
$D_1P_2L_1$	$D_2P_2L_1$	$D_3P_2L_1$	$D_4P_2L_1$
$D_1P_2L_2$	$D_2P_2L_2$	$D_3P_2L_2$	$D_4P_2L_2$
$D_1P_2L_3$	$D_2P_2L_3$	$D_3P_2L_3$	$D_4P_2L_3$
$D_1P_2L_4$	$D_2P_2L_4$	$D_3P_2L_4$	$D_4P_2L_4$
$D_1P_3L_1$	$D_2P_3L_1$	$D_3P_3L_1$	$D_4P_3L_1$
$D_1P_3L_2$	$D_2P_3L_2$	$D_3P_3L_2$	$D_4P_3L_2$
$D_1P_3L_3$	$D_2P_3L_3$	$D_3P_3L_3$	$D_4P_3L_3$
$D_1P_3L_4$	$D_2P_3L_4$	$D_3P_3L_4$	$D_4P_3L_4$

Test variables

The test variables as stated earlier are: (1) the pneumatic bicycle wheel of diameters, 405 mm (16"), 510 mm (20"), 610 mm (24") and 660 mm (26"). (2) Considering the manufacturer's specification on the inflation pressure and knowing fully from past researchers that, tyre life will be shortened by under-inflation as well as over-inflation (Elwaleed, 1999). Therefore, three levels of inflation pressures of 276 kPa (40 psi), 345 kPa (50 psi) and 414 kPa (60 psi) were selected. (3) Dynamic loads acting on the test wheel and (4) the three test surfaces.

The weight of the frame with each test wheel was measured with multi-function bench scale (model AND HW-100K) and recorded. Four levels of loads of 98.1 N, 196.2 N, 392.4 N and 588.6 N were used during the investigative studies. Each of these levels of load was added to the weight of the frame, holding the test wheel making up the vertical loads under consideration and the summary of the dynamic (vertical) loads for each of the test wheels in Table 2.

The added dead weights (dynamic load levels) are designated as L1, L2, L3 and L4 corresponding to 98.1 N, 196.2 N, 392.4 N and 588.6 N respectively. The tyre inflation pressures of 40 psi (276 kPa), 50 psi (345 kPa) and 60 psi (414 kPa) were respectively denoted as P1, P2, and P3. While, D1, D2, D3 and D4 represent 16" (405 mm), 20" (510 mm), 24" (610 mm) and 26" (660 mm) test wheels, respectively. On each test surface, there were 48 treatment combinations, 12 per wheel and a 2 x 2 factorial design was followed, in which the surface and the wheel size were constant and the dynamic load and the tyre inflation pressure were varied, to measure the motion resistance. Table 3 shows the treatment combinations on each test surface. Prior to the tests, preliminary tests were done to determine the average towing speed to be used for the tests. A tractor (Fiat 640 2WD) was used to determine the average speed by varying the low and the high gear at the selected engine rpm over a measured distance of 40 m and with a Mitutoyo stop watch of 0.01 s resolution (sensitivity) until the desired velocity (speed) of 4.44 km/h, was achieved which was used for all the tests.

Tilled soil properties, some physico-mechanical properties of the undisturbed soil at 20 cm depth were determined before the tests were carried out on the loose soil, in accordance with the ASTM D4318 (2005). The following are the summary of the properties of the soil:

Textural classification – Sandy- clay-loam (60 sand, 32 clay, 8% silt)
Soil bulk density – 1.48 to 1.72 kg/m^3 (mean = 1.55 kg/m^3 d.b)
Liquid limit – 28.06% db
Plastic limit – 11.14 to 24.26% (mean = 17.09% db).
Moisture content range- 10.75 to 28.95% wb
Cone Index (CI) range of the test tilled surface – 0.6 to 1.8 MPa (mean CI = 1.1 MPa).

Test surface preparation

The preparation for data acquisition on the different test surfaces differ. The paved surface was located within the Faculty of Engineering, UPM, at the same surface where speed tests were carried out. A test area of 60 x 2 m was demarcated and the start and the end points were marked out. The tests were conducted in one direction only.

On the grass field located at Taman Pertanian Universiti (TPU), the test area of 45 x 4 m was demarcated for the tests and the same travel direction was used for all the test wheels and the test variables. The starting and the end points were also marked as for the paved surface. The undisturbed soil of 45 x 20 m was first ploughed and after 48 h, the rotavator was used to break the large clods into smaller soil clods similar to soil bed preparation ready for planting operation. The loose soil was left for another 3 days before the tests commenced. Fifteen (15) Echo dielectric aquameter were buried randomly on the test plots for at least 18 h before taking the moisture contents of the field prior to motion resistance tests (traction data acquisition) for that day. The average soil moisture content was then calculated and the range was as stated above. Since it was difficult to get a large area of land for this test, considering the number of test runs, after the completion of two pressure levels (experimental runs at 276 and 344 kPa), the field was re-prepared by using a rotavator, to make the soil surface even and loose, to ensure uniform test conditions. The distance of tractor travel during the test from the starting to the end point was set as 35 m, for all the tests conducted on the loose soil.

Procedure for data acquisition

The tractor towing the test rig was prepared to be in a very good condition for the test. The test rig was assembled (that is, the test wheel was fixed to the test rig). The first level of vertical load (10 kg) was screwed to the load hanger and the first level of inflation pressure (276 kPa) was maintained. The data acquisition system was put on, to facilitate real time data transfer to the data plot software installed on the notebook for data acquisition. The distance of the test (starting and the end point) was marked. The tractor was allowed to attain a steady speed of 4.44 km/h, as stated above before the starting point and the start icon on the data plot environment was also initiated and the real time data acquisition of measuring the towing force (N), against the time taken (seconds) in the form of Force –Time graph, was taken progressively until at the end point when the stop icon was also clicked, to stop the data transfer and the plot. The minimum, maximum and the average towing force (motion resistance) was obtained from the data plot. Each of the treatments was replicated three times and the average was taken, at least 95% of the measured data, around the mean ($\mu \pm 2\delta$).

Statistical analysis

Analysis of variance (ANOVA) was used to test whether there is significant difference between the means of the measured motion resistance on the three test surfaces (factor 1) and the four pneumatic wheels of different sizes (factor 2) and the interactions between the two factors. This test was divided into three categories,, based on the 3 levels of tyre inflation pressure and four levels of added dynamic loads per pressure level.

RESULTS AND DISCUSSION

The analysis of variance at 95 to 99% confidence levels showed that, there are significant differences between the mean of the motion resistance measured on all the three test surfaces, under the three levels of inflation pressures and the four levels of dynamic loads. However, at 95% confidence level, there were significant differences between the observed means of motion resistance among the different wheel sizes tested but no significant difference exists between the means of the different wheel sizes and their interactions with test surfaces at 196.2 N (added load) and 276 kPa (tyre inflation pressure) and at 98.1 N, 392.4 N (added loads) and 345 kPa (tyre inflation pressure).

At all levels of added loads and 414 kPa tyre inflation pressure, there were significant differences between the means of the motion resistance on the test surfaces and within the test wheels and their interaction. Based on the ANOVA, 9 out of 12 outcomes showed significant differences between the two factors (test surfaces and the wheel sizes) and out of this 9, 67% of the lowest motion resistance was recorded against the 660 mm (26") while the remaining 33% was recorded against the 610 mm (24"). This implied that, the larger the diameter the smaller the motion resistance as the smaller wheels recorded the highest motion resistance. Figures 4 to 12 show the graphical representations of the motion resistances of the four wheel sizes, according to the diameter of the wheels as 1, 2, 3, and 4 on the three test surfaces, under three levels of inflation pressures and four levels of additional loads.

Motion resistance on paved surface

Figures 4 to 6 show the motion resistances obtained on paved surface at inflation pressures of 276 kPa (40 psi), 345 kPa (50 psi) and 414 kPa (60 psi), respectively. The measured motion resistance ranged from 3.6 N to 20.4 N being the minimum and the maximum motion resistances on that surface. The 3.6 N corresponds to the motion

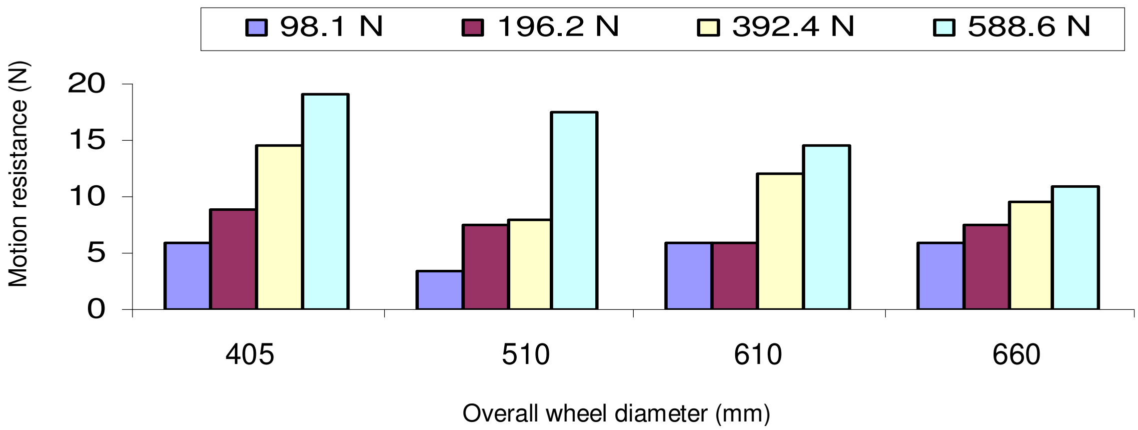

Figure 4. Motion resistance of pneumatic bicycle wheels at 276 kPa pressure and 4 added loads on paved surface.

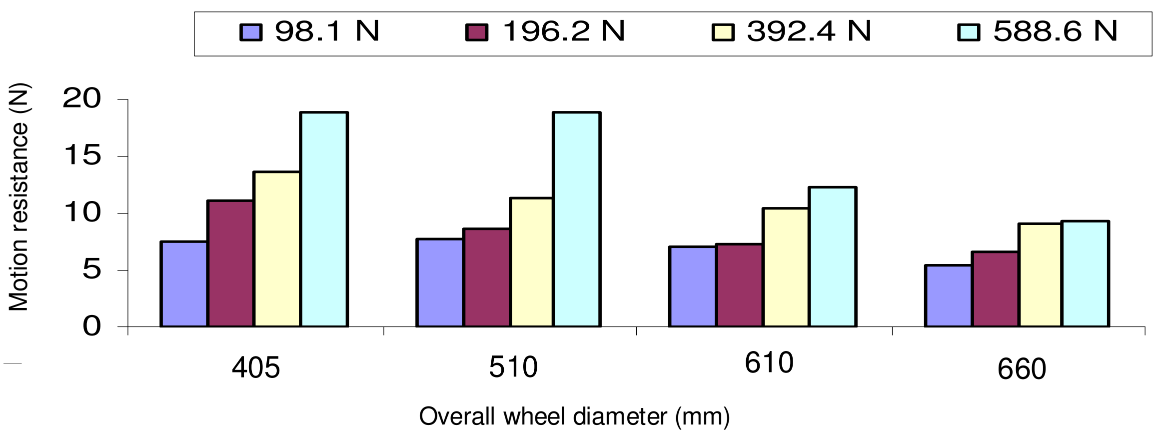

Figure 5. Motion resistance of pneumatic bicycle wheels at 345 kPa pressure and 4 added loads on paved surface.

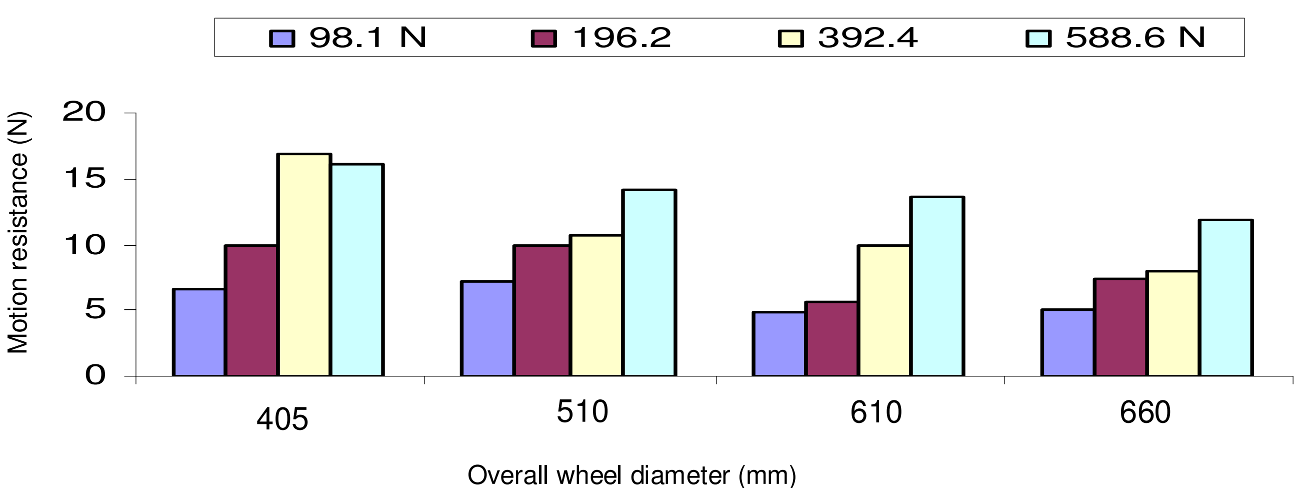

Figure 6. Motion resistance of pneumatic bicycle wheels at 414 kPa pressure and 4 added loads on paved surface.

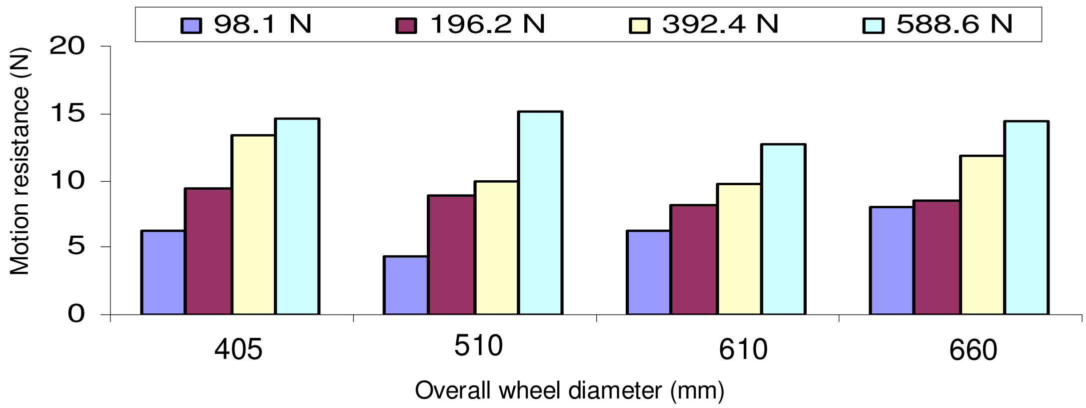

Figure 7. Motion resistance of pneumatic bicycle wheels at 276 kPa pressure and 4 added loads on grass field.

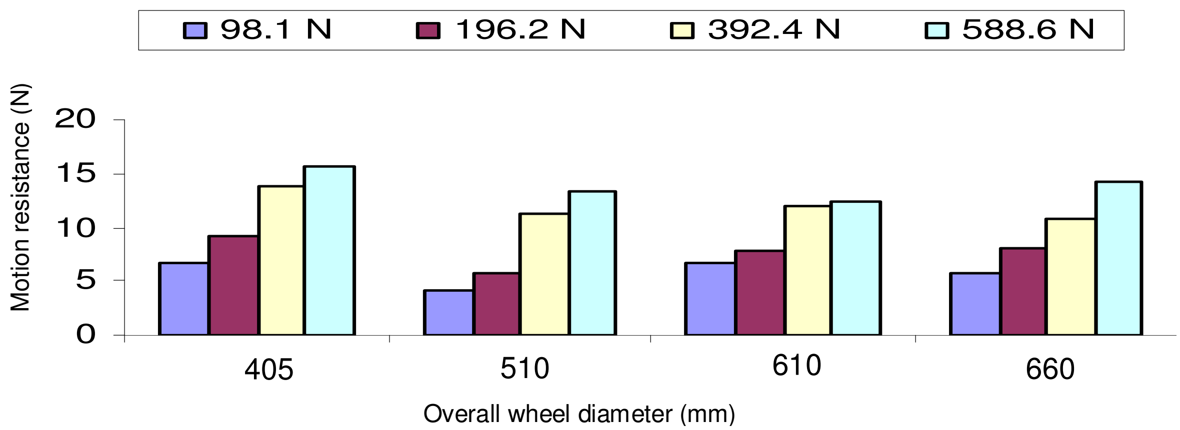

Figure 8. Motion resistance of pneumatic bicycle wheels at 345 kPa pressure and 4 added loads on grass field.

resistance of 510 mm (20") wheel at 276 kPa (40 psi) inflation pressure when a load of 98.1 N was added to the test rig frame, making a total dynamic load of 315.69 N. The motion resistance of 20.4 N corresponds to the motion resistance of 405 mm (16") at 345 kPa (50 psi) inflation pressure when a load of 588.6 N (60kg) was added (total dynamic load of 803.24N). Fifty-eight percent of the outcome revealed that, the 660 mm (26") wheel had the lowest occurring motion resistance, most of which occurred at higher inflation pressure (415 kPa) and higher added loads (588.6 N).

This implies that more pull can be achieved using a larger wheel at higher vertical (dynamic) loads (Taylor et al., 1967) and higher pressure in narrow wheels; although, the higher pressure may not be advisable in broader or wider wheels. Seventeen percent of the outcomes showed that, the 510 mm (20") wheel had the lowest occurring motion resistance, taking place at low level of inflation pressure but at lowest level of vertical load of 98.1 N (10 kg). The remaining twenty-five percent were observed from the 610 mm (24") wheel occurring at higher pressure level and average dynamic loading. No lowest motion resistance was recorded for the smallest 405 mm (16") wheel, considering the outcomes closer to the least occurring ones, the 660 mm (26") diameter was found to be closer in values to the other two wheels. Hence, it can be concluded that on this surface, at higher inflation pressure the larger the wheel, the lower the motion resistance at higher loads.

Motion resistance on grass field

The motion resistances measured on the grass field under the same test, as on the paved surface, are as shown in Figures 7 to 9 in increasing levels of inflation pressures. The values of the motion resistances on the grass field ranged from 4.1 N to 15.7 N, being the minimum and the maximum motion resistances obtained

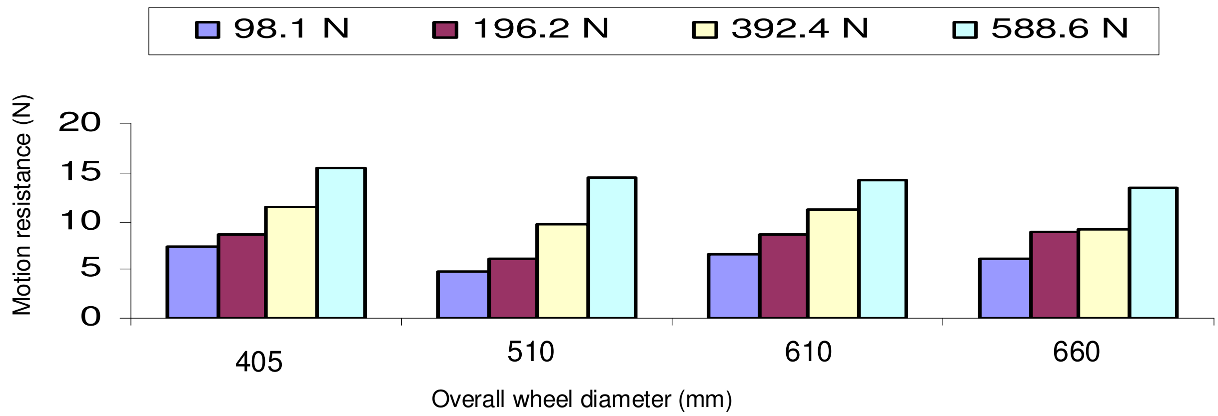

Figure 9. Motion resistance of pneumatic bicycle wheels at 414 kPa pressure and 4 added loads on grass field.

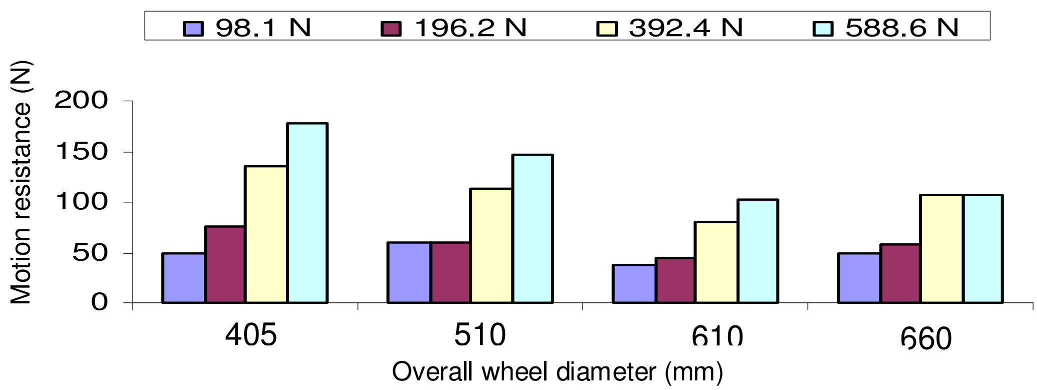

Figure 10. Motion resistance of pneumatic bicycle wheels at 276 kPa pressure and 4 added loads on tilled sandy-clay-loam soil.

on the grass field. The minimum corresponds to the measured motion resistance of 510 mm (20") wheel at 50 Psi when an additional load of 98.1 N was placed on the test rig, making a total dynamic load of 315.69 N, while the 405 mm (16") wheel had the maximum motion resistance at 414 kPa (60 psi) and 588.6 N (60 kg) additional load (total dynamic load of 803.24 N).

On this surface, 42% of the lowest occurring motion resistance was measured with the 510 mm (20") wheel occurring at all levels of inflation pressure and at the first two levels of additional loads while wheels 610 mm (24") and 660 mm (26") had 33 and 25%, respectively of the lowest occurring motion resistances at all levels of inflation pressure but at higher 392.4 N (40 kg) and highest 588.6 N (60 kg) of additional loads. The closeness of the motion resistance values of wheels 610 mm (24") and 660 mm (26") to the 510 mm (20") wheels values was also 40:60. This indicates that, the motion resistance decreases with increase in diameter, as no lowest motion resistance was measured against the 405 mm (16") wheel. From this surface, it cannot be generalised that, the larger the diameter the smaller the motion resistance, but it can be concluded that, as in the case of the first surface, that at higher inflation and higher vertical loads, the larger wheels give low motion resistances.

Motion resistance on tilled soil

Motion resistances measured on the tilled sandy-clay-loam soil for all the four pneumatic wheels under the same test variables of inflation pressures and vertical loads used on the first two test surfaces, are as illustrated in Figures 10 to 12. The motion resistances measured on this surface ranged from 23.9 N to 176.9 N, being the lowest and the highest motion resistance recorded on this surface. The minimum motion resistance was measured with 660 mm (26") wheel, at 414 kPa (60 psi) and 98.1 N additional loads (total dynamic load of 319.02 N).

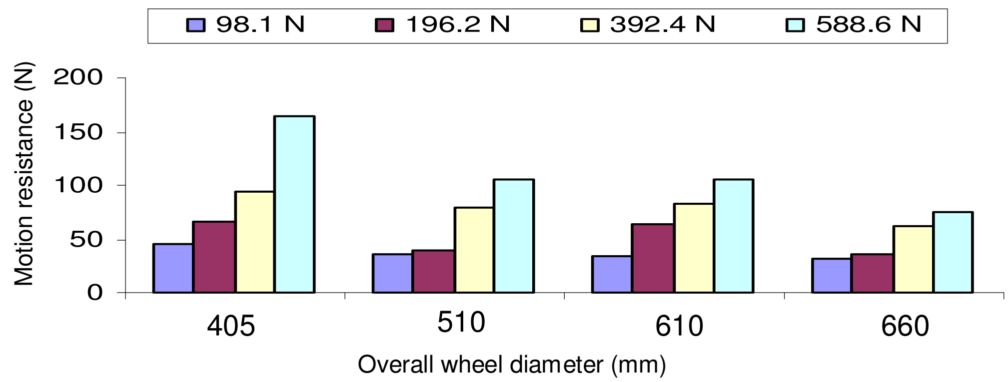

Figure 11. Motion resistance of pneumatic bicycle wheels at 345 kPa pressure and 4 added loads on tilled sandy-clay-loam soil.

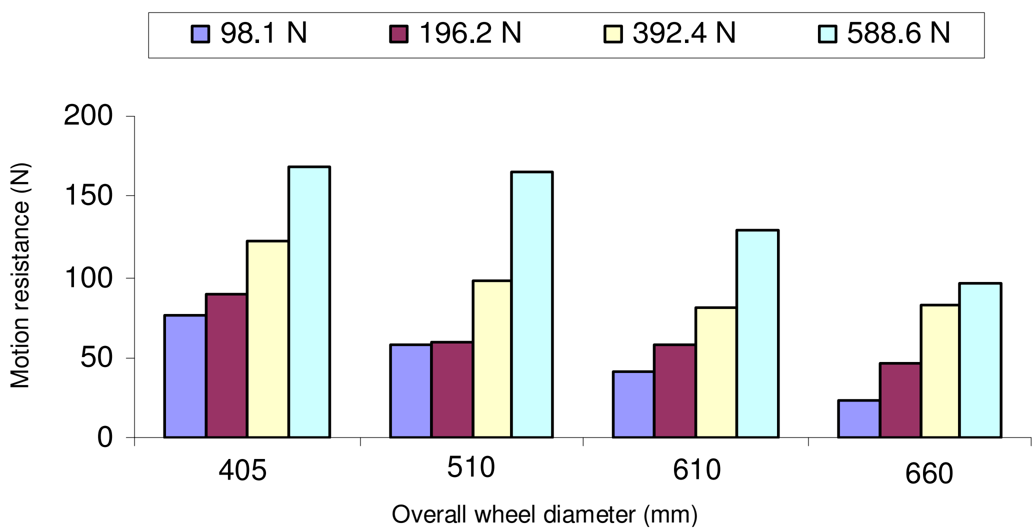

Figure 12. Motion resistance of pneumatic bicycle wheels at 414 kPa pressure and 4 added loads on tilled sandy-clay-loam soil.

Fifty-eight percent of the lowest occurring motion resistance were measured against the 660 mm (26") wheel at 345 kPa (50 psi) and 414 kPa (60 psi) inflation pressures and at all levels of additional loads except at P3L3, where the 610 mm (24") wheel had the lowest motion resistance, making a total of 42%, the lowest motion resistance measured against the 610 mm (24") wheel. The bulk of these lowest motion resistances were measured at 276 kPa (40 psi) and all load levels of additional loads. The 660 mm (26") wheel had values close to the 610 mm (24") wheel and vice-versa. This implies that on the tilled sandy-clay-loam soil, the lowest motion resistances were measured in larger wheels at almost all levels of test variables, as the 405 mm (16") and 510 mm (20") wheels had the highest motion resistances.

Summary of results

There were 12 outcomes per test wheel per surface as shown in Table 3; each of these treatments was present in all the wheels on each test surface. Hence, a comparison was made among each corresponding treatment in each wheel. On each test surface, there were 12 outcomes representing the single wheel with the lowest motion resistance and this has been identified in previous subsections on the three test surfaces. Figure 13 shows the frequency (degree) of occurrence of lowest motion resistances by all the test wheels in all the test surfaces. There were 36 outcomes from the three test surfaces and the 660 mm (26") wheel has the highest degree (frequency) of occurrence in the combined test surfaces. It has the highest on surfaces 1 and 3. The 510

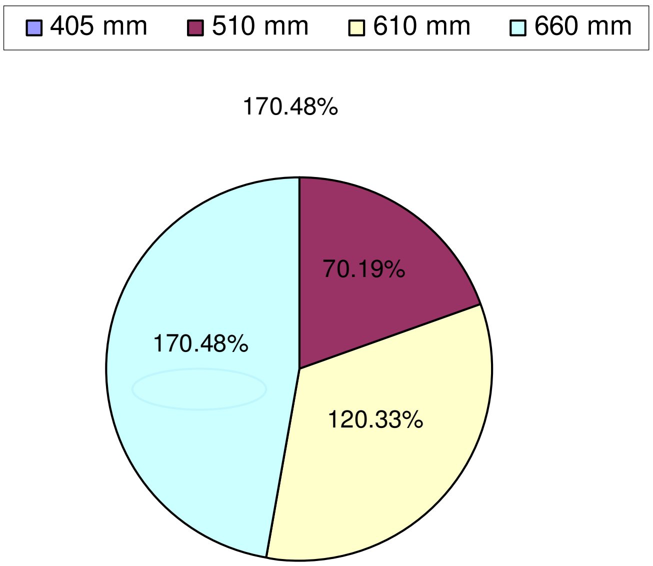

Figure 13. Degree of occurrence of lowest motion resistance of test wheels.

mm (20") and 610 mm (24") wheels had the same frequency (degree) of lowest occurring motion resistances on the test surfaces but the 510 mm (20") wheel had the highest on surface 2, but the 610 mm (24") wheel was closer to the 660 mm (26") wheel on surface 3. It can be inferred that the larger wheels have the lowest occurring motion resistances in all the test surfaces which shows that, the larger the diameter, the smaller the motion resistance especially on off-road condition.

Reducing the average motion resistances (outcomes) to 12 by finding the averages in the three test surfaces, 75% of the lowest occurring motion resistances were recorded against the 660 mm (26") wheel while the remaining 25% were recorded against the 610 mm (24") wheel. This showed that the lager wheels have lowest occurring motion resistances. The motion resistances measured on the paved and grass field were within the same range of less than 20 N with the highest on the paved surface. However, the minimum on the tilled soil was just 24 N and the maximum was 176 N, which implies that the motion resistance on the tilled soil is almost 10 times greater than those obtained on the grass field and the paved surfaces. This could be as a result of the deformable nature of the loose soil which resulted in more energy in the contacting surfaces between the wheel and the soil upon which the wheels roll.

Generally, with increase in added dynamic load, the motion resistance also increases; this could be seen in Figures 4 to 12. It was observed that with the smallest wheel which had the highest motion resistance in all the tested surfaces, the motion resistance at higher pressures and highest dynamic load (additional load) reduced because at low pressures and higher loading, the tyre flexing could contribute to higher motion resistance. The inflation pressures may not have any effect on the motion resistance in most cases because as the inflation pressures increased, the motion resistance either increased or decreased without a constant pattern.

Previous findings as reported by Macmillan (2002), Inns and Kilgour (1978) and Taylor et al. (1967) showed that for wider agricultural tyres of different sizes on different terrains, the rolling resistance (now motion resistance) and the motion resistance ratios (then coefficient of rolling resistance) of the wheels decreased with increase in overall wheel diameter. This shows that, the results obtained from this study are not at variance with their findings. However, the motion resistance obtained on freshly cultivated loam was higher than those obtained on concrete and grass field. Motion resistances of wider tyres on grass and concrete were very close, although, higher on grass field than on the concrete surface (Inn and Kilgour, 1978). Gee-Clough (1980) in his studies on the selection of tyre sizes for agricultural vehicles found out that, the tractive performance of agricultural tyres increases with increase in wheel diameter. A similar result was also obtained from the studies with narrow wheels. As it could be observed from this study, the added dynamic loads had a direct relationship with the motion resistances obtained on all the test surfaces and at every level of tyre inflation pressure, a similar finding was also reported by Arregoces (1985) and Burt et al. (1989).

Conclusions

The motion resistances of the four pneumatic bicycle wheels have been measured on paved surface, grass field and tilled sandy-clay-loam soil with the minimum on the paved surface and the maximum on the tilled sandy-clay-loam soil. The motion resistances measured on the paved and the grass field were in the same range. However, motion resistance on the tilled sandy-clay-loam soil was about 10 times greater than those obtained on the two other surfaces. The 660 mm (26") wheel has been identified to have the highest frequency of lowest motion resistance compared to the other wheels (610 and 510 mm) with 33 and 19% respectively, of lowest occurring motion resistances while 660 mm (26") wheel had 48%. The 405 mm (16") wheel had the highest occurring motion resistances in all the surfaces tested. The 510 mm (20") wheel had the highest occurring motion resistances on the grass field.

The 660 mm (26") wheel had the lowest occurring motion resistances at higher inflation pressures of 345 kPa (50 psi) and 414 kPa (60 psi) and at higher dynamic loads on all the tested surfaces while the 510 mm (20") wheel has the lowest occurring motion resistances at all inflation pressure levels and lower vertical loads.

From the conclusions, design information for low-cost, easy to maintain agricultural machinery with narrow wheels as traction members for off- and on-road usages can be obtained.

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