Research Trends for Performance, Safety, and Comfort Evaluation of Agricultural Tractors: A Review

Md. Shaha Nur Kabir[1], Myong-Jin Ryu[1], Sun-Ok Chung[1]*, Yong-Joo Kim[2], Chang-Hyun Choi[3], Soon-Jung Hong[4], Je-Hoon Sung[5]

[1]*Department of Biosystems Machinery Engineering, Chungnam National University, Daejeon, Korea*
[2]*Machinery Technology Group, Advanced R&D Center, LS Mtron Ltd., Gunpo, Korea*
[3]*Department of Bio-mechatronic Engineering, Sungkyunkwan University, Suwon, Korea*
[4]*Rural Development Administration, Gyeonggi-do, Korea*
[5]*Department of Agricultural Engineering, National Academy of Agricultural Science, Rural Development Administration, Suwon, Korea*

Abstract

Background: Significant technological development and changes happened in the tractor industries. Contrariwise, the test procedures of the major standard development organizations (SDO's) remained unchanged or with a little modification over the years, demanding new tractor test standards or improvement of existing ones for tractor performance, safety, and comfort. **Purpose:** This study focuses on reviewing the research trends regarding performance, safety and comfort evaluation of agricultural tractors. Based on this review, few recommendations were proposed to revise or improve the current test standards. **Review:** Tractor power take-off power test using the DC electric dynamometer reduced human error in the testing process and increased the accuracy of the test results. GPS signals were used to determine acceleration and converted into torque. High capacity double extended octagonal ring dynamometer has been designed to measure drawbar forces. Numerical optimization methodology has been used to design three-point hitch. Numerous technologies, driving strategies, and transmission characteristics are being considered for reducing emissions of gaseous and particulate pollutants. Engine emission control technology standards need to be revised to meet the exhaust regulations for agricultural tractors. Finite Element Analysis (FEA) program has been used to design Roll-Over Protective Structures (ROPS). Program and methodology has been presented for testing tractor brake systems. Whole-body vibration emission levels have been found to be very dependent upon the nature of field operation performed, and the test track techniques required development/adaptation to improve their suitability during standardized assessment. Emphasizes should be given to improve visibility and thermal environment inside the cab for tractor operator. Tractors need to be evaluated under electromagnetic compatibility test conditions due to large growing of electronic devices. Research trends reviewed in this paper can be considered for possible revision or improvement of tractor performance, safety, and comfort test standards.

Keywords: Agricultural tractor, Comfort, Performance, Safety

Introduction

The standards associated with agricultural and forestry tractors are more complicated than normally expected. Tractor standards handle mainly three issues: safety, performance, and interoperability (Ingle, 2011). These basic standards are supervised by the major Standard Development Organizations (SDOs) for the agricultural tractor industry internationally: the Organization for Economic Co-operation and Development (OECD), International Organization for Standardization (ISO), Society of Automotive Engineers (SAE), American Society of Agricultural and Biological Engineers (ASABE), European Community (EC, type approval), and Nebraska Tractor Test Laboratories (NTTL).

*Corresponding author: Sun-Ok Chung
 Tel: +82-42-821-6712; **Fax:** +82-42-823-6246
 E-mail: sochung@cnu.ac.kr

OECD Codes provide a set of rules and procedures to certify tractors and their protective structures. Implementation of these codes ensures a comparative basis performance, increasing transparency, simplifying international trade procedures, and extending open markets (OECD, 2013). ISO is the world's largest standard developing organization and serves as one of the governing bodies with 67 ISO standards specifically for agricultural and forestry tractors (ISO, 2013). ASABE is recognized worldwide as a standard developing organization for food, agricultural, and biological systems, with more than 120 standards for agricultural equipment and systems (ASABE, 2013). EC Type Approval for vehicles is applicable in the whole European Economic Area and Directive 2003/37/EC (formerly 74/150/EEC) is about the Type Approval for agricultural or forestry tractors (EC, 2013). NTTL is the official American tractor testing station for OECD. The Board of Engineers is responsible for rules and regulations for official tractor testing and also interpreting the Nebraska Tractor Test Laws (NTTL, 2013).

In the past few decades, significant technological development and changes happened for agricultural tractors, leading to great improvements in various aspects of operation such as higher energy efficiency, lower pollutant exhaust gas emission, higher quality of agro-technical operations, better soil protection, and enhanced working conditions for human operators (Stojic et al., 2011). Despite of dramatic advances in tractor technology, the test procedures of the major SDO's remained unchanged or with a little modification over the years, demanding new tractor test standards or improvement of existing ones for tractor performance, safety and comfort, reflecting modern technical advances in tractors. This paper reviews the research trends regarding performance, safety, and comfort evaluation of agricultural tractors. Then, recommendations to revise or improve the current test standards based on the review were proposed.

Scope of Performance, Safety, and Comfort Evaluation

Tractor performance tests are generally conducted to assess the power-takeoff (PTO) performance, drawbar performance, hydraulic-lift capacity, and hydraulic-system pressure and flow. In addition, sound-level measurements are taken at operator and bystander locations (Grisso et al., 2009).

Table 1. Selected categories reviewed in the study

Division	Category
PTO	PTO power, PTO safety
Drawbar	Drawbar power
Hydraulic system	Hydraulic power, hydraulic lift capacity
Fuel & emission	Fuel saving technology, Emission of gaseous and particulate pollutants
Safety	ROPS, brakes, operator's field of vision
Comfort	Vibration, thermal load
Other	EMI/EMC

Agricultural tractor industry has been globally expanded, meaning that tractors are routinely produced in one country and distributed for sale in other countries (Ingle, 2011). Design and technology of farm tractors has evolved over the years, as manufacturers continue to develop tractors which fulfill various requirements of farmers (GIA, 2013). This review focused on tractor performance, operator's environment, and safety. The division with categories is shown in Table 1.

PTO Power and Their Protection

During PTO performance test, engine power output (torque and speed) and fuel consumption levels are measured as increasing load is applied via the dynamometer which is initially done with the throttle control/governor set for maximum engine speed. A series of PTO tests are conducted for the power parameters at rated engine speed, at standard PTO speed (either 1,000 or 540 rpm), at the engine speed where maximum power is produced, at varying loads, and at maximum torque (OECD, 2012a). Pexa et al. (2011) measured power parameters (torque and engine power) of 63 and 88 kW tractors using GPS signals with scanning frequencies of 5 and 20 Hz. If the acceleration is measured by any GPS based system when the tractor is new, a standard can be created by measuring the acceleration on a particular track and under specific conditions. Then standards can be easily converted directly to the torque by using tabulated vales and observed values. Jiankang et al. (2011) investigated the engine testing bench and the effect of DC electric dynamometer used in PTO power test (Figure 1). To achieve automatic control and automatic recording, they found the system greatly reduced the labor intensity of testing personnel and the human error in the testing process, but also
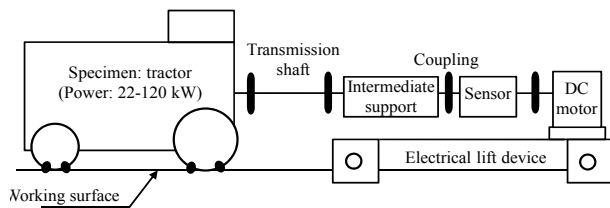
Figure 1. Schematic diagram of structure about the test bench (Jiankang et al., 2011).
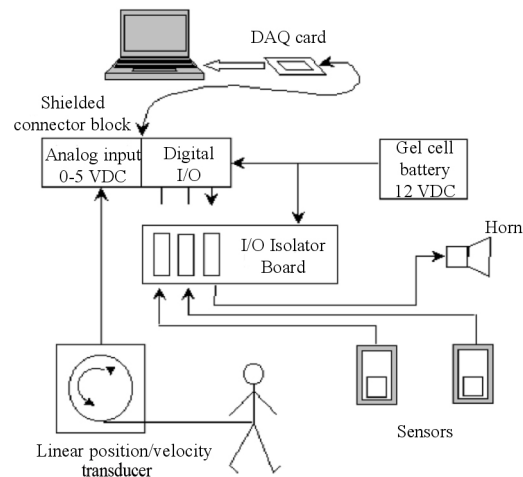

Figure 2. Concept of a security system to disengage PTO of a tractor (Venem et al., 2006).

greatly increased the accuracy of the test results.

The PTO should be protected by a guard mounted on the tractor which provides protection from the rotational PTO stub and shaft. Among the SDO's OECD does not provide information regarding safety protection of PTO. To improve safety in hazardous area near tractor's PTO, Venem et al. (2006) designed and tested a safety sensor system using off-the-shelf security sensors to detect people in the PTO hazard area between a self-unloading forage wagon and a tractor. A total of 288 tests with four different sensor technologies explored the reliability of human presence security sensors for operator detection (Figure 2). After sensor tests, a low-cost prototype automatic shut-off system were designed, which showed that it is possible to tie together a human presence sensor with a shut-off circuit to disengage the PTO when a person enters into the hazard area.

Drawbar Power

Drawbar test measures the ability to transfer power from the engine to the wheels and ground. A loading car is towed by the tractor around a concrete or asphalt test tracks. Similar to PTO performance test, drawbar performance is measured at different rates of pull and in different gears. Power measured at 75 percent of pull at maximum power is the reflection of performance during typical heavy work (OECD, 2012a).

Several different configurations of linkage type drawbar dynamometers have been developed in the past. Robust linkage type dynamometers, such as plain extended rings (Hoag and Yoerger, 1975) and extended octagonal rings (EOR) have been developed. Double extended octagonal ring (DEOR) drawbar dynamometer (Godwin et al., 1993; Leonard, 1980) was designed later. Chen et al. (2007) developed a 2D DEOR drawbar dynamometer with a high draft capacity of 180 kN. The two extended octagonal rings were oriented vertically on either side of the tractor drawbar which provided a better match of strain to expected drawbar draft and vertical load than could be achieved with a horizontal orientation in previous designs. Younis et al. (2010) designed and constructed a strain gage pull dynamometer to measure the draft of the tractor under test on the concrete road and field test from which the power requirements can be determined. Havasi et al. (2012) designed a digital tractor dynamometer using simple and prevalent Integrated Circuits (IC) for use in laboratory experiments. Despite of simplicity in circuit design and performance as well as low cost of the set, these devices had satisfactory final function, accuracy and linearity. Strong point of the device is the utilization of a load cell based on the resistance strain gauges that provides very high accuracy.

Hydraulic Power and Lift Capacity

Hydraulic power output test procedure measures the tractor's ability to produce hydraulic power, as would be required to operate hydraulic motors or actuate hydraulic rams on attached implements. External test equipment is used to measure the maximum hydraulic pressure (at max. engine speed) and hydraulic flow rate delivered by the coupler at 90% of this maximum pressure needs to be recorded for calculating the maximum hydraulic power availability. Sufficient hydraulic lift capacity is also an important requirement for most modern tractors and the geometry of the three-point linkage has an important influence upon a tractor's lift capacity. During lift capacity

test, maximum lifting force is recorded at various points throughout the lift range, at 90% of the hydraulic lift system's relief valve pressure (OECD, 2012a).

Mattetti et al. (2012) presented a numerical optimization methodology to design a three point hitch for a 90-kW power tractor, enabling to follow the ISO standard and to optimize the load capacity defined by the OECD standards. The optimization technique firstly permitted to design the three point hitch in a reduced time, and also allowed to give some guidelines on the dimensioning through the sensitivity analysis. The sensitivity analysis has shown how the length of lift rods allows increasing the load capacity of the hitch as well as the regulation range. The distance of lower link pivot points to lift rod pivots is the parameter that deeply influences the uniformity of the load capacity in the height range. This methodology has permitted to accelerate the design process of the three point hitch, quickly defining the solution with the higher lifting force for the selected tractor.

Fuel and Emission

Fuel consumption test is performed along with the PTO power test and drawbar power test both in terms of hourly consumption (L/hr & kg/hr) and specific consumption (g/kWh). These indicate how efficiently the tractor can convert fuel into usable energy or work. Several methods have been developed for predicting fuel consumption. Grisso et al. (2004) reviewed the current fuel consumption data from ASABE Standards and compared it to 20 years of Nebraska Tractor Test Lab (NTTL) data. They also
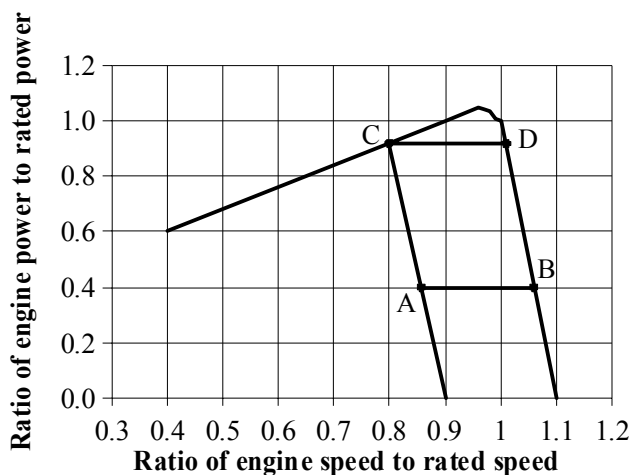
developed a generalized model that predicted fuel consumption during full and partial-load tests and under conditions when engine speeds were reduced from full throttle. Kim et al. (2011) developed a mathematical model to predict fuel consumption of agricultural tractors under different operational conditions using OECD tractor test data (Figure 3). Fuel consumption at an arbitrary operational point A defined by engine speed and its power can be estimated using PTO power performance data. BD represents engine power as a function of speed ratio at varying load with full throttle. Point C is the interaction between straight line and full-load power curve.

It was found that the fuel consumption at varying load with full throttle was linearly proportional to power, and the difference in fuel consumptions at varying load with full and reduced throttles was equal regardless of engine power level if their speed difference was the same. The developed model may be used to estimate reasonably the fuel consumptions of a given tractor under various operation conditions.

OECD Code 2 does not have a procedure designed to examine the fuel efficiency of tractors with continuously variable transmissions (CVTs). Coffman et al. (2010) developed a test procedure developed to measure fuel efficiency of CVT-equipped tractor models and found that the CVT automatic transmission was more fuel efficient than a standard gear transmission with a finite number of fixed gear ratios when the drawbar power was 78% or less of maximum power and the throttle was set to maximum. Modeling of the tractor fuel consumption was conducted by Ajdadi et al. (2011) using Artificial Neural Network (ANN) and stepwise multiple ranges regression methods.

Development of eco-friendly technologies have been increasing in tractor design concerning the regulations on emission such as EURO-6, TIER-4, and the Enforcement Rule of the Clean Air Conservation Act (Choi et al., 2013). More precise data on average specific and absolute emissions from agricultural tractors are needed in calculations of environmental loads, but the standards used to calculate these data are not adapted to agricultural conditions (Hansson et al., 2001). There are numerous technologies being considered to reduce emissions of gaseous and particulate pollutants. These included low carbon fuels (e.g. biofuels); advances in engine technologies such as direct injection gasoline engines, cooled exhaust gas recirculation (EGR) for gasoline engines, and downsizing;

Figure 3. Estimation of fuel consumption at operational point A (Kim et al., 2011).

and electrification of the drivetrain such as with hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), and battery electric vehicles (BEV) (Johnson, 2010). By using varying driving strategies and transmission characteristics, it is possible to influence the amount of emissions to a considerable extent without effecting the time or fuel consumption for the operation. Park et al. (2010) analyzed the factors affecting fuel consumption of agricultural tractor and found that specific fuel consumption and CO_2 emission increased as throttle engine speed increased but reversely proportional with gear step of tractor, by which fuel consumption and CO_2 emission can be reduced with practicing of "Gear up and Throttle down" technique. Kim et al. (2013) evaluated the performances of a tractor diesel engine fueled by three different animal fats biodiesels those produced less exhaust gases of CO_2, CO, NO_X and THC. Janulevicius et al. (2013) presented a methodology for determining operational indicators suitable for collection and analysis of information on engine operating modes, fuel consumption and exhaust gas emissions during tractor's operation period. Most of the fuel (almost 43%) was consumed at high torque (> 50% M_{max}) and medium speed (from 1100 to 1900 rpm) mode and approximately 30% was consumed at high torque and high speed (> 1900 rpm) mode. Largest amounts of CO were (> 85% of total emissions) emitted at modes of small load and small, also medium engine speeds. Largest amounts of CO_2 (> 60% of total emissions) were emitted at modes of large load and medium, also high engine speeds. Lowest values of CO, CO_2 and NO_x emission comparative indicators were at the mode of maximum load (> 50% M_{max}) and maximum engine speed (> 1900 rpm).

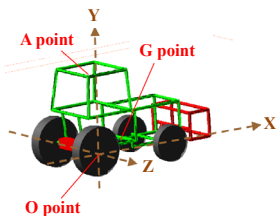## Roll-Over Protective Structure (ROPS)

ROPS, as described in SAE J2154 (ASABE, 2009), is a cab or frame for the protection of operators of agricultural tractors to minimize the possibility of serious operator injury resulting from accidental upset. ROPS tests are done to ensure that the ROPS would safely absorb a certain level of strain energy during loading, without the structure failing or deflecting into the safety 'clearance' zone likely to be occupied by the operator. The level of test loading is related directly to the test tractor's mass because, during a roll-over, the heavier the vehicle, the greater the forces and impact energy which will be applied to the ROPS (OECD, 2013). Static test procedure is currently adopted worldwide in order to resolve the limitations of the dynamic procedure. Four static loads are applied to the ROPSs tested according to the static test. The first longitudinal loading is applied on the rear or on the front of the protective structure, depending on the 50% mass of the tractor on the rear or front axle. First crushing test was carried out at the same end of the protective structure as the longitudinal loading. The loading from the side is followed and then the second crushing test is applied at the opposite end of the protective structure and equal in force to the first one (OECD, 2012b).

Numerous researchers studied the dynamic behavior of the tractor during an overturn and the energy absorbed in the impact of the ROPS depending on the type of overturning. A computer program named 'ESTREMA' was developed by Mangado et al. (2007). This model was developed for the construction of a more complex 4-post ROPS, and utilized OECD ROPS codes for the performance criteria. Rondelli et al. (2012) investigated the changes in design, mainly in terms of mountings to the tractor chassis and ROPS shape for evaluating whether these modifications produced any effects on test performance and/or test results so as to influence the safety level provided for the tractor driver. They found that these changes affect the behavior of the ROPS cabs during the loadings, while test procedure of SDO's remained unchanged over time.

Alfaro et al. (2010) used finite element (FE) analysis program to develop a procedure to calculate the maximum reference mass in the equations that define the energies to be absorbed by ROPS, during loading tests, and the forces to be exerted during crushing tests according to OECD Code 4 and SAE J2194. For FE simulation, the forces were applied as defined in the standards and the deformations were determined. Lenain et al. (2010) proposed a generic model for agricultural tractor able to study the variation of energy level absorbed by ROPS during an impact induced by rollover situation with respect to several parameters (e.g., mass, shape, environment). Such a model (designed using the simulation software Adams) allowed the simulations of hazardous situations for impact energy calculation. Based on this material, a sensitivity study was conducted to define a kind of validity limit of the linear equations supplied in OECD Code 4 procedure,

Table 2. Design variable limit values extracted to preserve OECD 4 validity

Figure	Design variables	Limit values for longitudinal rollover	Limit values for lateral rollover
	Centre of gravity along X	-	-
	Centre of gravity along Y	<150 mm	<150 mm
	Centre of gravity along Z	-	>800 mm
	Impact point along X	<50 mm	-
	Impact point along Y	-	-
	Impact point along Z		< -50 mm (wheel side absorption) > +300 mm
	Lateral slope value	-	<10°
	Longitudinal slope value	<10	-
	Ballasting mass	-	-
	Mounted implement mass	<40% of Nominal mass	<40% of Nominal mass

linking nominal tractor mass and level of energy to be absorbed by tractor structure (Table 2). Based on the results of this research, a scope for the application of OECD Code 4 testing procedure for tractor can be proposed. This allowed evaluating the relevance and the potential adaptation of the testing methodology to the agricultural machinery evolution.

Pessina et al. (2010) studied to determine clear and unambiguous criteria about the strength equivalence of two or more different versions of ROPS and how minimum modifications affect their performances. Taking as a reference the figure of 5% (OECD Code 4) admitted for increased energy due to the increase of reference mass, it could be taken into account a similar limit in order to evaluate the possibility to avoid the execution of a new test in case of slightly structural modifications, such as the height of mountings, or their shape and thickness. In several situations, light structural modifications lead to little differences in maximum forces and deflection figures; in many cases they do not exceed 5%. On the contrary the increase of reference mass caused a higher variance.

Brakes and Braking Devices

Performance test of service and secondary braking systems are based on measured deceleration and on stopping distance and the performance of the parking braking systems are based on the ability to hold the tractor stationary, facing up and down slopes (OECD, 2012a). As agricultural tractor size and speeds have increased during recent years, heavier loads are transported on public roads at higher speeds (Ahokas and Kosonen, 2003). Due to the increased speed of tractors, their braking system has been enhanced. In view of the road safety, the braking systems of agricultural vehicles must meet a number of requirements for, among other things, braking efficiency, the follow-up action during slow braking, and a high speed of action during sudden braking. The operation of a high speed modern agricultural tractor with high-efficiency brakes coupled with a low braking-efficiency trailer will lead to the accelerated wear and premature damage of the trailer's braking system and, on the other hand, cause overloading, rapid wear and possible damage of the tractor's braking system (Scarlett, 2009). Kaminski and Czaban (2012) described the requirements for type approval testing of agricultural tractors with regard to braking while taking into account the draft regulation drawn up by the European Commission's Working Group on Agricultural Tractors (WGAT). The program and methodology for testing the performance of the tractor brake system to supply and control the braking system of a towed vehicle were presented in Figure 4 and Figure 5. Efficiency tests of the tractor's main brakes included the recording of the distance, deceleration and the brake pedal force during the braking process. The conditions and requirements assumed in individual diagnostic tests were consistent with the proposals of the new Regulation of EC for testing agricultural vehicle brakes. The proposed provisions should consider the testing of the response time of an agricultural tractor's air system control circuit similarly as the utility vehicles designed for towing trailers. The presented braking system diagnosing methodology may be wholly or partially used to develop a programme of qualification
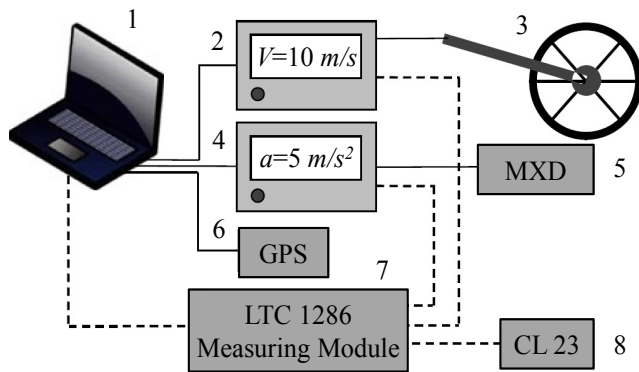
Figure 4. Schematic of the measuring system for testing the vehicle braking process: 1–portable computer, 2–"fifth wheel" controller, 3-fifth wheel, 4-electronic decelometer, 5-MXD7202 acceleration sensor, 6–Holux GPSlim 236 GPS receiver, 7–LTC1286 measuring module, 8–CL23 brake pedal pressure sensor (Kaminski and Czaban, 2012).
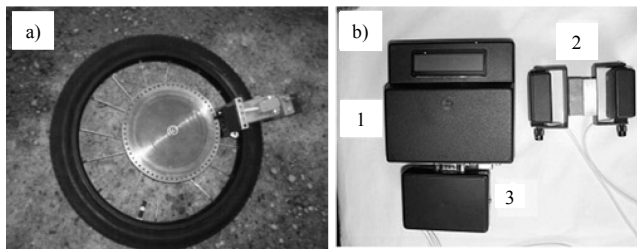

Figure 5. Devices for measuring the braking distance and braking deceleration: a – fifth wheel pulse disc with an optical sensor, b–decelometer components: 1–microcontroller, 2–measuring sensors, 3–signal amplifier (Kaminski and Czaban, 2012).

testing of tractors on production lines and a programme of periodic technical inspections of operated tractors.

Operator's Field of Vision

Clarity of operator field of view is of primary importance for ergonomic, efficient and safe operation of field machinery as 90% of the operator's perception is visual (Drury and Clement, 1978; Barron et al., 2005). By upgrading the quality of this visual information, the driver gets a better chance to conduct field operations and to avoid a collision or an accident. Vision limitation and mirror's visibility determination method was described by Olejnik (1999 and 2005) and EEC (1974). The requirements concerning the extensiveness and location of the fields which should be visible in the mirrors, according to Directive EU 74/346/EEC (EEC, 1974) and examples of results obtained in a tested agricultural tractor are illustrated on Figure 6 and Figure 7, respectively.

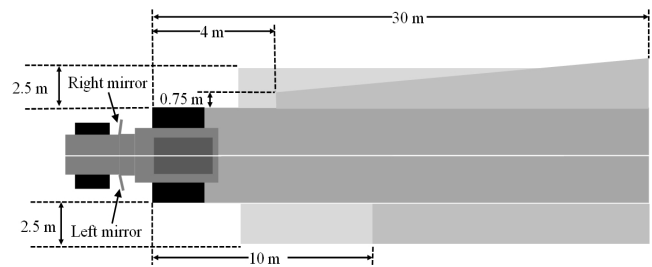Lund and Butters (2011) investigated the operator's

Figure 6. Visual fields in mirrors according to Directive EU 74/346/EEC (Olejnik, 2005).
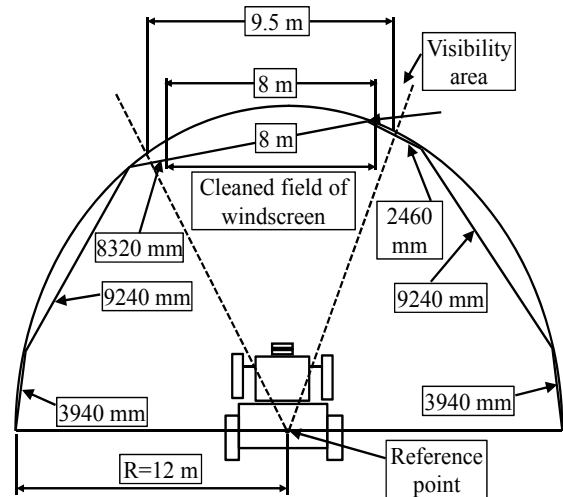

Figure 7. Distribution and number of vision limitations on a vision circle and a field of windscreen wiper work (Olejnik, 1999).

field of vision of modern agricultural tractor cabs. Visibility patterns and areas of blind spots were compared according to ISO 5721:1981 (ISO, 1981) for people of different heights and for 2 tractors (same manufacturer) but fitted with different operator's cabs. It was found that the forward visibility on a standard equipment tractor was poor, even for the tallest person. Rear vision either side of the tractor was also poor. Sideways vision was not good and the driver was not able to see other traffic or pedestrians who come alongside. This emphasizes the importance of ways required to improve forward visibility to reduce the possibility of accidents caused by this blind spot.

Vibration

Tractor operators are exposed to high levels of whole body vibration (WBV) during field operations and on/off-road transportation (Bovenzi and Betta, 1994). Standardized tests are performed for measuring the whole body vibration

of the operator while exposed on standard 75m rougher and 100m smoother test tracks. Vibration exposures of the operator are also measured under non-standard conditions. Gorabal et al. (2011) discussed the investigations carried on the pneumatic friction and hydro-pneumatic friction dampers. Laboratory prototype models of friction dampers and two-dimensional vibration isolator were developed. Pressure control regulator controls the friction load coming to the damper, was considered in that model. The non-linearity behavior of the friction pads and pressure developed at the axial hole on the piston for different loads were investigated and finally prototype model was tested with two-dimensional vibration isolations for a passenger seat. The dynamic test and vibration dose value (VDV) results showed that the hydro-pneumatic friction damper model exhibits better damping performance as compared to pneumatically activated friction damper.

Scarlett et al. (2007) conducted a study to quantify whole-body vibration (WBV) emission and estimated exposure levels found upon a range of modern, state-of-the-art agricultural tractors (unsuspended, suspended cab, suspended front axle and cab and fully-suspended cab: front and rear axles) when operated in controlled conditions (traversing ISO ride vibration test tracks and performing a range of agricultural operations) and whilst performing identical task under normal 'on-farm' use. Tractor WBV emission levels were found to be very dependent upon the nature of field operation performed, but largely independent of vehicle suspension system capability (due to the dominance of horizontal vibration). Upon the 35 m (rougher) track, seat WBV emission levels

in X and Y axis were of similar magnitudes, irrespective of the vehicle suspension system, and significantly greater than Z axis WBV levels. Upon the 100 m (smoother) track, WBV levels increased markedly with increasing forward speed and the seat WBV emission levels for fully suspended tractor is shown in Figure 8. Few examples (~9%) of tractor field operations approached or exceeded the PA(V)D Exposure Limit Value (ELV) during 8 h operation, but this figure increased (to 27%) during longer working days. However virtually all (~95%) 'on-farm' vehicles exceeded the Exposure Action Value (EAV) during an 8-h day. Variation in WBV exposure levels was found between examples of similar 'on-farm' tractors/operations.

Marsili et al. (2002) measured and analyzed the vibration transmitted through the seat of a four-wheel drive tractor, developing 92 kW at the PTO, and equipped with front suspension axle and shock absorber for the implement. Several tests were carried out in different conditions considering type of operation (transfer with and without mounted implement, ploughing, harrowing), type of track (conglomerate bituminous track, macadam dirt track, country lane), connected and disconnected suspension and/or shock absorber, and a range of forward speeds. In the transfer test on track, the vehicle suspension caused an average acceleration reduction of about 15%, and it could reach 30%. The shock absorber displayed a variable behavior depending on the test condition, possibly causing both attenuation and amplification, although the combination with the suspension often involved a high average reduction in acceleration (24%). In the soil tillage tests, the suspension could cause a substantial reduction in acceleration (up to 36%), but only in some conditions and could compromise the driver's health through an increase in daily exposure time of about 50% during ploughing and of more than 100% during harrowing.
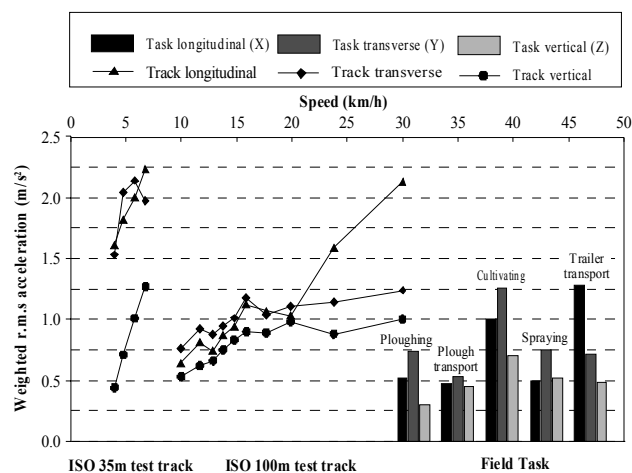
Thermal Load

The thermal environment may affect operator's health, performance and comfort. Even in moderate outdoor conditions, vehicle is subjected to various heat loads such as direct and reflected solar radiation, heat transfer through the cab walls due to the temperature difference, and heat gain from the powertrain (Ruzic, 2011). On the other hand, ergonomics of the thermal environment
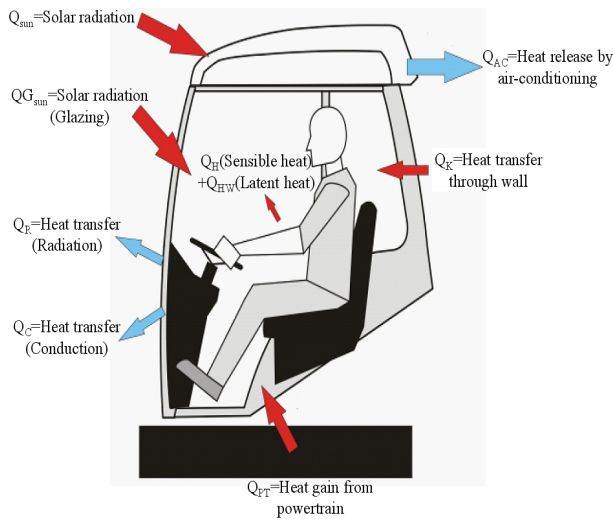

Figure 8. Fully suspended (front and rear axle) tractor seat WBV (frequency weighting factors: 1.4).

Figure 9. Thermal processes between a tractor cab and hot environment (Ruzic and Casnji, 2011a).

inside the tractor cab is based on the relationship among air temperature, interior surfaces radiant temperature, air velocity and relative humidity, which in combination should obtain the absence of discomfort, for given operator's activity and clothing (Fanger, 1970; Parsons, 2003).

Ruzic and Casnji (2011a) identified and evaluated the most important influences in order to create the basis for microclimatic and energy consumption reduction aspects of a tractor cab design. It was shown that the cab glazing was probably the most influencing factor, where the selection of the appropriate properties could be the way for cab and operator heat load reduction (Figure 9). Control of microenvironment is necessary because of relationship between microclimate parameters and human thermal sensation is not reliable, due to large individual differences (Parsons, 2003; Watanabe et al., 2010). The personalized ventilation should be designed in such a way that there is optimum heat loss from individual body parts for maintenance of required skin temperature, but without local discomfort, especially without draught and eye irritation in the face region, where breathing zone have to be provided with fresh and clean cool air (Ruzic and Casnji, 2011b). Hwang and Kim (2009) evaluated environmental comfort within the tractor cab from 31 tractors during ploughing and rotavating operations and found that operators of 75% the studied tractors worked under uncomfortable thermal condition. 25% of the tractors showed Predicted Mean Vote (PMV) in a range of -0.5 to +0.5, which indicated their operators worked under comfort criteria.

EMI/EMC

During the past decade, manufacturers of agricultural equipments have increasingly turned to electronics to provide products with improved functionality, productivity, and performance to customers (Stone et al., 1999). Electromagnetic compatibility (EMC) studies the unintentional generation, propagation, and reception of electromagnetic energy with reference to the unwanted effects (Electromagnetic Interference, EMI) that such energy may induce (Stellini, 2009). EMC measurements could be influenced by different setup conditions such as table positioning (Taylor and Kuyatt, 1994) and the material, and conducted emissions could be influenced by factors such as length (Mills, D.L. 1992), height, and manner of main cable meandering (Freris and Kumar, 2007) as well as positioning of the equipment under test (IEEE, 2002).

Mark et al. (1985) reviewed radiated emissions and susceptibility measurement methodologies used for assessing the EMI/EMC characteristics of electronic devices and systems. Traditionally, open area test site (OATS) measurement provides a straight forward approach to evaluating the EMI performance, and disadvantages associated with this method is the necessity of a sizable measurement site and the metal-free surrounding area. On the other hand, transverse electromagnetic cell (TEM) offers several advantages such as portability, simplicity to build (Decker et al., 1979), usefulness for broad-band swept-frequency measurements, and capability of wide test field strength range from a few microvolts per meter to a few hundred volts per meter. But TEM has limitations such as the usable frequency range is from dc to an upper limit determined by the appearance of the lowest high order mode (Crawford, 1974; Tippet et al., 1976; Tippet, 1978).

Masuda et al. (2009) investigated how to change the antenna height by using the minimum beam width (BW) of the radiated-wave directivity in a fully anechoic room. In the proposed method, the narrowest vertical directivity of a noise source was calculated first based on the size of equipment under test (EUT). Secondly, the step increment was done for changing the antenna height using calculated directional characteristic. Then the feasibility of this method was evaluated by using a notebook computer as a EUT, and verified that the difference of the measurement results between proposed and conventional method was within ± 3 dB and the measurement time was reduced about 22% compared to the conventional method.

Recommendations

Based on the review of the research trends, following recommendations were made to improve or revise the current test standards:

(1) DC Electric Dynamometer for the PTO power test of tractors may be applied as it reduces the labor intensity, human error and also greatly increase the accuracy of the test results in the testing process. The option of using GPS receiver to determine the torque of the engine and its backup torque may be an appropriate option and if acceleration is measured by any GPS based system when the tractor is new, a standard may be created which can be easily converted directly to the torque. To reduce the risk associated with PTO drive shaft, off-the shelf security sensors may be used to detect people in the PTO hazard area.

(2) Due to more accurate and convenient in utilization as compared to mechanical systems, digital tractor dynamometer can be used to measure the tractor drawbar power. Numerical optimization methodology can be utilized to design three-point hitch systems of tractors.

(3) A procedure should be designed in test standards to measure fuel efficiency of CVT-equipped tractor models. The ANN and multiple ranges regression models can be used to predict fuel consumption of tractor engines because of fast, accurate and reliable results. Engine emission control technology standards should be revised to meet the exhaust emissions regulations for agricultural and forestry tractors.

(4) To evaluate the possible impact of structural modifications on the strength of a ROPS, and their role in changing the rear and side force/deflection curves trends, Finite Element analysis (FEA) technique can profitably adopted and can be used to design safer ROPS. Revision or improvement of current ROPS test standards should be made as newly developed ROPS models are proliferating.

(5) As operators are more productive when their work environment is designed for best human performance, that's why ergonomics of thermal environment inside the cab needs to be improved. Emphasizes should be given to improve visibility of tractor operator for their safety.

(6) Test track techniques require development/adaptation to improve their suitability for WBV emission assessment. Such developments would ideally deliver standardized testing methodologies, capable of quantifying the effectiveness of tractor WBV-reducing design features when operating in typical agricultural conditions.

(7) As tractor manufacturers are using more and more electronic devices in tractor to provide improved functionality, performance and safety, therefore, the electrical and electromagnetic environment in which these devices works needs to be evaluated.

Conflict of Interest

The authors have no conflicting financial or other interests.

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References

Ahokas, J and S. Kosonen. 2003. Dynamic behaviour of a tractor-trailer combination during braking. Biosystems Engineering 85(1):29-39.

Ajdadi, R. F and Y. A. Gilandeh. 2011. Artificial neural network and stepwise multiple range regression methods for prediction of tractor fuel consumption. Journal of the International Measurement Confederation 44: 2104-2111.

Alfaro, J. R., Arana, I., Arazuri, S and C. Jaren. 2010. Assessing the safety provided by SAE J2194 Standard and Code 4 Standard code for testing ROPS, using finite element analysis. Biosystems Engineering 105: 189-197.

ASABE. 2009. SAE J2194. Roll-over protective structures (ROPS) for wheeled agricultural tractors. 2950 Niles Road, St. Joseph, MI 49085-9659.

ASABE. 2013. American Society of Agricultural and Biological

Engineers. 2950 Niles Road, St. Joseph, MI 49085.

Barron, P. J., Owende, P. M. O., McDonnell, K. P and S. M. Ward. 2005. A method for assessment of degradation of task visibility from operator cabins of field machines. International Journal of Industrial Ergonomics 35(7): 665-673.

Bovenzi, M and A. Betta. 1994. Low-back disorders in agricultural tractor drivers exposed to whole-body vibration and postural stress. Applied Ergonomics 25:231-241.

Chen, Y., McLaughlin, N. B and S. Tessier. 2007. Double extended octagonal ring (DEOR) drawbar dynamometer. Journal of Soil and Tillage Research 93:462-471.

Choi, S. H., Kim, H. J., Ahn, S. H., Hong, S. H., Chai, M. J., Kwon, O. E., Kim, S. C., Kim, Y. J., Choi, C. H and H. S. Kim. 2013. Modeling and simulation for a tractor equipped with hydro-mechanical transmission. Journal of Biosystems Engineering 38(3):171-179.

Coffman, B. A., Kocher, M. F., Adamchuk, V. I., Hoy, R. M and E. E. Blankenship. 2010. Testing fuel efficiency of a tractor with a continuously variable transmission. Applied Engineering in Agriculture 26(1):31-36.

Crawford, M. L. 1974. Generation of standard EM fields using TEM transmission cells. IEEE Transactions on Electromagnetic Compatibility EMC-16(4):189-195.

Decker, W. F., Wilson, W. A and M. L. Crawford. 1979. Construction of a large transverse electromagnetic cell. NBS Tech Note 1011. Washington D.C. UNT Digital Library.

Drury, C. G and M. R. Clement. 1978. The effect of area, density, and number of background characters on visual search. The Journal of the Human Factors and Ergonomics Society 20(5):597-602.

EC. 2013. European Commission, Enterprise and Industry DG, B - 1049 Brussels (Belgium).

EEC. 1974. Directive EU 74/346/EEC. Rear view mirrors-On the approximation of laws of the member states relating to rear-view mirrors for wheeled agricultural or forestry tractors. European Commission, Enterprise and Industry DG, B - 1049 Brussels (Belgium).

Fanger, P. O. 1973. Thermal comfort, New York: McGraw-Hill Book Co. New York, 1973, pp. 244.

Freris, N. M and P. R. Kumar. 2007. Fundamental limits on synchronization of affine clocks in networks. In: *Proceedings of the 46th IEEE Conference on Decision and Control*, New Orleans, USA.

GIA. 2013. Rising demand for agricultural produce and advanced tractors drives the global farm tractors market, Global Industry Analysts, Inc., USA.

Godwin, R. J., Reynolds, A. J., O'Dogherty, M. J and A. A. Al-Ghazal. 1993. A triaxial dynamometer for force and management measurement on tillage implements. Journal of Agricultural Engineering Research 55: 189-205.

Gorabal, S. V., Kurbet, S. N., Appukuttan, K. K and V. V. Kuppast. 2011. Two dimensional vibration isolations for a passenger seat using semi-active pneumatic and hydro-pneumatic friction damper suspension system. International Journal of Advanced Engineering Sciences and Technologies 6(1):150-156.

Grisso, R., Vaughan, D. H., Perumpral, J. V., Roberson, G. T., Pitman, R and R. M. Hoy. 2009. Using tractor test data for selecting farm tractors. Virginia Cooperative Extension Publication 442-072, 1890 Extension Program, Virginia State, Petersburg.

Grisso, R. D., Kocher, M. F. and D. H. Vaughan. 2004. Predicting tractor fuel consumption. Applied Engineering in Agriculture 20(5):553-561.

Hansson, P. A., Lindgren, M and O. Noren. 2001. A comparison between different methods of calculating average engine emissions for agricultural tractors. Journal of Agricultural Engineering Research 80(1): 37-43.

Havasi, M. R., Shiekhdavoodi, M. J., Shini, N. A and M. Sami. 2012. Design, development and evaluation of a digital tractor dynamometer. Asian Journal of Agricultural Sciences 4(2):145-148.

Hoag, D. L and R. R. Yoerger. 1975. Analysis and design of load rings. Transactions of the ASAE 19(4):995-1000.

Hwang, K. Y and K. U. Kim. 2009. Evaluation of environmental comfort of tractor cabs. Journal of Biosystems Engineering 34(1):1-7.

IEEE. 2002. IEEE-1588[TM]. Standard for a Precision Clock Synchronization Protocol for Networked Measurement and control Systems. Available at: http://ieee1588.nist.gov.

Ingle, C. 2011. Agricultural tractor test standards in America. CMGT 564 Strategic Standards, The Catholic University of America.

ISO. 1981. ISO 5721- Tractor's for agriculture - Operator's field of vision. International Organization for Standardization, ISO central secretariat, Geneva.

ISO. 2013. International Organization for Standardization. ISO central secretariat, Geneva.

Janulevicius, A., Juostas, A and G. Pupinis. 2013. Engine performance during tractor operational period. Journal of Energy Conversion and Management 68: 11-19.

Jiankang, W., Mingliang, W., Ping, J., Songlin, S and X. Fangping. 2011. Application of DC electric dynamometer in the PTO power test of tractors. In: *Proceedings of Fourth International Conference on Intelligent Computation Technology and Automation (ICICTA)*. Shenzhen, China.

Johnson, T. V. 2010. Review of CO_2 emissions and technologies in the road transportation sector. SAE International Journal of Engines 3(1):1079-1098.

Kaminski, Z and J, Czaban. 2012. Diagnosing of the agricultural tractor braking system within approval tests. Journal of Maintenance and Reliability 14(4): 319–326.

Kim, S. C., Kim, K. U and D. C. Kim. 2011. Prediction of fuel consumption of agricultural tractor. Applied Engineering in Agriculture 27(5):705-709.

Kim, Y., Lee, S., Kim, J., Kang, D and H. Choi. 2013. Testing of agricultural tractor engine using animal-fats biodiesel as fuel. Journal of Biosystems Engineering 38(3): 208-214.

Lenain, R., Hugo, E and T. Langle. 2010. Sensitivity of the absorbed energy into a ROPS during a rollover situation: Comparison to the security level proposed into OECD Code 4. In: *International Conference on Agricultural Engineering*, Clermont-Ferrand, France.

Leonard, J. J. 1980. An extended-octagon rigid drawbar dynamometer. Agricultural Engineering Australia 9(1):3-8.

Lund, M and L. Butters. 2011. An investigation and comparison into operator field of vision for modern tractor cabs. Scientific Papers, University of Agronomic Sciences and Veterinary Medicine, Bucharest, Series A, Agronomy, Vol. LIV (1):414-419.

Mangado J., Arana., J. I., Jaren, C., Arnal, P., Arazuri, S and J. L. P. de Leon. 2007. Development and validation of a computer program to design and calculate ROPS. Journal of Agricultural Safety and Health 13(1):65-82.

Mark, T. MA., Kanda, M., Crawford, M. L and E. B. Larssen. 1985. A review of electromagnetic compatibility/interface measurement methodologies. In: *Proceedings of the IEEE*. 73(3):388-411.

Marsili, A., Ragni, L., Santoro, G., Servadio, P and G. Vassalini. 2002. Innovative systems to reduce vibrations on agricultural tractors: comparative analysis of acceleration transmitted through the driving seat. Biosystems Engineering 81(1):35-47.

Masuda, K., Tagi, H., Saito, Y and Y. Fukumoto. 2009. A proposal for an efficient EMI measurement method in a fully anechoic room. In: *International Symposium on Electromagnetic Compatibility*, Kyoto, 21R2-2, pp. 113-116.

Mattetti, M., Molari, G and A. Guarnieri. 2012. Optimization of a three point hitch in an agricultural tractor. In: *International Conference of Agricultural Engineering*, CIGR-AgEng 2012, Valencia, Sapin.

Mills, D. L. 1992. Network time protocol (version 3) specification, implementation and analysis. RFC 1305, Internet Engineering Task Force Network Working Group, University of Delaware.

NTTL. 2013. Nebraksa Tractor Test Laboratory, 134 Splinter Labs, UNL, East Campus, Lincoln.

OECD. 2012a. OECD code 2. OECD standard code for the official testing of agricultural and forestry tractor performance. OECD, Parish. France. Available at www.oecd.org.

OECD. 2012b. OECD code 4. OECD standard code for the official testing of protective structures on agricultural and forestry tractors (static test). OECD, Parish. France. Available at www.oecd.org.

OECD. 2013. Standard codes for the official testing of agricultural and forestry tractors. OECD, Parish. France. Available at www.oecd.org.

Olejnik, K. 1999. Report 0110/R71/ZBH/98 from the agricultural tractor research URSUS 2812 /KMF-235/1 aspect of driver's visibility zone corresponding with Regulation 71 EKG correction 00, and in rear mirrors. ITS work. Warsaw.

Olejnik, K. 2005. Agricultural tractor driver's limitations of visual transmission in aspect of road safety in Poland. TEKA, Commission of motorization and energetics in agriculture. An International Journal on Motorization, Vehicle Operation, Energy Efficiency and Mechanical Engineering 5:158-167.

Park, S. H., Kim, Y. J., Im, D. H., Kim, C. K., Jang, Y and S. S. Kim. 2010. Analysis of factors affecting fuel consumption of agricultural tractor. Journal of Biosystems Engineering 35(3):151-157.

Parsons, K. 2003. Human thermal environments: The effects of hot, moderate and cold environments on human health, comfort and performance. 2nd ed. Taylor & Francis, London.

Pessina, D., Facchinetti, D and M. Belli. 2010. Definition of unambiguous criteria to evaluate tractor ROPS equivalence. In: *XVIIth World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)*, Canadian Society for Bioengineering (CSBE/SCGAB), Quebec City, Canada.

Pexa, M., Cindr, M., Kubin, K and V. Jurca. 2011. Measurements of tractor power parameters using GPS. Research in Agricultural Engineering 57(1):1-7.

Rondelli, V., Capacci, E., Franceschetti, B and A. Guarnieri. 2012. ROPS design evolution with respect to the requirements of the strength test procedures. In: *International Conference of Agricultural Engineering*, CIGR-AgEng, Valencia, Spain.

Ruzic, D. 2011. Improvement of thermal comfort in a passenger car by localized air distribution. ACTA Technica Corviniensis-Bulletin of Engineering, pp. 63-67.

Ruzic, D and F. Casnji. 2011a. Agricultural tractor cab characteristics relevant for microclimatic conditions. Journal of Applied Engineering Science 9(2):323-330.

Ruzic, D and F. Casnji. 2011b. Personalized ventilation concept in mobile machinery cab. International Journal for Vehicle Mechanics, Engines and Transportation Systems 37(1):9-22.

Scarlett, A. J. 2009. In-service assessment of agricultural trailer and trailed appliance braking system condition and performance. The agricultural trailer braking study. RR697 Research report for the Health and Safety Executive (HSE), Scarlett Research Limited, Biggleswade, UK.

Scarlett, A. J., Price, J. S and R. M. Stayner. 2007. Whole-body vibration: Evaluation of emission and exposure levels arising from agricultural tractors. Journal of Terramechanics 44:65-73.

Stellini, I. M. 2009. Evaluation of uncertainty and repeatability in measurement: two application studies in synchronization and EMC testing. Ph.D. Thesis, Department of Information Engineering, University of Padova.

Stojic, B., Casnji, F and A. Poznic. 2011. The role of the mechatronics in technological development of the contemporary agricultural tractors. ACTA Technica Corviniensis-Bulletin of Engineering, pp. 59-62.

Stone, M. L., McKee, K. D., Formwalt, C. W and R. K. Benneweis. 1999. ISO 11783: An electronic communications protocol for agricultural equipment. In: *Agricultural Equipment Technology Conference*. pp. 1-17, Louisville, Kentucky, USA.

Taylor, B. N and C. E. Kuyatt. 1994. Guidelines for evaluating and expressing the uncertainty of NIST Measurement Results, NIST Technical Note 1297, U.S. Department of Commerce.

Tippet, J. C. 1978. Modal characteristics of rectangular coaxial transmission line. PhD dissertation, Dept. of Electrical Engineering, University of Colorado, Boulder.

Tippet, J. C., Chang, D. C and M. L. Crawford. 1976. An analysis and experimental determination of the cutoff frequencies of higher-order TE modes in a TEM cell, NBSIR 76-841.

Venem, M. T., Shutske, J. M and W. J. Gilbert. 2006. Testing and creation of a safety system to disengage the PTO of a tractor. Applied Engineering in Agriculture 22(1): 5-12.

Watanabe, S., Melikov, A. K and G. L. Knudsen. 2010. Design of an individually controlled system for an optimal thermal microenvironment. Building and Environment 45(3):549-558.

Younis, S. M., Elashry, EL. S. R., Bahnasy, A. F. and I. M. Elsybaee. 2010. Development a local system for measuring tractors performance. Misr Journal of Agricultural Engineering 27(1):34-53.