

Agricultural Tractor Test

Ensaaios de Tratores Agrícolas

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ABSTRACT - Machine tests are standardized procedures that aim to present reliable and impartial information of the evaluated machines. The agricultural tractor is the main source of power in the agricultural setting. Therefore, to acquire an in-depth knowledge of the operational and performance characteristics of these machines, a tractor test is necessary as this will help in achieving higher yields in the field. Performance of tests of tractors and agricultural machinery is usually the responsibility of the manufacturers, official government agencies, and research institutions. New machines and technologies are being developed; therefore, information on the current status of tractor testing and the procedures and advances in the methodologies used for the evaluation of machines is fundamental in today's agriculture 4.0. This review aims to examine the current state of agricultural tractor testing worldwide, with special focus on that in Brazil. Agriculture 4.0, or intelligent agriculture, incorporates new and advanced resources, such as computers, sensors, and actuators, which are used in operational performance and efficiency testing, thus contributing to the modernization of technology and improvement of machines. New methods of performance assessment and data collection are under consideration and should be established through clear and specific standards.

Key words: Mechanization. Agricultural Engineering. Intelligent Agriculture.

RESUMO - Os ensaios de máquinas em geral são procedimentos padronizados que objetivam apresentar informações confiáveis e imparciais a respeito dos espécimes avaliados. O trator agrícola é a principal fonte de potência no meio agrícola e os ensaios de tratores permitem conhecer profundamente as características construtivas dessa máquina, conferindo a estes maiores rendimentos no campo. A realização de ensaios em tratores e máquinas agrícolas normalmente é de responsabilidade de órgãos governamentais oficiais ou instituições de pesquisa, além dos próprios fabricantes. Novas máquinas e tecnologias estão sendo desenvolvidas e, conhecer a situação atual dos ensaios de tratores, detalhar seus procedimentos e avançar na elaboração de metodologias voltadas para avaliação de máquinas é fundamental na atual agricultura 4.0. Esta revisão buscou apresentar o estado da arte na realização de ensaios com tratores agrícolas no mundo e, particularmente, no Brasil. A agricultura 4.0 ou agricultura inteligente, incorpora novos e avançados recursos, tais como a computação embarcada, os sensores e os atuadores aos ensaios de desempenho operacional e de eficiência, contribuindo assim com a modernização da tecnologia e o aprimoramento das máquinas. Novas formas de avaliação do desempenho e coleta de dados estão latentes e precisam ser estabelecidas através de normas claras e específicas.

Palavras-chave: Mecanização. Engenharia Agrícola. Agricultura Inteligente.

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INTRODUCTION

Since the development of the first agricultural machine, continuous research efforts have been directed towards the investigation of the performance of agricultural machines to enable procurement of the best yield through their utilization. The standardized machine tests appear to meet the increasing demand for mechanization in rural areas because they are impartial and comprise precise procedures.

Agricultural tractors are the most important source of mobile power in modern agriculture; therefore, acquirement of an in-depth knowledge of the operational and performance characteristics of these machines is fundamental for achieving optimum results and resource utilization (CUTINI; BISAGLIA, 2016; RAIKWAR *et al.*, 2019).

Tractor tests allow the generation of performance data with precision and impartiality and this requires the implementation of standardized procedures, with wide recognition and acceptance by the scientific community.

The performance testing of tractors and agricultural machineries is usually the responsibility of the manufacturers, government bodies, research institutions, such as universities, and duly accredited specialized centers (MIALHE, 1996).

The main purpose of agricultural machine and tractor testing is to generate data on engine performance, transmission systems, traction capacity, protective structures, ergonomics, and energy efficiency.

New machines and technologies are being developed today and it is therefore necessary to technically evaluate each equipment and their test procedure. New test and simulation methodologies are being developed in line with the evolution of machines (FIORESE *et al.*, 2015; KUMAR and PANDEY, 2012; MATTETTI *et al.*, 2019; RAIKWAR *et al.*, 2019; SALMASI, 2007).

The knowledge of the current state and trend of tractor testing and the methods, rules, and procedures involved is of importance in the development of efficient machine testing and assessment methods for agriculture 4.0.

Large tractors with high operational capacity, autonomous or even electric, demonstrate the development of innovative strategies for futuristic agricultural practices and it is important to evaluate these new machines to maximize their operational efficiency.

The history of tractor testing in the world and in Brazil

After considerable research and improvement, the first demonstration of tractors in the United States was held in the city of Omaha, Nebraska in 1911. In 1919, the state of Nebraska passed a law requiring the testing of every tractor sold in the state and the publication of the results of such tests. Additionally, it was necessary for manufacturers to maintain a stock of spare parts for the sold units. These tests, which were conducted at the test station of the University of Nebraska, Lincoln, quickly gained worldwide recognition and were decisive in the development of standards for the classification of tractors and in the improvements of their components through the continuous incorporation of newer technologies. Thus, models that presented design problems and low performance were discontinued.

There was a gradual increase in the available engine power of agricultural tractors following the rapid increase in the size of agricultural areas for preparation and cultivation. In 1950, more than 90% of the tractors manufactured had less than 26 kW of engine power; however, in the 1960s, less than 20% possessed this power. In 1975, only 13% of the tractors manufactured had less than 30 kW and 50% of the tractors had more than 75 kW of power.

Over time, several innovations and components were added to tractors to improve their operating conditions and to meet modern farming practices. When the mass production of tractors was initiated, their sale price decreased significantly, which contributed significantly to their worldwide acceptance and perhaps made them the machines that most influenced the social development of humanity, especially rural exodus.

Presently, there are several models of tractors with different wheel systems and advanced systems with specific functions. Additionally, tractors are now being equipped with shock absorbers and upholstered seats to improve the comfort of operators, cabs with air conditioning, on-board computers, and safety systems, such as a rollover protection structure, safety belt, moving part protection systems, alarms, and electronic control sensors.

For a long time, Brazil relied solely on imported tractors, which resulted in variations in tractor types and models and the costs of purchase, maintenance, and replacement of parts.

To minimize standardization problems and to provide information on the efficiency of the different tractor models, the Ministry of Agriculture established a testing

and rural training center (CENTRI) in Ipanema, Sorocaba-SP, to conduct official testing of tractors and agricultural machineries. CENTRI was later changed to the National Center of Agricultural Engineering (CENEA), which in partnership with the agricultural engineering division of Jundiaí, Agronomic Institute of Campinas, and performed standardized tests on tractors and machines according to specific Brazilian standards, such as NBR 10400 and former MB 484 of the Brazilian Association of Technical Standards (ABNT).

Tractor testing stations in Brazil

Tractor testing commenced in Brazil in the early 1950s in the CENEA, at the Ipanema farm, Iperó-SP, and in the 1980s, it was also accredited by the DEA/IAC, which was located at Jundiaí-SP.

In Brazil, after a long period of tractor testing, which considerably contributed to the establishment and improvement of the national tractor industry, tests gained a negative reception because they were perceived solely as a way to “fail” or “approve” the tested machines, which harmed the continuity of work and culminated in the closure of the testing centers.

In the early 1990s, with the closure of CENEA and DEA/IAC, the national industry was left without the support of the valuable information generated through official tests. Currently, the testing of tractors and machines in Brazil is performed according to international methods and standardized procedures in institutions of higher education and unofficially by public-private partnerships. Examples of these institutions are UNESP, USP, UFSM, UFV, UFC, UFSC, UFPR, and UFMT.

Tractor manufacturers continue to equip and modernize their support centers for the development of new products. Although to a lesser extent, a few private companies have been offering consultation and evaluation services for agricultural machineries and equipment, including tractors.

Test stations abroad

The University of Nebraska in Lincoln, USA, is home to one of the world’s most traditional and famous testing stations, the Nebraska Tractor Test Laboratory (NTTL), which has conducted a myriad tests and is an international reference in the field of agricultural tractor testing.

The Nebraska test station commenced its activities, driven by the effort of a farmer who was dissatisfied with the performance of a purchased tractor and the unavailability of spare parts in the region; he sought assistance from the agricultural engineering

department of the University of Nebraska. This led to the drafting of a law making tractor testing before commercialization mandatory.

In 1885, the German test station, known as the agricultural machinery test station of the *Deutsche Landwirtschafts-Gesellschaft* (DLG) was founded in Gross-Umstadt and accredited by the agricultural government body of the country. The station is managed by the German Agricultural Society. The tests are voluntary and the results are published as test reports, which are distributed to members of the German Agricultural Society and sold to the general public. Machines and products that comply with the requirements established by the minimum quality standard, receive a “DLG quality seal”.

In Spain, the Agricultural Mechanics Station of Madrid (EMA) is recognized by the Organization for Economic Cooperation and Development (OECD) and the Ministry of Industry and Energy as the official laboratory for tests related to the homologation of agricultural tractors. The station is active and respected in the agricultural setting and has made tremendous contribution to the development of several types and models of agricultural machinery tests.

In England, the Silsoe Research Institute, which was affiliated with Oxford University was established in 1924 in the Bedford region. The institute conducted tractor testing in accordance with OECD codes and European Community standards; however, it has ceased activities.

In 1944, the Institute of Rural Engineering (*Instituto de Ingeniería Rural - INTA*), Buenos Aires, Argentina, initiated its activities in several areas of agriculture, including performance of the assessment of tractors, sowers, and sprayers, and the standardization of agricultural machineries.

Italy is an active country in the field of agricultural machinery and has developed advanced OECD test stations, including the Milan, Bologna, and Naples test stations.

In France, the National Center for Studies and Experimentation on Agricultural Machines (*Centre National d’Etudes et d’Experimentation de Machinisme Agricole - CNEEMA*), Antony, is one of the most active test centers in the field and is the central coordinating body for tractor testing.

Compliance testing, certification, and approval of tractors

According to their application and the use of their results, tractor tests may have different objectives or purposes, and may be classified as certification, compliance, or approval tests.

The certificate of conformity is intended to certify that characteristics of a certain product are in compliance with or in accordance with standards specified by its manufacturer. The test follows internationally standardized models, which involve duly accredited institutions. The certificate of conformity is the same as the certificate of quality and can be provided through a document or graphic symbol, usually a seal.

The approval is the act of verifying that a product meets certain requirements, which are established by a competent authority before being commercialized or authorized for mass production. Approval considers technical aspects; however, economic and political factors are also considered.

Approval was the system used by CENEA throughout its existence and was directly associated with actions of the Ministry of Agriculture and funding provided by financial institutions to farmers.

In general, the certificate of conformity attest that a product, service, system, or employee complies with the requirements of a technical standard. Certification serves as a guarantee to consumers that the product or service meet the minimum quality standards.

Certification is important for foreign trade, for the participation of countries in economic blocks, and in the establishment of commercial relations, which in some cases, are only possible if the member countries have a harmonious and mutually recognized certification system.

Brazil is currently initiating the process of joining the OECD, which offers new perspectives for the compliance with standardization and the establishment of good practices for economic development.

International and national standards are a fundamental part of certification. Several standards have been adopted abroad, such as SAE, DIN, and ISO. In Brazil, the Brazilian Association of Technical Standards (ABNT), a private non-profit organization, is the national forum for standardization.

The ABNT aims to ensure consensus among the involved parties, which include industries, consumers, and the government by guaranteeing a seat and vote for the parties in officially established committees.

In addition to numerous standards aimed at mechanized agricultural systems, the ABNT NBR/ISO 789 standards includes several methods and instructions for tractor testing. Developed by the Brazilian committee for tractors and machinery for agriculture and forestry, the standard includes information categorized into 13 chapters, which are focused on providing reliable guidelines for performing agricultural tractor tests.

The Brazilian set of standards was based on the international ISO standard, developed by Technical Committee ISO/TC 23: Tractors and Machinery for Agriculture and Forestry, Subcommittee SC 2, Common Tests (ABNT ISO 789-1:2020).

The principal Brazilian standards on the testing of agricultural tractors include the following: NBR 789-1 – Agricultural tractors — Test procedures, part 1: Power tests for power take-off; a NBR 789-2 – Agricultural tractors — Test procedures, part 2: Rear three-point linkage lifting capacity; NBR 789-3 – Agricultural tractors — Test procedures, part 3: Turning and clearance diameters; NBR 789-4 – Agricultural tractors — Test procedures, part 4: Measurement of exhaust smoke; NBR 789-5 Agricultural tractors — Test procedures, part 5: Partial power PTO — Non-mechanically transmitted power; NBR 789-6 Agricultural tractors — Test procedures, part 6: Centre of gravity; NBR 789-7 Agricultural tractors — Test procedures, part 7: Axle power determination; NBR 789-8 Agricultural tractors — Test procedures, part 8: Engine air cleaner; NBR 789-9 Agricultural tractors — Test procedures, part 9: Power tests for drawbar; NBR 789-10 Agricultural tractors — Test procedures, part 10: Hydraulic power at tractor/implement interface; NBR 789-11 Agricultural tractors — Test procedures, part 11: Steering capability of wheeled tractors; NBR 789-12 Agricultural tractors — Test procedures, part 12: Low temperature starting; NBR 789-13 Agricultural tractors — Test procedures, part 13: Terms, definitions, and test specimen report.

International research institutions and machine manufacturers that have their own test stations use the OECD codes to conduct the evaluation of farm tractor performance. The test codes proposed by the OECD cover various applications and situations and include codes 2 to 10.

Among the test codes proposed by the OECD, code 2 focuses on the standardization of tests on agricultural tractors and these tests are related to tractor performance in static dynamometer tests and in dynamic traction tests on tracks with standardized rolling surface.

OECD codes 3 and 4 address the testing of tractor protective and safety structures. Code 5 involves the measurement of noise level at the operator's station. Codes 6 to 10 specify the standards for the evaluation of tractor protection structure, ergonomics, and safety.

Tractor tests - different interpretations and applications of the results

The main objective of performing tests on agricultural tractors is to generate information and technical data on the performance of the machine during

agricultural activities, which are free from commercial interference or bias.

From the perspective of the tractor user or final consumer, the test station and the results published are an indirect guarantee of the minimum operating conditions and durability of the machine. Providing users with data that allow the adoption of rational criteria for the selection and operation of tractors is an important benefit of standardized tests.

Additionally, machine and equipment manufacturers should have quantitative data to improve their products and systems, because they can always install and maintain their own testing stations. Furthermore, manufacturers need a third-party agent to certify or evaluate their products, thus ensuring the authenticity of the results.

The advantages of these tests for machine manufacturers include the authenticity of the results obtained, the use of the results for sales and marketing promotions, and the constant improvement of their products.

Units of measurement and tolerances used in tractor tests

Tractor testing requires instrumentation and equipment for data collection, with minimum tolerance, which are defined by the international standards ISO and OECD. All tests performed on agricultural tractors, both static dynamometer test and traction tests, must meet the requirements and tolerances recommended for the instrumentation, otherwise the results obtained may not be acceptable.

The unit of rotation measurement is revolutions per minute (r/min), with tolerance of $\pm 0.5\%$; the unit of time measurement is second(s), with tolerance of $\pm 0.2s$; distance is measured in meters (m), with tolerance of $\pm 0.5\%$; the unit of force is Newtons (N), with tolerance of $\pm 1\%$; fuel consumption is measured in kilograms per kilowatt-hour (kg/kWh), with tolerance of $\pm 1\%$; atmospheric pressure is determined in kilopascals (kPa), with tolerance of $\pm 0.2kPa$; tire pressure is measured in kilopascals (kPa), with tolerance of $\pm 5\%$; fuel temperature is measured in degrees Celsius ($^{\circ}C$), with tolerance of $\pm 2^{\circ}C$; wet-and-dry bulb thermometers for measuring relative air humidity have a Celsius ($^{\circ}C$) scale with, tolerance of $\pm 0.5^{\circ}C$.

Tractor power take-off testing

Power take-off (PTO) testing is the first step in the evaluation of a tractor's power performance, as it analyzes power losses generated by the engine's accessory elements

and the tractor's transmission elements. Additionally, it is an indirect way of obtaining information on the tractor's engine.

For PTO testing, the tractor power take-off shaft is connected to a brake dynamometer using an articulated transmission or cardan shaft at an angle not exceeding 5° . The relationship between PTO rotation and engine rotation is positive, passing through one or two pairs of gears; hence, a drop in PTO rotation value implies a proportional drop in engine rotation.

The basic principle of a brake dynamometer relies on application of loads on the tractor's PTO to prevent its rotational movement (Figure 1). When the brake is activated, a force is applied to the load cell of the equipment, indicating the force applied to the dynamometer shaft in real time. Torque at PTO is force times the length of the lever arm. In electric current dynamometers, the rotation of the main shaft and the force applied to the brake produce an electric current proportional to the torque, which is obtained indirectly through this relationship.

Figure 1 - Dynamometer test of an agricultural tractor, work bench, and instrumentation. NEMPA/Botucatu 2017



For the standardized test, the PTO shaft must rotate at the recommended or rated speed (540 rpm/1000 rpm), with the flow rate of the engine injector pump at its maximum. After PTO rotation has been stabilized, the brake should be applied until the lowest engine speed is reached and this value is recorded. Subsequently, the brake is released gradually and torque values for various speed and load conditions should be recorded.

Thus, it is possible to create a graph of torque as a function of PTO or engine rotation (considering the transmission ratio between the engine and the PTO). Engine or PTO power can be calculated under various conditions using the torque-speed pair.

The data recorded in the official tests should include the following: engine and PTO angular velocity, moment of force on the dynamometer, temperatures of cooling fluids, fuel, lubricant, intake air, and wet-and-dry bulb, atmospheric pressure, and fuel consumption.

The testing modalities include testing the available power at different engine angular velocities, testing the available power at engine rated angular velocity, and testing the available power at partial moments of force.

In the available power test, the engine's variable angular velocity should be recorded together with the data necessary to plot the power, moment of force, specific fuel consumption, and hourly fuel consumption curves as functions of angular speed.

Tests are conducted at angular velocities from 15% below, which corresponds to the maximum moment of force up to the maximum angular velocity without load.

Procedures for PTO testing

Tests on the PTO can be divided into the following three main parts:

Two-hour test: test of the available power at engine-rated angular velocity in continuous operation for two hours, during which readings are taken at time intervals not exceeding ten minutes. The power recorded in the report is the average of all readings taken over the defined period. The deviation should not exceed 2% of the average of the last six readings (the test should be repeated if it does).

Maximum power test with PTO at 540 rpm (1000 rpm optional): test of the available power at PTO-rated angular velocity in continuous operation for one hour, during which readings are taken at time intervals of less than ten minutes and the average of the readings is recorded.

Test with partial loads (torques): test of the power available at partial moments of force, lasting at least 20 minutes in each phase, with readings taken at intervals not exceeding 5 minutes. The loads should include the following conditions: 85% of the moment of force obtained in the available power test at engine-rated angular velocity; without moment of force; with the full moment of force obtained in the available power test at engine-rated angular velocity; and 75%, 50%, and 25% of the maximum moment of force at rated rotation velocity.

Tractor tests performed under different conditions using a dynamometer, serve as an initial parameter for performance tests on standard tracks, as they show the maximum potential performance and power of the tractor in a static situation. However, due to the action of friction variables, ground surface, and type of wheels, a reduction in maximum performance is expected in traction tests.

Rear lift and three-point hitch capacity

This test is primarily governed by NBR/ISO 789-2 and specifies the procedures for determination of the lifting capacity of three-point hitch implements attached to the rear of tractors.

The position of the applied load should be monitored, and the center of gravity should be 610 mm at the rear of the coupling points. The pressure and temperature of the hydraulic fluid at each stage of the test should be checked during the tests, with the zero point being considered when the arms are unladen and at the lowest point in relation to the ground.

The pressure of the hydraulic system (in kPa) and the lifting height should be obtained under each loading condition at the hydraulic arms.

Turning diameter and turning space

Agricultural tractors are used in locations where it is difficult to maneuver and steer; hence, it is essential to evaluate their ability to make turns in the smallest possible radius. Tractors with good performance in tests of turning diameter are more versatile regarding maneuvers with machines and implements in the field.

For the turning diameter test, the NBR ISO 789-3 standard recommends using preferably a dry, compact, or paved flat surface with a grade not greater than 3% in any direction. The paved surface should have adequate tire adhesion, should be capable of displaying legible markings, and should be resistant to defacement by the turning of the machines.

The measurements are conducted on the ground using the marks left by the tires and can be performed with the aid of global navigation satellite system, with the use of a GNSS receiver in the point or route storage mode.

The test consists in making sharp turns, with the steering wheel at its maximum extension, with and without the use of the brakes in both directions of movement of the tractor. Right and left turns should be made at idling speed not exceeding 2 km/h, and in the case of brake steering, the pressure on the pedal should not exceed 60 daN.

All operational characteristics of the tractor should be clearly defined and the configuration should be original,

as specified by the manufacturer. Preferably, tractor gauge should be adjusted to values close to 1.5 ± 0.025 m. Full details of the manufacturer, types of wheels, ballasts, and tire pressures should be described in the test report.

Gas exhaust assessment

The gas exhaust assessment of agricultural tractors is important for determining the environmental impact and pollution potential of mechanized activities. Gas assessment tests can be performed on engines or tractors.

The test procedure should include the use of an opacimeter to measure the presence and opacity of gases emitted as exhaust smoke. The test requires precise control of the ambient temperature and atmospheric pressure at the data collection site. Another relevant factor is the detailed characterization of the fuel used.

The opacity of the smoke produced by an engine should be measured with the engine subjected to 80% of its maximum load and at constant speed of rotation. Opacity data should be collected at six different points, the highest and the lowest being obligatorily the maximum power rotation and 55% of the maximum power or 1000 rpm, whichever occurs first.

The test results should be described in the report together with full tractor and manufacturer data, detailed data on the opacimeter used, fuel data, and absorption values.

Determination of the center of gravity

The tractor's center of gravity (CG) is not a fixed point in the tractor; moreover, changes made by placing ballasts and accessories and by attaching agricultural equipment, such as bars and reservoirs for the application of pesticides and correctives and sower simply that the tractor's CG be calculated whenever any change is introduced in the system.

Tractor manufacturers usually provide the main dimensions of the tractor and its weight distribution on the tires, which enables determination of the CG of the tractor under static conditions, without additional accessories or loads.

Drawbar power tests

Traction is one of the most important applications of agricultural tractors and the position of the drawbar and its angle relative to the ground for coupled machines or implements should be appropriate.

For this test, the drawbar should be coupled to the resistant element of the tractor (dynamometer installed for force measurement), such that the traction line is parallel to the support plane and positioned in the central

longitudinal plane of the tractor, and its height relative to the ground should remain constant, leveled, and aligned.

Drawbar performance tests should be performed on a standard track (concrete, asphalt, or dirt track) or under field operating conditions, with the tractor pulling an agricultural machine or implement. The tractive force should not exceed 80% of the weight transferred from the front to the rear wheels (static reference).

It is not recommended to correct the traction test data for atmospheric conditions or other factors, and the atmospheric pressure of the site should not be less than 96.6kPa. If the altitude of the test region is not suitable for this determination, a modification can be made to the fuel supply system, which should be mentioned in the official report.

The following data should be recorded: average force on the drawbar; angular velocity of the engine; number of wheel or belt turns; the time spent on straight-line sections of the track to cover a given distance and fuel consumption under these conditions; total volume of fuel consumed; temperatures of cooling fluid, lubricating oil, engine intake air, fuel, wet-and-dry bulb, and transmission oil; and the local atmospheric pressure.

According to ABNT ISO 789-9, the atmospheric temperature of the test track should be between 15 °C and 20 °C. Tractor tread bar height should be at least 65 % of the height of a new tread bar.

In a traction test, it is necessary to apply controlled braking loads on the agricultural tractor, which can be generated by other tractors or by dynamometer cars (Figure 2) coupled to the rear of the tested tractor. For load application and data collection and storage for subsequent adjustment and presentation, braking systems should be equipped with devices, sensors, controllers, and a data acquisition system (GABRIEL FILHO *et al.*, 2008). Currently, intelligent communication and data transmission systems are also warranted.

Testing of wheeled tractors on concrete tracks

Concrete tracks are the most used surfaces in tractor test stations because they are easier to standardize. They should be flat, with straight-line stretches long enough to facilitate the stabilization of the measuring equipment and the storage of sufficient data in a stable travel regime at constant speed.

Concrete tracks are usually oval, with straight-line stretches of 100 m to 200 m and an internal curve radius of around 20 m. Measurements should be made solely on straight stretches of the track.

To evaluate all parameters recommended in the standard, the tractor being tested should pull a trailer

Figure 2 - Dynamometer unit for the application of controlled loads in drawbar performance tests. NEMPA/Botucatu 2018

with a brake system or a dynamometer car equipped with a traction dynamometer (load cell), an independent tachometer (odometer wheel), a tachometer on the tractor's driving wheels, a tachometer on the engine spindle, a precision apparatus (flow meter) for measuring fuel consumption during short distance travel, and apparatuses for measuring temperature and atmospheric conditions. Generally, a load that is sufficient for the tractor to be tested to its extreme limits should be provided.

For small dynamometer cars that do not have good braking capacity, other tractors should be added to the brake set, which should be engaged in a specific gear, with

the engines turned off (working as compressors) to increase movement resistance and, the tractive force, which serves as a resistance to the tested tractor. The set formed by the tractor to be tested, the dynamometer car, and the auxiliary tractor is known as the test train (Figure 3).

The main parameters obtained in traction tests can be determined according to equations 1 to 3. The slip (or skidding) parameters of the wheels are shown in equation 1.

$$\text{Wheel or track slip (\%)} = 100 (n1 - n0) / n1 \quad (1)$$

Where: $n1$ = is the sum of the revolutions of all driving wheels or tracks for a given distance with slip; and

Figure 3 - Dynamometer unit for the application of controlled loads in drawbar performance tests. NEMPA/Botucatu 2018

$n\theta$ = is the sum of the revolutions of all driving wheels or tracks for the same distance without slip.

Traction yield (η_b) is the ratio of the maximum power at the drawbar, obtained in the desired ground conditions to the maximum engine power transferred to the wheels, as shown in equation 2.

$$\eta_b = N_b / N_m \quad (2)$$

Where: N_b = power on drawbar for the conditions of wheel/ground contact;

N_m = engine power transferred to the wheels.

Traction coefficient (TC) is the ratio of the tractive force on the bar to the load on the driving wheels (dynamic load), as shown in equation 3.

$$TC = F_b / W_2 \quad (3)$$

Where: F_b = force on drawbar in operating conditions; W_2 = dynamic load on drive wheels.

Traction tests under agricultural field conditions

Owing to environmental variability and the difficulty of controlling the sources of variation in results, there are no specific standards for field tests. However, the OECD has a procedure for performing tests under real field conditions (Figure 4). As a fundamental step to ensure the reliability and comparability of results obtained in field tests, a detailed description of all processes, equipment, and components of the test is necessary.

The field test should commence with a perfect characterization of the type of soil, initial conditions of the soil, the equipment to be towed, the desired travel speed, and the dimensions of the plot where the assembly will operate.

All instruments used to obtain data in standardized tests, such as the load cell of the tractor and the equipment for determining tractive force, fuel consumption meters, tachometers installed on the wheels, and engine speed sensors, should be compatible with the operational conditions and described in detail.

Parameters evaluated and analysis of the results of standardized traction tests

The main tests performed on the drawbar can be divided into maximum power tests, in which various loads are applied using different gears and maximum acceleration until the tractor loses engine speed or until it reaches the limit slip of the surface (MASIERO; LANÇAS; MONTEIRO, 2011). All tests are performed on tractors with and without ballast.

Different curves consisting of the following variables, travel speed, power at the drawbar, hourly fuel consumption, specific fuel consumption and slip should be plotted as a function of tractive force.

The traction tests with constant force on the drawbar may be divided into two sections. In the first section, the tractor should be operated for five hours in a gear normally used in agricultural work (agreed by the test station and the manufacturer) and which enables a tractive

Figure 4 - Field tests to assess tractor performance with a dynamometer car; subsoiler; tipping trailer. NEMPA/Botucatu 2018



force equivalent to 75% of the maximum power on the drawbar in the selected gear.

In the second stage of the test, it is necessary to apply a tractive force for five hours, which should result in a decline of 15% in tractors with pneumatic wheels and 7% in crawler tractors in the maximum power test. The gear used should be the fastest, to provide the required tractive force, with the engine running under the control of the governor.

The determination of the power lost in wheel slip (ND) is one of the main checks and analyses of this test and it is achieved using equation 4.

$$\text{Where: } ND = [N_o(100/100 - D)] - N_o \quad (4)$$

Where: ND = power lost in wheel slip; N_o = power observed in the wheel slip situation; D = wheel slip (%).

In addition to energy performance (equation 4), it is also possible to determine parameters, such as fuel consumption, power at the bar, tractive force, traction yield, traction coefficient in each condition, with and without ballasts in the tractor. These variables can be compared with the results of the dynamometer tests such that the efficiency of the transmission and wheel mechanisms in power conversion can be demonstrated.

Incident vibration tests at the operator station

Mechanical vibrations are caused by the running engine and the roughness of the ground surface. Vibrations become problematic when the frequency to which the human body is exposed affects vital functions.

Most of these problems can be avoided by conducting data surveys relating to working conditions and by adopting limit values for exposure levels. Vibration tests allow the quantification of variables and provide fundamental information for the improvement of machine construction.

Vibration tests are conducted according to the guidelines of NBR/ISO 2631, Mechanical vibration and shock — Evaluation of human exposure to whole-body vibration.

The standard defines the limits of exposure of the human body to vibrations, establishing the levels of comfort, work efficiency, and health risk. These limits are established according to the levels of vibration frequency, accelerations, exposure time, and direction of vibration relative to the trunk.

Additionally, test procedures require standardized surfaces; therefore, vibration tracks are used for these tests. On standard tracks, it is possible to vary tractor travel speed, engine speed, tire inflation pressure, and operator station damping systems.

To completely understand the impact of vibrations on operators, the standards recommend that measurements should be made as close as possible to the point or area in which the vibration is transmitted to the tractor operator. It is common to use the seat index point (SIP), which is defined by the NBR/ISO 5353 standard, to obtain the vibration values that affect the whole body of the operator (Figure 5).

The frequency range obtained in the tests determines the workload to which the operator may be subjected. The higher the vibration, the shorter the time of exposure of the operator. It should be noted that these standards and tests are usually neglected by manufacturers and research centers, because the standards propose critical values that are difficult to meet, which results in legal problems and labor issues.

Noise tests on agricultural tractors

Noises cause acoustic trauma to and occupational problems for agricultural machinery operators. As tractors are widely used in agriculture and the working hours are

Figure 5 - Vibration tests on a standardized surface: a. datalogger system; b. vibration sensor in the operator seat; c. instrumented tractor on an ISO 5008 standardized surface



extensive, it is essential to assess the noise levels which operators are subjected to in each machine and work condition.

Noise tests are conducted based on the OECD code 5, which recommends that precision equipment should be used for sound data acquisition. The decibel meter should comply with the international IEC 60651 standards, and the measurement should be performed at A-weighted frequency, with slower response, which is more suitable for the assessment of noise emitted by machines.

The measurement should be performed in a quiet and open location and the tractor should be unballasted. The terrain surrounding the measuring area should be flat, within a radius of at least 20 meters and the rolling surface should be smooth enough to prevent excessive noise.

In tractors with cabs, the internal measurements should be conducted with the doors and windows completely closed and the microphone diaphragm should face forward such that its center is 250mm from the center plane of the operator's seat, on the noisiest side of the tractor, positioned 700mm above the operator's central index point, and 10mm forward of that point (Figure 6).

Agricultural tractors tests at NEMPA/UNESP Botucatu

The Agroforestry Machinery and Tire Testing Center (NEMPA) was established by the Department of Rural Engineering of the School of Agronomic Sciences of Universidade Estadual Paulista "Júlio de Mesquita Filho" (UNESP/Botucatu).

NEMPA, in partnership with international organizations, has been conducting studies on machines and tractors for more than 20 years. It possesses an

infrastructure appropriate for tractor tests according to the OECD standards and includes qualified staff and exclusive devices for the evaluation of agroforestry machines and tires.

NEMPA, in partnership with the Agricultural and Forestry Teaching and Research Foundation (FEPAF), has been undertaking several testing and evaluation activities for machines of a vast majority of national manufacturers of tractors, sprayers, harvesters, and tires (AGCO – Massey Ferguson and Valtra; Agrale; CNH - Case New Holland; John Deere; Siltomac; Jacto; Goodyear - Titan; Michelin; Pirelli - Bridgestone; Trelleborg), in addition to field tests with large companies in the sugar-energy sector.

NEMPA has an experimental area consisting of five test tracks and one vibration track (Figure 7).

Tractor testing procedures in NEMPA

The initial tractor tests are performed on a dynamometer; subsequently, tractors are subjected to traction tests on different surfaces. As a standard procedure, the tractors are appropriately weighed and instrumented before testing.

In the traction tests without ballast, liquid and solid ballast are completely removed from the tractor for concrete track tests. For the test with ballast, tractor adjustment is performed using a ratio of total tractor mass to engine power of approximately 75kg for each kW of engine power.

Ballasting has a direct influence on the traction capacity of the tractor and should be adequately distributed among the axles to provide better adhesion between the wheels and the ground, without resulting in excessive strain, especially on the transmission system.

Figure 6 - Instrumentation for testing noise in an agricultural tractor



Figure 7 - Standardized tracks for agricultural tractor testing, from left to right: OECD oval concrete track; mobilized soil track; conventional soil-in-preparation track; no-tillage soil track, firm soil track, and ISO 5008 tractor vibration track



The distribution of mass in the tractor for the ballast tests should be as close as possible to $65\% \pm 5\%$ of the total mass on the rear axle and $35\% \pm 5\%$ on the front axle for tractors with 4×2TDA or 4×4 traction, depending on the recommendation of the manufacturer and the test conditions.

All weighing tests should be performed with a filled fuel tank of the tractor and the weight of each wheel should be recorded with and without the operator in the tractor (Figure 8).

After completion of loading for the tests, complete instrumentation of the tractor should be performed, with the installation of rotation sensors in the wheels and in

the PTO, flow meters to measure fuel consumption, and temperature sensors for engine oil, cooling fluid, and fuel inlet and return.

All data collected during the tests should comply with the tolerance limits indicated by the applicable standards. The flow sensors for determining fuel consumption should be installed in accordance with the tractor's supply system. Usually, one of the flow sensors is installed in the tractor's engine supply inlet, between the fuel supply pump (low pressure) and the injection pump (high pressure), while the other is installed in the fuel return circuit. The difference between the values obtained indicates the fuel consumption of the tractor.

Figure 8 - Adjustment, instrumentation and weighing of tractors in tests



Drawbar test mobile unit

The drawbar test mobile unit (UMEB) was built to determine drawbar performance. The tests using the UMEB are performed strictly following the OECD guidelines (Figure 9).

An instrumentation bench should be assembled inside the UMEB to accommodate the reading panels and the electronic system for data acquisition and brake control, which are driven by a pneumatic valve for its six wheels.

To determine the force required on the drawbar, a load cell with a capacity of 100 kN is installed at the front of the UMEB. To ensure that the tractive force on the bar remains constant during the working distance (normally from 25 to 40 meters, depending on the standard), the operator indicates the desired value of the load to be applied; additionally, an electromechanical system controls the brake pressure regulating valve, thus maintaining the stability of the load on the traction bar, with a final value variation of $\pm 1\%$.

The 30 meter-long segments ("shots"), with the tractor subjected to constant and steady tractive force, are repeated and the force applied to the traction bar is increased gradually until the force that causes a tractor slippage of more than 15% or an engine rotation below 1700 rpm is reached.

The results obtained in the traction tests enable the study of the correlation of the power developed in each tractor gear under different operating conditions with the traction coefficient, wheel slip, fuel volumetric consumption, specific fuel consumption, engine rotation, and displacement speed of the assembly.

All data obtained in the traction tests with and without ballast, in addition to the data on environmental characteristics and atmospheric conditions, are compiled in a final performance report according to the format proposed in OECD code 2. Table 1 partially presents the results of a tractor with a 58-kW power engine and a mass of 3200kgf in a test conducted on a concrete track without ballast.

Field tests and machine performance

The field tests enable the evaluation of the performance of tractors in real work situations and the parameters evaluated in these tests are mainly related to energy performance (MONTANHA *et al.*, 2011; MONTANHA *et al.*, 2012; MONTEIRO *et al.*, 2013;) and machine operation (YANAI *et al.*, 1999; LOPES *et al.*, 2005) (Figure 10).

To perform field tests, it is necessary to comprehensively describe the mechanical assemblies as well as the variables and covariates involved in the process. The application of a sufficient number of repetitions in the treatments should guarantee the statistical reliability of the results, because performance of these tests using randomized experimental designs is not always possible.

There are several possibilities of data interpretation and presentation; however, the most recurrent approaches in the literature involve the investigation of the correlation of energy performance to traction variables, because these evidently account for the cost of operations and are determinants in the evaluation of machines.

Figure 9 - Drawbar test mobile unit - UMEB



Table 1 - Results of a traction test in a concrete track using a medium power tractor. Example of data compilation. NEMPA - 2018

Tractor Model XXX: Drawbar Performance								
Unballasted (3200kgf) - Front Drive Engaged								
Maximum Power in Selected Gears								
Tire Pressures - Front (96kPa); Rear (110kPa)								
Gear number and range	Power	Drawbar pull	Speed	Engine speed	Fan speed	Slip of wheels and/or tracks	Specific fuel consumption	Specific energy
	kW	kN	km/h	min ⁻¹	min ⁻¹	%	g/kWh	kWh/l
3.3.1 POWER IN TESTED GEARS/SPEED SETTINGS								
A1	15.86	26.13	2.19	2518	2845	13.85	416.45	1.99
A2	23.87	27.94	3.08	2494	2818	12.33	363.77	2.28
A3	31.51	27.05	4.2	2471	2792	12.17	353.58	2.35
B1	35.8	26.63	4.84	2392	2702	10.24	332.27	2.5
B2	37.78	21.71	6.42	2072	2341	4.54	269.8	3.08
B3	38.16	14.92	9.21	2180	2463	2.54	272.43	3.05
C1	40.11	12.7	11.37	1917	2166	1.27	254.22	3.27
3.3.2 FUEL CONSUMPTION								
3.3.2.1 in selected gear/speed setting nearest 7.5km/h, at maximum power at rated engine speed								
B2	36.78	20.65	6.42	2104	2377	3.79	272.14	3.05
3.3.2.1.1 75% of the pull corresponding to maximum power at rated engine speed								
B2	25.59	14.61	6.31	2036	2300	2.41	319.17	2.6
3.3.2.1.2 50% of the pull corresponding to maximum power at rated engine speed								
B2	17	9.96	6.15	1962	2217	1.08	372.28	2.23
3.3.2.1.3 highest gear/speed setting at reduced engine speed able to achieve both 3.3.2.1.1 and 3.3.2.1.2; same pull and travelling speed as those in 3.3.2.1.1								
B3	26.31	14.61	6.49	1536	1735	3.26	261.95	3.17
3.3.2.1.4 same gear/speed section as 3.3.2.1.3 at reduced engine speed; same pull and travelling speed as those in 3.3.2.1.2								
B3	18.65	9.64	6.97	1641	1854	2.73	322.64	2.57
3.3.2.2 in selected gear/speed setting between 7km/h and 10km/h at rated engine speed								
B3	36.96	15	8.88	2090	2361	2.01	279.07	2.97
3.3.2.2.1 75% of the pull corresponding to maximum power at rated engine speed								
B3	25.77	11.01	8.43	1985	2243	2.71	304.08	2.73
3.3.2.2.2 50% of the pull corresponding to maximum power at rated engine speed								
B3	19.14	7.85	8.78	2056	2323	2.2	365.5	2.27
3.3.2.2.3 highest gear/speed setting at reduced engine speed able to achieve both 3.3.2.2.1 and 3.3.2.2.2; same pull and travelling speed as those in 3.3.2.2.1								
C1	27.69	10.89	9.16	1543	1743	1.78	285.54	2.91
3.3.2.2.4 same gear/speed setting as 3.3.2.2.3 at reduced engine speed; same pull and travelling speed as those in 3.3.2.2.3								
C1	18.68	7.1	9.47	1571	1775	1.03	286.15	2.9

Figure 10 - Field tests of mechanized sets on different surfaces performed by NEMPA Botucatu



Figures 11 to 14 present some examples of graphs for the presentation of field test results with agricultural tractors. These graphs allow easy interpretation of the data and quick understanding of variable behavior by the reader.

A majority of the international standards recommend the presentation of test results (through official reports) in a table format; however, this may improve with the use of new presentation methods.

Field test reports follow the basic format of official test reports but allow inclusion of comprehensive descriptions of the experimental process, which is highly recommended and ensures future comparability with similar work.

How can tractor tests contribute to agriculture 4.0?

The modern agricultural tractor has come a long way compared to its previous versions. Technologies such as onboard electronics, steering and geolocation systems, and telemetry have made the tractor an extremely complex and expensive multipurpose machine.

Machine tests allow the optimization of energy resources and the reduction in the variable costs of mechanized operations. However, contemporary methodologies should include novel ways of evaluating hybrid and electric engines and autonomous systems, and this evolution of the current standards will pose a challenge for the standard-setting authorities. The OECD has recently included subgroups of studies for autonomous tractors and for electric tractors.

Agriculture 4.0 or intelligent agriculture allows the introduction of new features such as embedded computing, sensors, and actuators in tractor performance and efficiency tests, thus contributing to the modernization of technology and the improvement of machines. New forms of performance assessment and data collection are latent and should be established through clear and specific standards. An example of this progress is the collection of fuel consumption data through the tractor’s CAN network, which removes the necessity of installing flow sensors.

Figure 11 - Example of presentation of the results of tests conducted on a firm soil track with a 132kW engine agricultural tractor, in L4 gear with three sets of agricultural tires. Regression analysis of the slip (%) and drawbar power (kgf) variables was performed

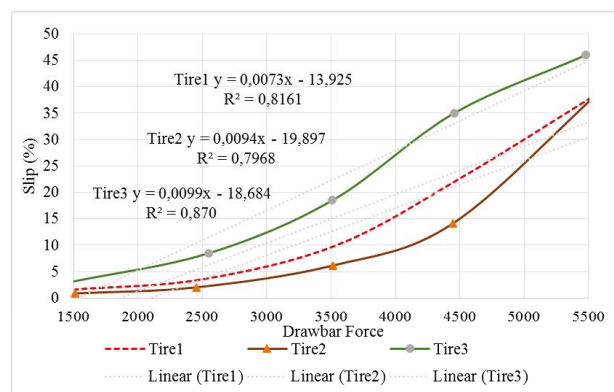


Figure 12 - Example of presentation of the results of tests conducted on a firm soil track with a 132kW engine tractor, in L4 gear with three sets of agricultural tires. The plotted variables indicate specific fuel consumption and slip

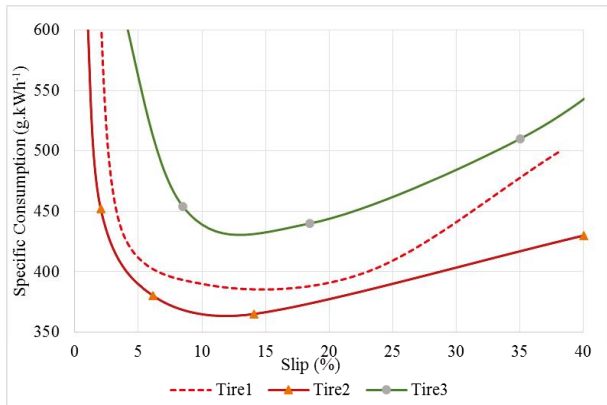


Figure 13 - Example of presentation of the results of tests conducted on a firm soil track with a 132kW engine tractor, in L4gear with three sets of agricultural tires. Regression analysis of the variable traction coefficient and slip was performed

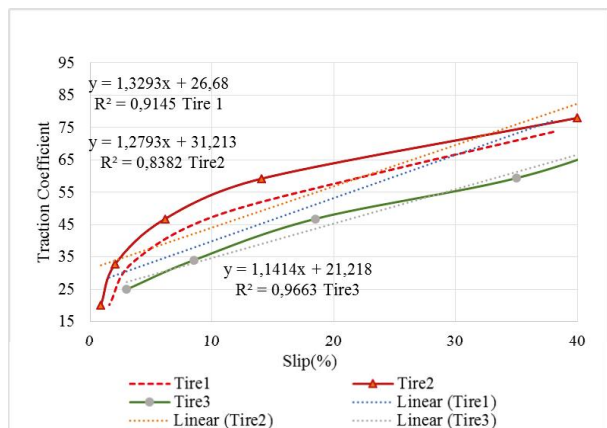
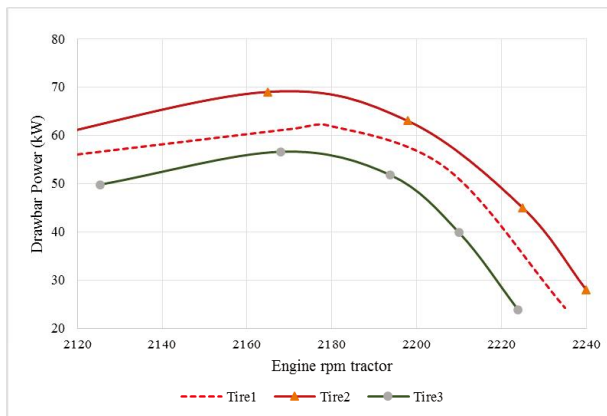


Figure 14 - Example of presentation of the results of tests conducted on a firm soil track with a 132kW engine tractor, in L4 gear with three sets of agricultural tires. The plotted variables indicate drawbar power and engine rotation



Since the development of the first tractors with internal combustion engine, the energy supplied by the tractor is obtained through the calorific power of fuel, usually diesel oil, which is converted to mechanical energy, with thermomechanical efficiency close to 35%. The low energy efficiency of engines is one of the factors that make fuel consumption a relevant item in the cost of operations (GRISSE *et al.*, 2010; KARPVARFARD; RAHMANIAN-KOUSHKAKI, 2015).

New energy sources, such as hydrogen and methane are being studied for possible application in internal combustion engines and detailed standards for testing each new model should be formulated. Electric and autonomous tractors, including small robots with artificial intelligence, for application in agriculture present new challenges to research institutions.

Hybrid or electromechanical transmission systems show a high degree of evolution. Continuously variable transmissions (CVT) have been established in agriculture, as well as traction, movement, and slip electromechanical control in tractors. Standards and test procedures should accompany these changes and propose reliable evaluation methodologies.

New systems and tools have emerged to improve the performance of agricultural tractors, from logistic traffic control procedures and global navigation satellite systems (GNSS), known as controlled traffic, to modern transmission mechanisms with less loss of energy.

In the area of agricultural tractor testing, there are gaps to be explored regarding connectivity and data acquisition. There is room for the application of new technologies, such as embedded electronics and sensors that use wireless network protocols. The introduction of the 5G cellular communication network in agriculture can revolutionize data collection and transmission as these systems allow high processing and storage capacity in real time.

The application of wireless sensor technology (WSN), associated with a robust real-time communication network like the 5G, allows accurate diagnosis of real-time operation of tractors and motorized assemblies.

The development of a data collection system using high-speed communication WSN, allows the interchangeability of sensors for other test models such as field tests with soil preparation equipment, tests with grain harvesters, tests with sugarcane harvesters, laboratory and test bench static tests, and tests of equipment and engine machines in general.

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