Review

Journal of Biosystems Engineering

J. of Biosystems Eng. 39(3):158-165. (2014. 9)
http://dx.doi.org/10.5307/JBE.2014.39.3.158

eISSN : 2234-1862
pISSN : 1738-1266

Comparison of Test Standards for the Performance and Safety of Agricultural Tractors: A Review

Md. Shaha Nur Kabir[1], Sun-Ok Chung[1]*, Yong-Joo Kim[1], Sung-Hyun Shin[2]

[1]Department of Biosystems Machinery Engineering, Chungnam National University, Daejeon, Korea
[2]MogenKorea, Yongin, Korea

Received: August 1st 2014; Revised: August 9th 2014; Accepted: August 21st 2014

Abstract

Purpose: The objective of this paper was to compare test standards regarding the performance and safety of agricultural tractors to identify the differences in test conditions, measurement tolerances, and test procedures. Based on the comparison, some recommendations were proposed for possible revisions or improvements to current tractor test standards. **Methods:** The test standards and codes of major standards development organizations (SDOs), such as the Organization for Economic Co-operation and Development (OECD), the International Organization for Standardization (ISO), the American Society of Agricultural and Biological Engineers (ASABE), EC type approval, and the board of actions of the Nebraska Tractor Test Laboratories (NTTL), were selected and analyzed. **Comparison of the test standards:** The ISO provides references for fuel and lubricants for tractor tests, and the OECD provides additional measurements for calculating fuel consumption characteristics during the power take-off (PTO) tests. The ISO, EC type approval, and the ASABE provide PTO protective device and the safety requirements. During drawbar power tests, seven transmission ratios are selected for fully automatic transmissions, according to the OECD. In case of hydraulic lift tests, ISO 789-2 and OECD Code 2 advise the use of a static lift force, while SAE J283 advises the use of additional dynamic lift capacity tests for a better representation of in-field operations. The OECD, the ISO, and EC type approval determine the seat index point (SIP), whereas the ASABE determines the seat reference point (SRP) for roll-over protective structure (ROPS) tests. Diversified measurement tolerances were among the braking performance test standards. The European Union (EU) has developed daily limits for vibration exposures with adaptations from ISO 2631-1. Electromagnetic compatibility evaluations are emerging of high-efficiency tractors due to the long-term conformance to electromagnetic emissions and interferences. Comparisons of tractor test standards discussed in this paper are expected to provide useful information for tractor manufacturers and standards development personnel to improve the performance and safety test standards of tractors.

Keywords: Agricultural tractor, Performance, Safety, Test standard

Introduction

Agricultural tractors perform various operations during both the farming and off-farming seasons in off-road conditions; therefore, both performance and safety standards should be much higher for tractors than for general vehicles (Sim et al., 2011). For this reason, the safety of agricultural tractors is an emerging issue along with heightened performances. A survey showed that in Korea, approximately 79.3% of accidents involving tractors were tractor overturns, but there were no serious injuries when the tractors had a roll-over protective structure (ROPS) and a seat belt (Kim et al., 2010). Shin and Kim (2011) also suggested that the tractor operator's seat should be improved to meet the current ISO 5007 or

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

78/764/EEC standards, and an exposure limit value should be enforced in the European Union (EU) tractor market by the EU Directive 2002/44 EC standard.

Tractor test standards are an effective tool for meeting quality requirements, promoting improvements, facilitating international trade, securing the safety of operators, enhancing environmental conservation, and saving energy (Takahashi, 1998). Test procedures and standards for agricultural tractors have been established in several industrialized countries for many years. These standards are built on transparency, liberality, equity, unanimousness, effectiveness, and due process (OECD, 2014). Standardization offers obvious amenities to manufacturers and farmers by guaranteeing that tractors produced or purchased meet all national and international safety and performance standards (Bertram and Liberatori, 1998). Results from these standardized tests may also be useful for comparing the performances of various tractor models, as well as to help farmers obtain unbiased performance and safety information before making a purchase decision.

Agricultural tractors have undergone a technological evolution in design and normal field operation. They have gradually been improving in terms of engine performance, transmission efficiency, fuel consumption, and the matching of tractors and implements. At the same time, special attention has also been devoted to the safety and comfort of the driver by introducing air conditioning systems, reducing noise, and adding suspension systems to decrease the perceived whole-body vibration (WBV) (Day et al., 2009). However, the test procedures of the test standards provided by standard development organizations (SDOs) have remained unchanged, or they have been slightly modified over the years with respect to these technological innovations (Kabir et al., 2014).

The tractor testing business was confused because of the variations in requirements among the SDOs (PAMI, 1996). In our previous work, the research trends regarding evaluations of the performance, safety, and comfort of agricultural tractors were reviewed (Kabir et al., 2014). The motivation for our research was to provide information on testing the performance, safety, and comfort of large, high-efficiency tractors; therefore, we need to analyze the tractor test standards of different testing bodies. A comparison of the test standards may provide more favorable data and valuable information to the tractor manufacturer and standards development personnel for improving performance and safety test standards.

The objective of this paper was to compare the current international performance and safety test standards of agricultural tractors to identify the differences with regard to test conditions, measurement tolerances, and procedures. Based on the comparison, some recommendations were proposed for possible revisions or improvement to the current performance and safety test standards of agricultural tractors.

Standards Development Organizations (SDOs)

Standards are documents that provide, inter alia, requirements, rules, and guidelines for a process, product, or service; the process of formulating, issuing, and implementing standards is called standardization. Standardization contributes to achieving an international accord on all technical matters related to the exchange of goods and services between one nation and another (UNIDO, 2006). Major SDOs that produce the test standards for testing tractors internationally are the OECD, the ISO, the SAE, the ASABE, EC type approval, and the NTTL (Kabir et al., 2014).

Compared Test Standards

At present, tests of power take-off performance, drawbar power, hydraulic power and lifting force, axle power, brake performance, center of gravity, overturning angle, and the roll-over and falling object protective structures of agricultural tractors are being performed at the Foundation of Agri. Tech. Commercialization and Transfer (FACT), which is the official OECD-designated tractor test

Table 1. Performance and safety test standards reviewed in the study

Classification	Item
Performance	Power take-off (PTO) power
	PTO safety
	Drawbar power
	Hydraulic lift capacity
Safety	Roll-over protective structure (ROPS), Braking performance
	Vibration measurement
	Electromagnetic compatibility (EMC/EMI)

station in Korea (FACT, 2014). Focusing on these tests and based on our research interest, the performance and safety test standards of these major SDOs were collected (Table 1) and major differences were reviewed. For each test item, only the standards exhibiting major differences or important information were compared. For example, OECE Code 2 and ISO 789-1 were compared for the power take-off (PTO) power test.

Power take-off (PTO) power test

A comparison of the OECD Code 2 (OECD, 2014a) and ISO 789-1 (ISO, 1990a) test standards is provided in Table 2 in terms of test requirements and performance test procedures. ISO 789-1 provided specific references for fuel and lubricants for the PTO power test, whereas OECD Code 2 only specified the minimum standards for fuel and lubricants approved by the tractor manufacturer. For the maximum power test, OECD Code 2 and ISO 789-1 instruct to operate the tractor for 1 and 2 h, respectively, subsequent to a sufficient warming-up period for power to become stabilized. Five additional measurements need to be collected for fuel consumption characteristics according to OECD Code 2, while ISO 789-1 did not specify these additional requirements. Both standards provide average PTO rotational speeds of 540 or 1,000 rpm for the PTO test at varying loads. However, "540E" or a 750 rpm standard economical PTO operation may be alternatives to 540 rpm (Sumer et al., 2010; Isiktepe and Sumer, 2010).

Power take-off (PTO) safety test

A comparison of the ISO 500-1 (ISO, 2004a) and Directive 86/297/EEC (EEC, 1986) test standards is provided in Table 3 in terms of the types and characteristics of the protective guards. Directive 86/297/EEC was amended in Directives 2010/62/EU (EU, 2010) and 2012/24/EU (EU, 2012). PTO and the associated shafts cause incidents and injuries in agricultural operations; thus, the PTO shaft and the driven implements should be guarded by either a master shield or another equally protective guarding. Each SDO should have PTO safety standards to reduce the risks associated with the PTO and driven attachments.

Drawbar power test

A comparison of the OECD Code 2 (OECD, 2014a), ISO 789-9 (ISO, 1990b), and NTTL Board Action Nos. 6 and 8 (NTTL, 1988a and 1998b) test standards is provided in Table 4 in terms of definitions, conditions, and power transmission systems. A separate test procedure for tractors with continuously variable transmissions (CVT) is needed. Current tractor test procedures do not evaluate

Table 2. Comparison of PTO power test standards

Item	OECD Code 2	ISO 789-1
Fuel and lubricants	▸ References are not specified	▸ The Coordinating European Council (CEC) references fuels for specific engines ▸ Lubricants shall comply with the manufacturer's specifications
General test requirements	▸ Shaft connecting PTO to dynamometer shall not have any appreciable angularity	▸ The angle shall not exceed 2°
Maximum power test	▸ Tractor shall be operated for 1 h subsequent to warming-up period for power to become stabilized	▸ Tractor shall be operated where maximum power occurs for 2 h subsequent to the warming-up period for stabilized conditions
Fuel consumption tests	▸ Fuel consumption is measured five additional times to enable the evaluation of fuel economy	▸ Measurement of fuel consumption at additional points is not mentioned

Table 3. Comparison of PTO safety standards

Item	ISO 500-1	Directive 86/297/EEC (Amended in 2010/62/EU, 2012/24/EU)
Protective guards for PTO type 3	▸ Not provided	▸ User manual must contain instructions and warnings relating to coupling and releasing the PTO; use of tools or machines coupled to the rear PTO
Characteristics of the PTO protective guard	▸ Master shield may be made of flexible material	▸ Materials used must be able to withstand poor weather, must retain their mechanical properties in cold weather, and must be sufficiently sturdy

Table 4. Comparison of drawbar power test standards

Item	OECD Code 2	ISO 789-9	NTTL (Board action No. 06, 08)
Definition	▸ Power available at the drawbar, a distance of at least 20 m	▸ Power at the drawbar for at least 20 s, or time to cover 20 m, whichever is longer	-
Ambient temperature	▸ Shall not exceed 35°C	▸ Temperature at the test track shall be 20°C ± 15°C	▸ May be lowered from 10 to 4.5°C
Stepless variable/fully automatic transmission	▸ Power envelope curve can be obtained by determining maximum power for a sufficient number of transmission ratios	▸ Test carried out on six transmission ratios, including that at which the maximum power is obtained	▸ Tractor shall be operated at six or more travel speeds
Fuel consumption (FC) measurement	▸ FC is measured at nominal speeds of 7.5 and between 7 and 10 km/h ▸ FC test is designed to compare fuel efficiency of tractors with partial loads with either a GT or a CVT	▸ FC is measured when the tractor traverses a straight track of 100 m	▸ Upper speed limit involving measurement of FC for 2 h or more shall be 11.76 km/h

Table 5. Comparison of hydraulic lift capacity test standards

Item	ISO 789-2		OECD Code 2	ASABE (SAE J283)	
Accuracy of measurement	Time	±0.2 s	Same as ISO789-2	Time	±2%
	Distance	±0.5%		Distance	±3 mm
	Temperature	±0.5°C		Temperature	±2°C
Test procedures	▸ Uses a static lift force corrected to 90% of the minimum hydraulic pressure ▸ Maintenance of lift of load test (optional) is stated		▸ Same as ISO 789-2 ▸ The optional lift of load test is not stated	▸ Along with the static lift force test, additional lift times of 3 and 6 s are added to the existing lift time of 10 s for the dynamic lift capacity test	

the fuel-saving benefits of tractors with CVT transmissions. Recently, a test procedure has been designed in the updated OECD Code 2 (OECD, 2014a) to compare the partial-load fuel efficiencies of tractor models with a standard geared transmission (GT) or a CVT.

Hydraulic lift capacity test

A comparison of the ISO 789-2 (ISO, 1993), OECD Code 2 (OECD, 2014a), and SAE J283 (ASABE Standards, 2009a) test standards is provided in Table 5 in terms of measurement accuracy and procedures. Diverse measurement tolerances were among the test standards. The ISO 789-2 and OECD Code 2 test standards use a static lift force corrected to 90% of the minimum hydraulic pressure to reflect usable in-field lift forces. Alternatively, the SAE J283 test standards use additional dynamic lift capacity tests, including lift times of 3 and 6 s in addition to an existing lift time of 10 s for a better representation of in-field operations.

Roll-over protective structure (ROPS) test

A comparison of the OECD Code 4 (OECD, 2014b), ISO 5700 (ISO, 2006), SAE J2194 (ASABE Standards, 2009b), and Directive 2009/75/EC (EU, 2009a) test standards is provided in Table 6 in terms of scope, measurement tolerances, and procedures. Diverse measurement tolerances were among the ROPS test standards, and the OECD provided new tolerance values in their recent updated standards. However, previous tolerances can be used while performing tests outside the OECD station premises, as well as when non-electronic measuring instruments are used. The OECD Code 4, ISO 5700, and Directive 2009/75/EC test standards use SIP, whereas the SAE J2194 test standards use SRP for the ROPS test. Side loading (SD) is applied to the ROPS's upper extremity at points that are 160-a_h mm and 85 mm forward of the SIP, according to OECD Code 4 and ISO 5700, respectively, where "a_h" is half the horizontal seat adjustment. In accordance with the SAE J2194 test standards, SD is applied to the upper extremity of the ROPS at a point that is 300 mm forward of the SRP.

Table 6. Comparison of ROPS test standards (static)

Item	OECD Code 4	ISO 5700	ASABE (SAE J2194)	Directive 2009/75/EC
Scope	▸ Tractor mass ≥600 kg	▸ Tractor mass ≥800 kg	▸ Tractor mass minimum 800 kg	▸ Mass ≥ 800 kg
Tolerances	Distance ±0.5 mm Force ±0.1% Mass ±0.2% Time ±0.1 s	Same as OECD Code 4	Dimensions ±3 mm Deflections ±3 mm Mass ±20 kg Forces ±2%	Same as SAE J2194
Test procedures and conditions	▸ SIP is determined ▸ SD is applied to the ROPS's upper extremity at 160-ah mm forward of SIP ▸ An overload test is given	▸ Same as OECD Code 4 ▸ SD is applied to the ROPS's upper edges at 85 mm forward of SIP ▸ Same as OECD Code 4	▸ SRP is determined ▸ SD is applied to the ROPS at a point 300 mm forward of the SRP ▸ An overload and field upset test is outlined here	▸ Same as SAE J2194 ▸ Same as SAE J2194

Table 7. Comparison of braking performance test standards

Item	ISO 5697	OECD Code 2	ASABE (ANSI/ASAE S365.9)
Accuracy of measurement	Travel speed ±3% Mass ±3% Deceleration ±3% Stopping distance ±1% Input force ±5% Tire pressure ±5% Fluid pressure ±5%	Rotational speed ±0.5% Time ±0.2% Distance ±0.5% Force ±1.0% Mass ±0.5% Hydraulic pressure ±2.0% -	Temperature ±3°C Test speed ±2% Towing force ±3% Device to towed to test machine ±4° Brake temp ±2% Time to stop ±1% Ambiant temp ±3°C
Test procedures	▸ Performance shall be based on measured deceleration and stopping distance	▸ Based on mean fully-developed deceleration and mean deceleration calculated over the stopping distance	▸ Based on minimum stopping distance and corresponding braking control input force
	Cold performance test: ▸ Test surface shall not have a longitudinal slope > 1%, nor a side slope > 3%	▸ Brakes have not been actuated for 1 h, deemed to be cold	▸ Same as OECD Code 2
	Fade test: ▸ Describes separately for maximum design speeds of ≤ 35 and ≥ 35 km/h	▸ Describes a common fade test procedure	▸ Fade and recovery test procedure are described here

Braking performance test

A comparison of the ISO 5697 (ISO, 1982), OECD Code 2 (OECD, 2014a), and ASABE ANSI/ASAE S365.9 (ASABE Standards, 2011) test standards is provided in Table 7 in terms of measurement accuracy and test procedures. Diverse measurement tolerances were also among the braking performance test standards.

Vibration measurement test

A comparison of the EU Directive 2002/44/EC (EU, 2002), ISO 2631-1 (ISO, 1997), and ISO 2631-5 (ISO, 2004b) test standards is provided in Table 8 based on average weighted vibration (A_w), vibration dose value (VDV), and daily equivalent static compressive stress (S_{ed}) in terms of exposure limits and action values. The OECD does not provide a vibration measurement code and the ASABE referred to the ISO 5008 (ISO, 2002) test standards. WBV contributes to low back pain and is a major source of lost time in occupational environments; therefore, the OECD should include vibration standards in their tractor test codes. Moreover, the ISO 2631-5 test standards would be useful for further evaluations of transient shock vibration exposure in relation to human health.

Table 8. Comparison of vibration test standards based on daily (8 h) action and exposure limits for whole body vibration (WBV)

	Directive 2002/44/EC		ISO 2631-1		ISO 2631-5	
	A_w (m/s^2)	VDV $(m/s^{1.75})$	A_w (m/s^2)	VDV $(m/s^{1.75})$	S_{ed} (MPa)	Health risk probability
Action limit	0.5	9.1	0.5	9.1	0.5	Moderate
Exposure limit	1.15	21	0.8	14.8	0.8	High

Table 9. Comparison of EMC test standards

Item	Directive 2009/64/EC	ISO-14982
Scope	▸ Applicable to the EMC of tractors and ESAs intended to be fitted to tractor	▸ Not applicable to immunity for the parts whose functions are not involved in the direct control and modification of functions
Narrow band reference limits	▸ If signal strength <20 dBμV/m over frequency range of 88 to 108 MHz, no further testing will be required for narrow band electromagnetic radiation	-
Test procedure	▸ No type-approval test for electrostatic discharge, and conducted transients is deemed necessary	▸ Electrostatic discharge—referred to ISO/TR 10605 ▸ Conducted transients—referred to ISO 7637-0,I,2

Electromagnetic compatibility (EMC) test

A comparison between the ISO-14982 (ISO, 1998) and Directive 2009/64/EC (EU, 2009b) test standards is provided in Table 9 in terms of reference limits and test procedures. Both standards are applicable to tractors and their electrical/electronic sub-assemblies (ESAs) intended to be fitted into the tractors. The ISO-14982 test standards are not applicable to immunity for the parts whose functions are not involved in the direct control and modification of the state of the functions of the tractor. According to Directive 2009/64/EC, if the signal strength measured at the vehicle broadcast radio antenna is less than 20 dBμV/m (10 μV/m) over the frequency range of 88 to 108 MHz, the vehicle shall be deemed to comply with the limits of narrowband emissions. Therefore, no further testing will be required for narrow band electromagnetic radiation. As electronic components are increasing in prominence in large tractors, demands are growing for the evaluation of tractors using electromagnetic compatibility (EMC) tests.

Recommendations

Agricultural tractor test standards are intricate and complicated. In this article, the leading standards for agricultural tractors of major SDOs are compared. Based on the comparisons, the following recommendations were made for possible improvements or revisions to the current test standards or codes:

- The ISO provides references for fuels and lubricants used during tractor tests, while other SDOs did not specify such references. Reference fuels and lubricants should be provided by all SDOs in their standards to conform to a uniform assessment of tractor testing.
- Manufacturing tolerances are an inherent part of the mass production of tractors. Diversified permissible measurement tolerances or measurement units were among the standards. Harmonization should be achieved regarding permissible measurement tolerances or units.
- Evaluation of maximum power at PTO is conducted for 1 and 2 h, subsequent to warming-up periods, according to the OECD and the ISO, respectively. If it is difficult to carry out the test in the 2-h period, a 1-h test may be carried out. In addition, five additional measurements should be collected for calculating fuel consumption characteristics in compliance with the OECD Code 2 test standards to enable the evaluation of fuel economy. In addition, “540E” or a 750-rpm standard economical PTO operation may be alternatives to 540 rpm.
- The PTO shaft and its attachment must be guarded by a master shield to reduce the risks associated to PTO drive shafts. Standards regarding PTO and their protections should be considered to prevent hazards regarding the PTO shaft.
- Regarding the hydraulic lift capacity test, a dynamic lift test may be practiced by adding lift times of 3 and 6 s to an existing 10-s lift time, as reflected in the SAE J283 test standards, to represent in-field operations better.
- The evolution of ROPS design in agricultural tractors

demands an update of the test standards to fulfill the requirements for operator safety. A general harmonization among the codes and standards governing ROPS will need to be achieved.

- Tractor operators are exposed to vibrations, which are a major source of discomfort, and high levels of exposure could lead to numerous adverse health risks. The WBV exposure limit value (ELV) should not be exceeded during 8 h of operation. In recent years, there has been an increased emphasis on health and safety regarding agricultural tractors. Therefore, vibration measurement standards should be included in the OECD tractor test codes, and a braking performance test should be made mandatory by the OECD.
- EMC management is necessary while designing the electronic system. The increase in electronic devices in tractors raises the demands for evaluating the EMC of tractors to perform their functions satisfactorily without introducing intolerable electromagnetic disturbances.
- Standards relating to specifications and safety requirements for PTO drive shafts, the measurement of WBV affecting tractor operator, test methods, and acceptance criteria for evaluating the EMC of agricultural tractors might be considered for agricultural tractors in Korea.

Conflict of Interest

The authors have no conflicting financial or other interests.

Acknowledgement

This research was supported by the technology development program for agriculture and forestry (Project No. 312040031HD040), Ministry for Food, Agriculture, Forestry and Fisheries, Republic of Korea.

References

ASABE Standards. 2009a. SAE J283: Test procedure for measuring hydraulic lift capacity on agricultural tractors equipped with three-point hitch. St. Joseph, Mich.: ASABE.

ASABE Standards. 2009b. SAE J2194: Roll-over protective structures (ROPS) for wheeled agricultural tractors. St. Joseph, Mich.: ASABE.

ASABE Standards. 2011. ANSI/ASAE S365.9: Braking system test procedures and braking performance criteria for agricultural field equipment. St. Joseph, Mich.: ASABE.

Bertram, H-H. and S. Liberatori. 1998. On the certification of agricultural machinery. 9th OECD Members Meeting, Bologna, Italy.

Day, B., L. Field and A. Jarvis. 2009. The Wrest Park Story 1924-2006. Biosystems Engineering 103(1):36-47.

EEC. 1986. 86/297/EEC: Council Directive - On the approximation of the laws of the member states relating to power take-offs of wheel agricultural and forestry tractors and their protection. Official Journal of the European Union L 186/19-25.

EU. 2002. 2002/44/EC: Directive of the European parliament and of the council, on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration). Official Journal of the European Communities. L 177/13.

EU. 2009a. 2009/75/EC: Directive of the European parliament and of the council, on roll-over protection structures of wheeled agricultural or forestry tractors (static testing). Official Journal of the European Union L 261/40-77.

EU. 2009b. 2009/64/EC: Directive of the European parliament and of the council, on the suppression of radio interference produced by agricultural or forestry tractors (electromagnetic compatibility). Official Journal of the European Union L 216/1.

EU. 2010. 2010/62/EU: Commission Directive. Amending, for the purpose of adapting their technical provisions, Council Directives 80/720/EEC and 86/297/EEC and Directives 2003/37/EC, 2009/60/EC and 2009/144/EC of the European Parliament and of the Council relating to the type-approval of agricultural or forestry tractors. Official Journal of the European Union L 238/7-13.

EU. 2012. 2012/24/EU: Commission Directive. Amending, for the purpose of adapting its technical provisions, Council Directive 86/297/EEC on the approximation of the laws of the Member States relating to the power take-offs of tractors and their protection. Official

Journal of the European Union L 274/24-25.

FACT. 2014. Agricultural Machinery Testing and Evaluation: Foundation of Agri. Tech. Commercialization and Transfer (FACT), OECD official tractor test station, Suwon, Republic of Korea.

Isiktepe, M and S. K. Sumer. 2010. Comparing operational characteristics of 540 rpm and 750 rpm PTO in tractors through laboratory tests. Anadolu Journal of Agricultural Science 25(3):168-174.

ISO. 1982. ISO 5697: Agricultural and forestry vehicles - Determination of braking performance. Geneva, Switzerland: ISO.

ISO. 1990a. ISO 789-1: Agricultural tractors - Test procedures - Part 1: Power tests for power take-off. Geneva, Switzerland: ISO.

ISO. 1990b. ISO 789-9: Agricultural tractors - Test procedures - Part 9: Power tests for drawbar. Geneva, Switzerland: ISO.

ISO. 1993. ISO 789-2: Agricultural tractors - Test procedures - Part 2: Rear three-point linkage lifting capacity. Geneva, Switzerland: ISO.

ISO. 1997. ISO 2631-1: Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements. Geneva, Switzerland: ISO.

ISO. 1998. ISO14982: Agricultural and forestry machinery - Electromagnetic compatibility - Test methods and acceptance criteria. Geneva, Switzerland: ISO.

ISO. 2002. ISO 5008: Agricultural wheeled tractors and field machinery - Measurement of whole-body vibration of the operator. Geneva, Switzerland: ISO.

ISO. 2004a. ISO 500-1: Agricultural tractors - Rear mounted PTO types 1, 2 and 3 - Part 1: General specifications, safety requirements, dimensions for master shield and clearance zone. Geneva, Switzerland: ISO.

ISO. 2004b. ISO 2631-5: Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 5: Methods for evaluation of vibration containing multiple shocks. Geneva, Switzerland: ISO.

ISO. 2006. ISO 5700: Tractors for agriculture and forestry - Roll-over protective structures (ROPS) - Static test method and acceptance conditions. Geneva, Switzerland: ISO.

Kabir, M. S., Ryu, M. J., Chung, S. O., Kim, Y. J., Choi, C. H., Hong, S. J and J. H. Sung. 2014. Research trends for performance, safety, and comfort evaluation of agricultural tractors: A review. Journal of Biosystems Engineering 39(1):21-33.

Kim, H. J., Kim, K. W., Choi, S., Kim, J. S., Kim, Y. Y., Kim, J. O., Kim, H. K and S. H. Kwon. 2010. A study on improving the tractor ROPS and seatbelt use of Korean farmers. Journal of Biosystems Engineering 35(5):294-301.

NTTL. 1998a. Board Action No. 06, Nebraska Tractor Test Board. Department of Biological System Engineering, University of Nebraska, Lincoln: NTTL (Nebraska Tractor Test Laboratory).

NTTL. 1998b. Board Action No. 08, Nebraska Tractor Test Board. Department of Biological System Engineering, University of Nebraska, Lincoln: NTTL (Nebraska Tractor Test Laboratory).

OECD. 2014. Standard codes for the official testing of agricultural and forestry tractors. Parish, France: OECD. Available at www.oecd.org.

OECD. 2014a. OECD code 2: Standard code for the official testing of agricultural and forestry tractor performance. Parish, France: OECD. Available at www.oecd.org.

OECD. 2014b. OECD code 4: Standard code for the official testing of protective structures on agricultural and forestry tractors (Static test). Parish, France: OECD. Available at www.oecd.org.

PAMI. 1996. Standardized tractor performance testing - What it is - and isn't? Research update 727. Humboldt, Saskatchewan, Canada: Prairie Agricultural Machinery Institute (PAMI).

Shin, C. S and K. U. Kim. 2011. Evaluation of vibration reduction performance of operator seat for agricultural tractors. Journal of Biosystems Engineering 36(1): 1-8.

Sim, K., Cho, W and Y. Lee. 2011. Development on test specification of reliability of agricultural tractor. In: Proceedings of the Korean Society of Automotive Engineers, Autumn Conference, pp43-48, Guangzhou, Honam Branch.

Sumer, S. K., Kocabiyik, H., Say, S. M and G. Cicek. 2010. Comparisons of 540 and 540E PTO operations in tractors through laboratory tests. Bulgarian Journal of Agricultural Science 16(4):526-533.

Takahashi, H. 1998. Generality of the official testing system for agricultural machinery. 9th OECD Members Meeting, Bologna, Italy.

UNIDO. 2006. Role of standards- A guide for small and medium-sized enterprises, working paper. Vienna, Austria: United Nations Industrial Development Organization (UNIDO).