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AN UPDATED METHODOLOGY TO ANALYSE THE IDLING OF AGRICULTURAL TRACTORS

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ABSTRACT

Idling is a status of tractors in which the engine is not subjected to any substantial load and the vehicle is standing. Idling is detrimental for the environment and health of people and it is a frequent status for agricultural tractors. Indeed, agricultural tractors may idle from 10 to 43 % of the entire operating duration. Only in some conditions idling is necessary (e.g. implement hitching), otherwise it is a waste of fuel. The aim of the project is to report an updated methodology to analyse the idling practice of agricultural tractors. Idling was monitored through a dash-cam and a CAN-Bus data logger installed on a tractor with a maximum engine power of 191 kW. The tractor ran on idle for the 17% of the entire operating time and the most frequent stop occurred for the adjustment of the implement when the soil engaging tools become clogged by crop residuals. Moreover, in 67 % of the idling duration, no tractor subsystem was used, so most of the idling was not caused by a real need. This idling is responsible for a waste of 1.6 % of the fuel used. Considering that 8.3 % of the tractors belong to the same class (in terms of mass) of that used in this study, 43 million of litres of fuel are wasted per year. The results of this study could be used for developing anti-idling devices on agricultural tractors.

KEYWORDS: Real-world data; idling; ISO 11783; fuel consumption; pollution; driving cycle.

Acknowledgements

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Introduction

The engine industry is trying to improve the engine design to reduce fuel consumption and emissions so that modern society can lower the usage of fossil fuels. However, this might not be sufficient, if drivers do not use modern machines with the best available technologies and do not adopt driving habits that maximise the fuel economy, like avoid unnecessary idling (Takada, Ueki, Saito, Sawazu, & Nagatomi, 2007). Idling is a status of a tractor in which the engine is not subjected to any substantial load, so no useful work is accomplished in this state. In road vehicles, engine idling occurs when the engine is running and the transmission is not engaged. However, idling for agricultural tractors cannot be easily identified due to the fact that the different types of loads can be applied through different subsystems (i.e. PTO, hydraulic system).

Idling is detrimental for the environment, engine life (the engine accumulates fatigue damage but no useful work is delivered), environment, and health of people. Indeed, an idling engine is inefficient (i.e. fuel efficiency drops from 30 % of normal operating conditions to 11 % (Brodrick, Dwyer, Farshchi, Harris, & King, 2002)), wastes fuel and emits green-house gases. A previous study reports that idling of trucks is responsible for a waste between 3 and 8 billion of liters of fuel and an emission of 38 million of tons of CO_2 in the USA (Van den Berg, 1996). The fuel consumption during idling is dependent on engine size but also by the demands of auxiliaries. Those in many heavy-duty vehicles (e.g. agricultural tractors) are mechanically driven by the engine through belt transmission and the absorbed power is dependent on the engine speed and not on the real demands, which can be low during idling. For heavy-duty vehicles, the most energy demanding auxiliaries are the engine fan, alternator, brake air compressor, and air-conditioning compressor (Hnatczuk, Lasecki, Bishop, & Goodell, 2000). A previous study on heavy-duty trucks reported that the idling fuel consumption increases up to 170 % when the air conditioning is engaged (Brodrick et al., 2002; Khan et al., 2006).

Idling could be reduced with the anti-idling devices and the most popular one is the idling-stop. This device shuts-off the engine when it starts idling. However, engine restarts require additional energy (directly from fuel and battery), which should be lower than the energy from the fuel consumed during idling. Therefore, idling-stop might not be effective for very short idling stops, indeed according to a previous study, idling-stop is effective only when idling stops are longer than 8 s (Matsuura, Korematsu, & Tanaka, 2004). The design of effective anti-idling devices requires the knowledge of the idling activity of the vehicle in terms of idling duration and how frequent and long the idling stops are. These parameters are dependent by the activity carried out by drivers and therefore by the type of vehicle. For heavy-duty trucks, idling is an extremely frequent status, and it was extensively monitored through surveys and data-loggers (Gaines, Vyas, & Anderson, 2006). A truck may idle from 5 to 7 h per day and drivers tend to idle their engines for longer during extreme seasons to keep the cab temperature and the battery voltage to the optimum level (Lutsey, Brodrick, Sperling, & Oglesby, 2004). On the other hand, construction machines idle from 8 to 32 % of their entire operating duration depending on the type of machines (Lewis, Rasdorf, Frey, & Leming, 2012; Lewis Phil, Leming Michael, & Rasdorf William, 2012).

Idling is also a common operating activity of agricultural tractors. Indeed, a study conducted on a fleet of tractors based in different areas of the world reported that agricultural tractors idle for a period that ranges from 10 % to 43 % of their operating duration (Perozzi, Mattetti, Molari, & Sereni, 2016). The amount of idling is very variable and no study reports the reasons for idling and its fuel waste. Negligence of drivers could be a possible reason (e.g. overnight idling), but idling is also required for some activities and this type of idling is denoted as workday-idling (Gaines et al., 2006). The most known workday-idling task is the implement hitching. This task requires the utilisation of the transmission for moving the tractor forward and backward to longitudinally align the pins to the hitch points and the power-lift for raising the hitch points so they can be connected with the pins of the implement. For this task, both subsystems are needed for some seconds and force the drivers to idle the engine of their tractors for a few minutes. To evaluate when agricultural tractors are idled for real needs or for malpractices of drivers, real-world measurements should be carried out, where the usage of each tractor subsystem (e.g. engine, three-point hitch, auxiliary valves, etc) should be monitored. In modern tractors, the operating conditions of all the tractor subsystems can be monitored with CAN-Bus messages included in the SAE J1939 and ISO 11783 protocols (ISO, 2012; SAE, 2006). In previous studies, CAN-Bus messages were successfully used to outline the usage of agricultural tractors or to monitor the tractor or implement performance on real operating conditions. For example, the most frequent engine operating points and gear ratios were extracted with those protocols so that the durability demands of gear-wheels of a stepped transmission can be estimated (Mattetti, Maraldi, Sedoni, & Molari, 2019; Molari, Mattetti, Perozzi, & Sereni, 2013). Moreover, they were used to evaluate which driving events lead to higher damage of the axle housings (Mattetti, Molari, & Sereni, 2017) and to estimate the cultivated area of a plough (Heiß, Paraforos, & Griepentrog, 2019) and to minimise the infield non-working time spent when performing agricultural applications (Paraforos, Hübner, & Griepentrog, 2018).

The aim of this paper was to propose an updated methodology to study the idling habit of an agricultural tractor so that the following questions could be answered:

- What are the reasons for idling?
- When the tractor subsystems are used during idling?
- What is the fuel waste incurred due to the idling activity?

2. Materials and methods

The analysis was applied to a New Holland T7 (CNH Industrial N.V., Amsterdam, NL) and its main characteristics are reported in Table 1. This choice was carried out because tractors of this class are rich in terms of embedded sensors so that the different subsystems could be monitored.

Table 1 – Tractor engine specification.

Maximum engine power	[kW]	191
Wheelbase	[mm]	2884
Engine displacement	[m^3]	6.728
Number of cylinders	[-]	6
Engine tier	[-]	4B
Transmission	[-]	Continuously variable transmission
Number of auxiliary hydraulic valves	[-]	4
Three-point hitch	[-]	Rear
PTO	[-]	Front and rear

The tractor was used by different drivers from 12th of July and 14th of September 2018 in the Agricultural Farm of the University of Bologna (Cadriano, BO, Italy). The tractor was used by 3 different drivers, all of whom have more than 20 years of experience. The main operations carried out by the tractor were:

- ploughing with a 4 furrow semi-mounted plough manufactured by Nardi SpA (Selci Lama, Italy);
- harrowing with a 3m width grubber manufactured by Collari SNC (Castello D’argile , Italy);

- transportation with a trailer during the cereal harvesting manufactured by Zaccaria Srl (Montese, Italy).

The project consisted of two separate studies carried out in sequence. Firstly, the idling of the tractor was monitored with a dash-cam in order to monitor the activities of the driver when the tractor was idling; thus, the main reasons for idling could be identified. Then, the idling of the tractor was monitored with a CAN-Bus data logger so that the use of the different tractor sub-systems could be identified.

Idling monitoring with a dash-cam

For this study, 69 h of tractor usage were recorded with a Garmin Dash Cam 55 (Garmin Ltd., Olathe, KS, USA), which was installed on the windshield of the tractor and pointed backward, because it was foreseen that most of the driver activity during tractor idling occurs inside the cab or backward to the tractor. This was motivated by the fact that the tractor under study could be used only with rear-mounted implements. The camera power-supply was arranged so that the dash-cam started recording anytime the tractor engine was ignited. The camera has a wide-angle lens, which permitted it to monitor a large area around the tractor. This camera embeds a GNSS receiver and it reports the date, the time of the day and the tractor speed in the recorded video (Fig. 4 on the right bottom corner). All the portions of the videos where the tractor speed was 0 km h^{-1} were classified as idling and the activity of the driver in the camera field-of-view was observed and classified in order to evaluate the reason for the idling activity.

Idling monitoring with a CAN-Bus data logger.

In the second study, CAN-Bus data for 142 h was recorded through a stand-alone CAN-Bus data-logger optimised by CNH Industrial installed in the tractor. This automatically recorded all the CAN-Bus messages anytime the tractor engine was ignited. For the purpose of this study, only signals with the following Suspect Parameter Numbers (SPNs) and Parameter Group Parameters (PGNs) (ISO, 2012; SAE, 2013) were used for the analysis:

- SPN 190 and PGN 61444: "Engine Speed" that reports the revolution speed of the engine crankshaft.
- SPN 1894 and PGN 65090: "Rear PTO engagement", that reports the engagement of the rear PTO. It is a logical signal, which is 1 when the rear PTO is engaged and 0 otherwise.
- SPN 1893 and PGN 65090: "Front PTO engagement" that reports the engagement of the front PTO. It is a logical signal, which is 1 when the rear PTO is engaged and 0 otherwise.
- SPN 183 and PGN 65266: "Engine Fuel Rate" that reports the amount of fuel consumed by the engine per unit of time and it is denoted as FR in the following.
- SPN 9711 and PGN 64388: "Operator presence state" that reports the presence of the driver on the seat. It is a logical signal which is 1 when the driver is on the seat and is 0 when the driver is not on the seat and it is denoted as DP in the following.
- SPN 1873 and PGN 65093: "Rear Hitch Position" that reports the position of the rear three-point hitch. The signal is 0 when the rear three-point hitch is fully down and 100 % when it is fully up and it is denoted as RHP in the following.
- SPNs: 1907, 1919, 1931, 1943 and PGNs 65072, 65073, 65074 and 65075: "Auxiliary valve number port flow" that represent the flow through the valve in percentage with respect to the maximum flow. These signals are denoted as $AVF*$ in the following, where * stands for the number of the auxiliary valves (0, 1, 2, and 3).

Moreover, a GNSS receiver with an update rate of 10 Hz and with a claimed accuracy of 2.5 m (in terms of circular error probable) (IPESpeed, IPETronik GmbH, Baden Baden, Germany) was installed in the tractor to monitor the tractor position and its speed (V_t). All the data acquired when the tractor was run for less than 300 s in a day were excluded from the analysis, which could be caused by a non-real use of the tractor, like downloading data from the CAN-Bus data-logger. The recorded data was imported into Matlab (MathWorks Inc., Natick, MA, USA) for the analysis. The idling condition was identified as the condition where the tractor was standing and both PTOs were not engaged. The idling condition is indicated by a logical variable (I), that is 1 when idling occurred and 0 otherwise. For the sake of clarity, an example of calculation of the idling condition is reported in Fig. 1.

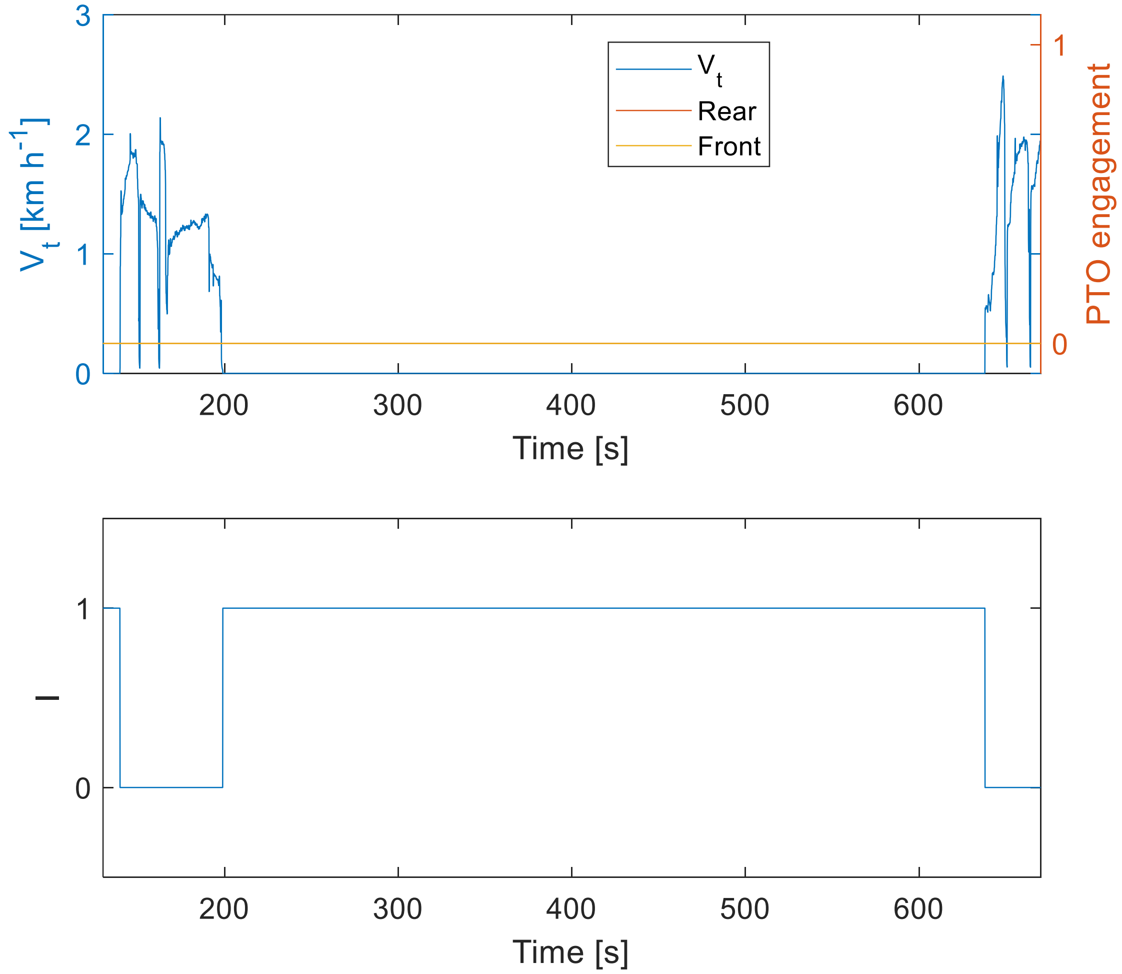

Fig. 1: Portion of signals to highlight the calculation of both idling conditions (on top) and idling logical signal where the idling stop duration was calculated. (on bottom).

The duration of each idling stop (T_s) was calculated as the period elapsed between a rising and falling edges of I (Fig. 1 on bottom) . Idling stops shorter than 5 s were excluded from the analysis which could be due to a particular manoeuvre of the driver, like reversing the tractor direction at the headland turns or inadvertent operations of the driver. Using this condition, 2.3 % of idling were not included in the analysis. In order to evaluate the usage of each tractor subsystem during each idling stop, the peak-to-peak values (i.e. the difference between the lowest and the highest values in a signal) of the portions of RHP and AVN_* signals during each idling stop were calculated. Thus, the use of the rear three-point hitch and auxiliary valves could be evaluated (Fig. 2).

Anytime the peak-to-peak value is larger than 0, a specific subsystem was used and therefore idling could be classified as workday-idling. Due to the fact that up to four auxiliary valves could be connected to the implement, the use of the auxiliary valves were identified by calculating the maximum value of the peak-to-peak values of $AVF*$.

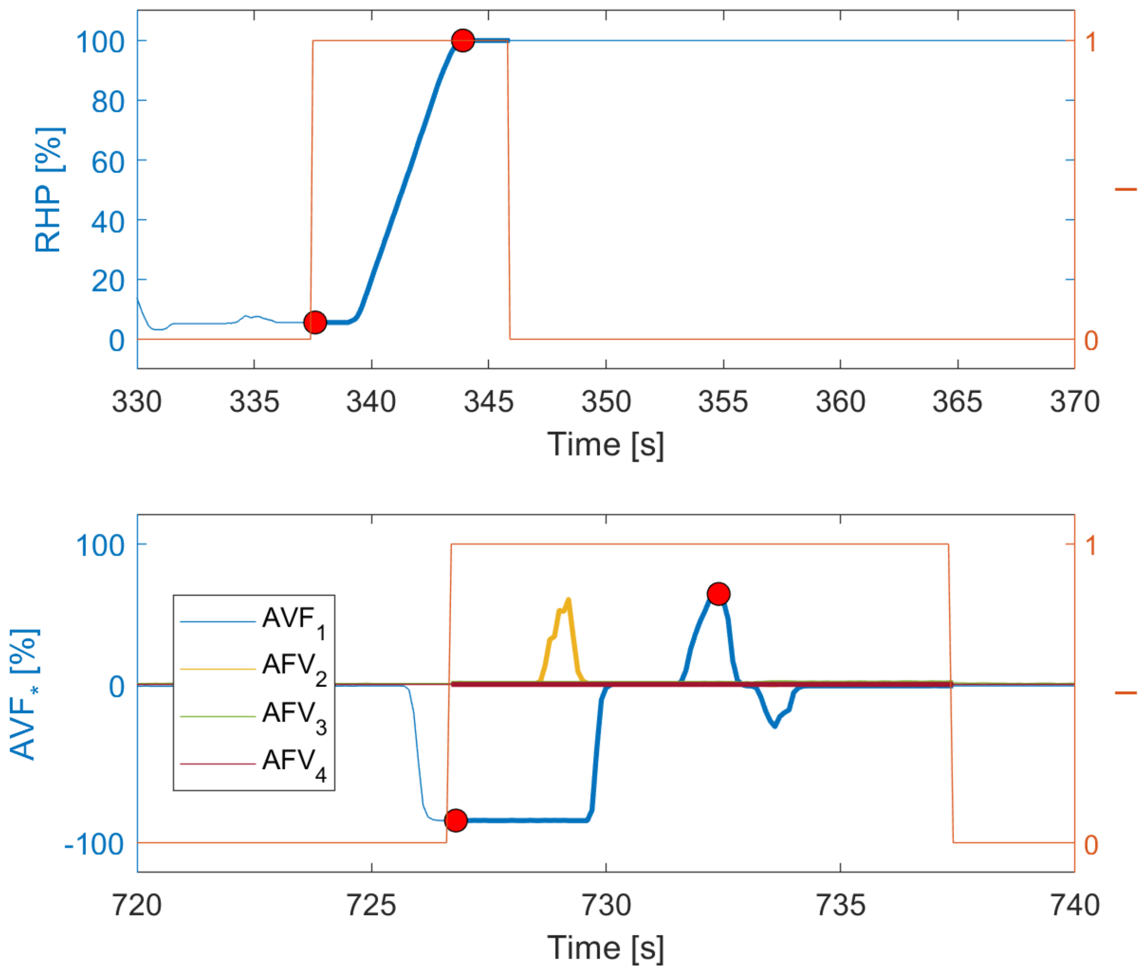

Fig. 2: Portion of RPH (on top) and AVF_* (on bottom) signals in two idling stops. Portions of the lines with a larger thickness are those in the idling stop. The two red points in both plots indicates the min and max values inside the idling stop. For AVF_*, the max peak-to-peak was that of AVF_1 signal, and it was the one used for extracting the use of auxiliary valves for that idling stop.

Moreover, in order to evaluate the idling stops with the driver inside the cab, the peak-to-peak value of DP in each idling stop was calculated.

Each idling stop was assigned to a specific location by observing the position held by the tractor. To this goal, a shapefile containing the road network, and the borders of the soil plots and of the farm workshop was created. Three different tractor position states where defined:

- farm: when the tractor position was inside the farm garage area;
- road: when the tractor position was closer than 3 meters to the road network, the distance threshold was set depending on the accuracy of the GNSS receiver;

- field: when the tractor position was inside a field plot in the shapefile;
- unknown: none of the previous conditions, mostly occurred when the GNSS receiver signal was not available (e.g. when the tractor was running inside a garage) and when the tractor was located in a position not included in the field shape file.

The classification of the tractor depending on the tractor position is reported in Fig. 3

Fig. 3: Example of the classification of idling status depending on the position classification.

Finally, the fuel consumed during the entire operating activity (CF) was calculated through the numerical integration of the fuel rate signal, while the fuel consumed for the idling activity (CF_I) was calculated through the numerical integration of the fuel rate signal multiplied by I. The two variables were calculated with the following formulas:

$$CF(t_k) = \sum_i \frac{FR(t_{k-1}) + FR(t_k)}{2} \Delta t_k$$

$$CF_I(t_k) = \sum_i \frac{FR(t_{k-1})I(t_{k-1}) + FR(t_k)I(t_k)}{2} \Delta t_k$$

being Δt_k the sampling period, $FR(t_k)$, and $FR(t_{k-1})$ two successive values of FR, while $I(t_k)$, and $I(t_{k-1})$ are two successive values of I.

3. Results and discussion

Idling with the dash-cam

The tractor was run on idle for 8h and 48 min equivalent to 13 % of the entire operating duration. The idling stops can be classified into categories and the percentage on the entire idling duration, the average and maximum durations and the number of stops of each idling category are reported in Table 2. The idling stop categories are explained in the following:

- Implement hitching and unhooking: this type of stop always occurred around the farm garage and their duration can be pretty variable in function of the type and amount of connections required by the specific implement. Indeed, shorter durations were observed with implements that require only the connection of the hitch point (e.g. trailers), while longer durations were observed with mounted implements that also require the connection to the hydraulic remotes and PTO shaft (Fig. 4).

Fig. 4: Frame of a video recorded with the dash cam where the idling stop was caused by the hitching of a plough.

- <u>Implement control and adjustment</u>: this type of idling stop occurred mostly on the field to remove crop residuals clogged on the soil engaging tools of the implement or to adjust the implement parts or to reinstall the safety shear screw of the plough bodies when it breaks. The most popular operation was the adjustment of the height of skim coulters that is required when crop residuals clogged too often in the soil engaging tools of the implement. This stop category has the largest variability due to the unpredictability of circumstances that happened on the field (Fig. 5).

Fig. 5: Frame of a video recorded with the dash cam where the idling stop was caused by an adjustment of the skim coulters of the plough.

- <u>Talk among drivers</u>: this stop occurred both on the field and around the farm garage and it was caused by shift rotation of drivers or for planning the activities (Fig. 6).

Fig. 6: Frame of a video recorded with the dash cam where the idling stop was caused by a talk between drivers.

- <u>Machine parking</u>: this stop mostly occurred at the beginning of the day for removing the tractor from the garage and to close its door or at the end of the day for driving the tractor into the garage. The average value of the stop duration category is quite large because very often, to drive the tractor into the garage, the driver had to remove other machines, as well (Fig. 7).

Fig. 7: Frame of a video recorded with the dash cam where the idling stop was caused by the parking of the tractor into the garage.

- <u>Rest</u>: pauses which occurred for resting or any other personal reason of the driver.
- <u>Tractor maintenance</u>: maintenance activities of the tractor, like greasing the tractor parts. In our study, only one idling stop of this category was observed, where the tractor was washed (Fig. 8).

Fig. 8: Frame of a video recorded with the dash cam where the idling stop was caused by washing the tractor.

- Use of the mobile phone: text messages and incoming and outgoing calls which could be also caused by organisation reasons (Fig. 9).

Fig. 9: Frame of a video recorded with the dash cam where the idling stop was caused by a phone call.

- Unclassified: all the stops which could not be classified because the driver was out of the field of view of the dash-cam.

Most of the idling stops are due to the categories “implement control and adjustment” and “talk among drivers”, both together are accounted for more than 65 % of the entire idling duration (Table 2). One can note that most of the categories do not require the use of any particular subsystem of the tractor, with the exception of the “implement hitching and hooking” and “implement control and adjustment”, which together are accounted of less than 40 % of the idling and that requires the three-point hitch and the auxiliary valves. Despite the fact that the area around the tractor could not be viewed entirely with the dash-cam, less than 2 % of the stops were not classified. This confirmed the supposition that the driver activities during idling occurred inside the cab or at the back of the tractor. The idling stop categories are dependent on the farm activities and also some stop categories mostly occurred with a specific driver.

Table 2 – Idling categories and main statistics. The duration is reported in percentage with respect to the total measured idling period.

Idling stop category	Idling duration [%]	Average idling stop duration [s]	Max. idling stop duration [s]	Num. of idling stops	Standard deviation [s]
Implement hitching and unhooking	9.2	263	603	11	133
Implement control and adjustment	31.7	186	1406	54	240
Talk among drivers	34.5	331	1111	33	203
Machine parking	5.7	363	874	5	309
Rest	5.4	211	1029	8	313
Tractor maintenance	6.3	1980	1980	1	0
Use of the mobile phone	5.8	152	562	12	139
Unclassified	1.4	49	179	9	54

Idling with the CAN-Bus data-logger

In this second experiment, the tractor was run on idle for 23 h 47 min, equivalent to 17 % of the entire operating duration. This value is aligned with the average value reported in previous studies (Jenkins, 1960; Perozzi et al., 2016). On average, the tractor worked for 4 h and 22 mins per day and it was run on idle for 42 min per day. The cross-plot between the daily working hours and the daily idling conditions is reported in Fig. 10. The daily idling ranges from 10 min up to 100 min (excluding the outlier of 222 min) and it is not dependent on the daily working hours (the Person’s coefficient between the two variables is 0.442), so for short working days, the percentage of daily idling with respect of the daily working hours is large (up to 92 %). This lead to thinking that idling is caused by a series of activities, which are carried out almost every day, like machine parking. The day where 222 min of daily idling was observed is also the day where the highest number of idling stops were observed and three of them are accounted of 42 % of the entire idling duration of that day.

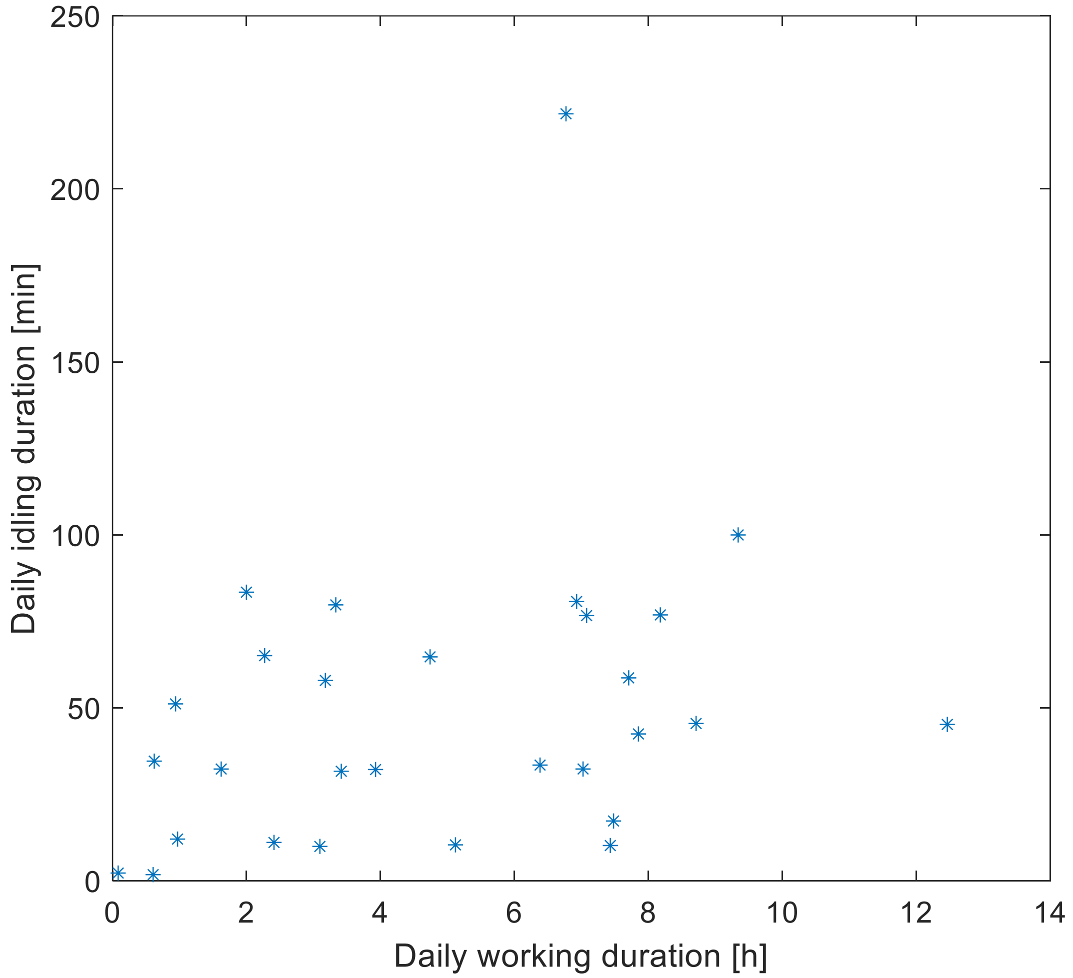

Fig. 10: Daily idling with respect to the daily working hours.

The number of idling stops observed in the acquired data is 798 and only in 37 % of these, the driver left the cab since a large value of the peak-to-peak value of DP signal was observed in those stops. The average value of the number of daily idling stops per hour is 16 and a mild correlation between the number of idling stops and the daily working hours was observed (Person's correlation coefficient between the two variables is 0.52). Idling stop durations ranged from 5 s (equal to the threshold value set for the analysis of the idling stops) up to 2329 s, this number is much lower than that of trucks, where most of the idling is caused by idling stops longer than 1 hour (Frey, Kuo, & Villa, 2009). Short idling stops were much more frequent than long idling stops; indeed, the 50 % of the idling stops were shorter than 25 s, while the 10% of the idling stops were longer than 295 s (Fig. 11). However, most of the idling duration is caused by a few long stops rather than many short stops (Perozzi et al., 2016). In comparison to trucks, agricultural tractors stop for idling much more often and for shorter times than of heavy-duty trucks.

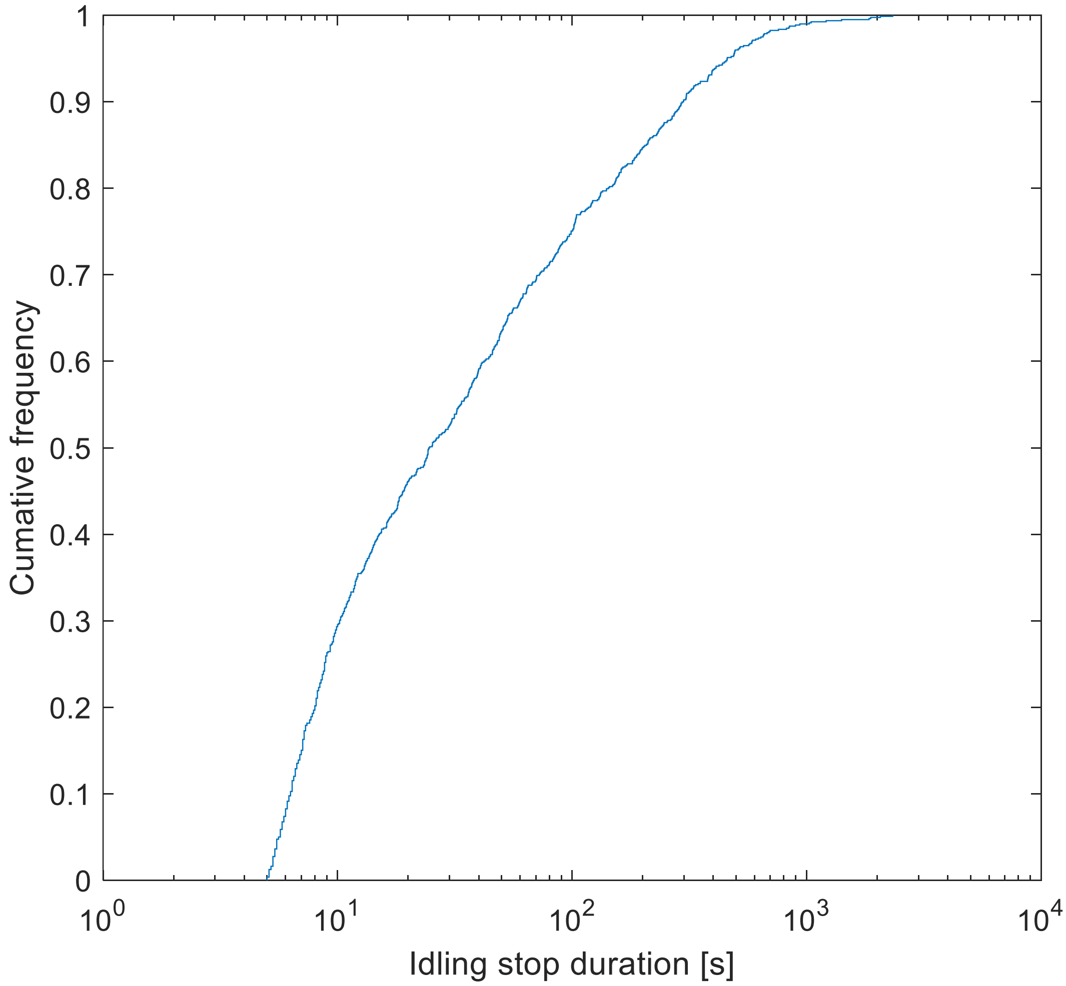

Fig. 11: Cumulative probability distribution of the idling stop duration

Idling stops mostly occurred on field probably caused by the stops required for the implement control and adjustment (Table 3). Idling stops on field are very frequent but on average shorter than those on farm. Moreover, the idling stops on field and farm are pretty variable due to the unpredictability of circumstances that can happen in these two locations. The longest idling stops occur at the farm and are probably caused by the operations of hitching and hooking of an implement, which on average is a longer idling stop than implement control and adjustment (Table 2).

Table 3 –Statistic summary of the idling stops grouped by the position. The duration is reported in percentage with respect to the total measured idling period.

Idling stop position	Idling duration [%]	Num. of idling stops	Average idling stop duration [s]	Standard deviation [s]	Max. idling stop duration [s]
Farm	31	19	174	331	2329
Road	7	9	73	119	573
Field	41	50	82	160	1879
Unknown	21	22	105	194	1401

In 29 % of the idling stops, usage of the three-point hitch was observed and these stops are accounted for 26 % of the total idling duration. Moreover, for 53 % and 97 % of the idling stops, the three-point hitch was used in idling stops shorter than 30 s and 500 s, respectively (Fig. 12). The idling stops where the peak-to-peak value of RHP is higher than zero occurred for 67 % and 15 % of the time on field and on farm, respectively. The much higher usage of the three-point hitch on field is caused by the fact that the implement adjustment activity, that occurs mostly on field, is much more frequent than implement hitching, that occurs only on farm.

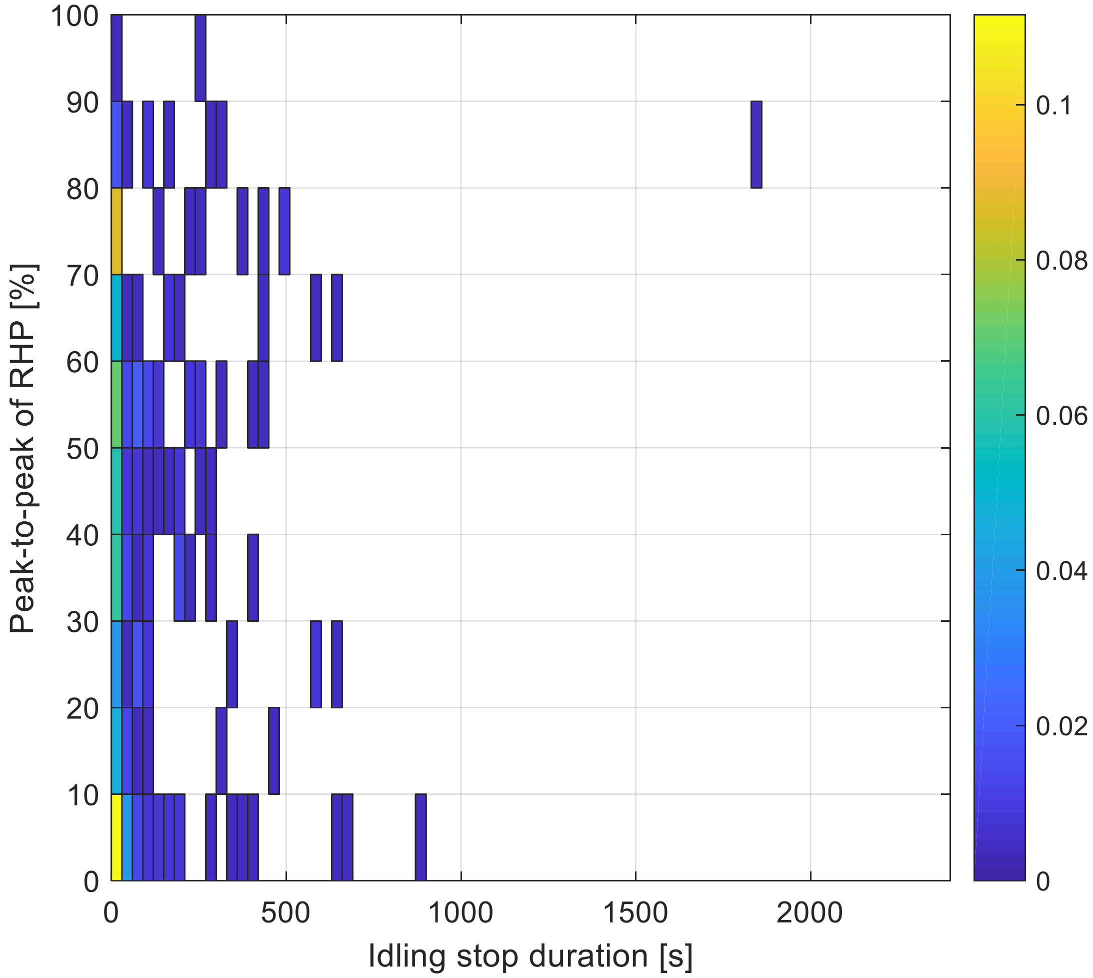

Fig. 12: Joint frequency distribution of the peak-to-peak values of RHP during idling stops with respect to the idling stop duration. Idling stops where the peak-to-peak value of RHP is 0 are not shown. The colour bar reports the relative frequency of occurrence of each bin.

In 6 % of the idling stops, any auxiliary valve was used due to the fact that the maximum of the peak-to-peak values of AVF_* is higher than 0, and these are accounted for the 8 % of the entire idling duration (Fig. 13). Moreover, auxiliary valves were used for 90 % of the time in idling stops between 100 and 700 s. Only for 3 % of the idling stop, the auxiliary valves were used together with the three-point hitch. The idling stops where the maximum peak-to-peaks of AVF_* is higher than zero occurred for 44 % and 25 % of the time on field and on farm, respectively.

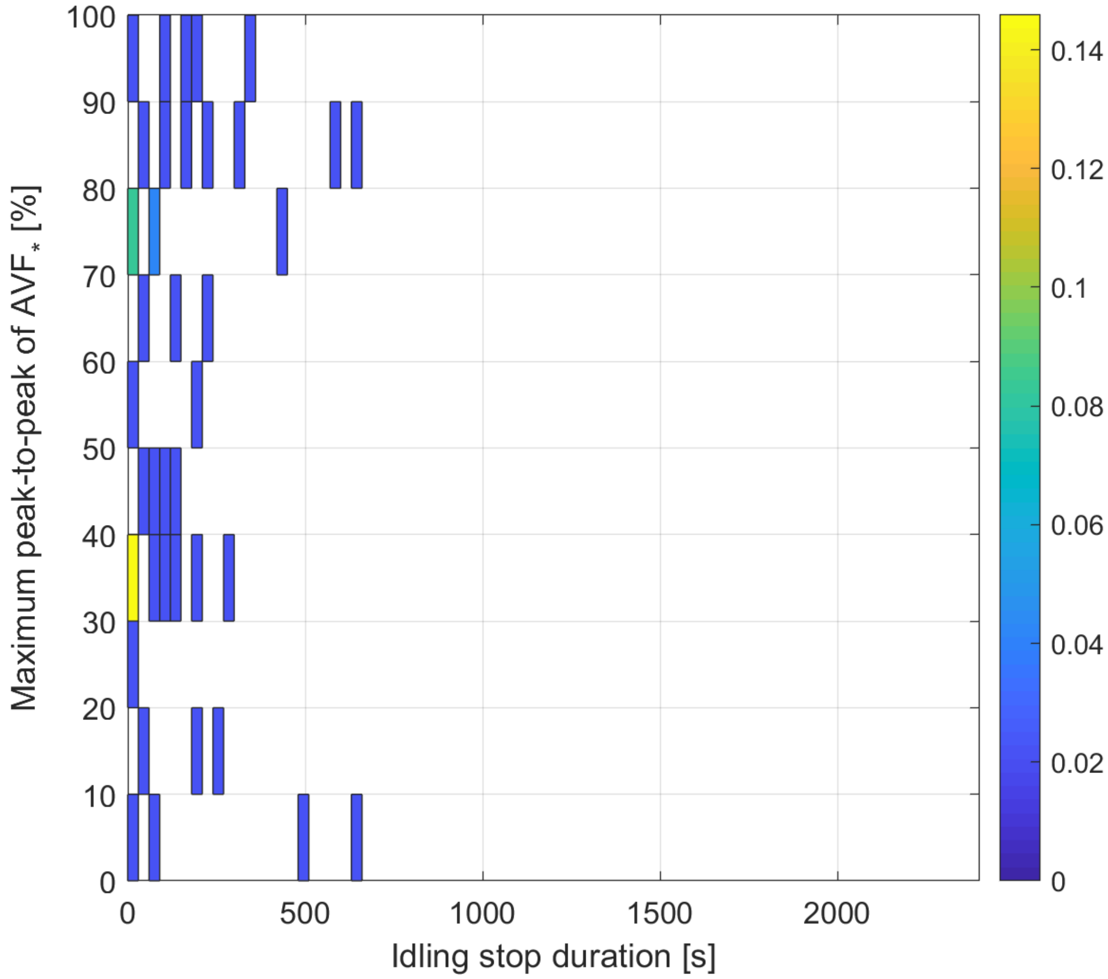

Fig. 13: Joint frequency distribution of the peak-to-peak values of the maximum peak-to-peak of all AVF_* during idling stops with respect to the idling stop duration. Idling stops where the max peak-to-peak is 0 are not shown. The colour bar reports the relative frequency of occurrence of each bin.

In 67 % of the idling, the three-point hitch of any auxiliary valve was used, so 33 % of the idling can be classified as workday-idling.

The average fuel consumption during the idling stop ranges from 2.2 to 6.4 l h^{-1}, but in the 78 % of the idling stops, the fuel consumption was lower than 3.6 l h^{-1} and only in 3 % of the stops, the fuel consumption was higher than 4.1 l h^{-1}. The fuel consumption during idling is not dependent on the stop duration, however, the highest fuel consumption levels were registered on idling stops shorter than 10 s, due to the fact that the engine operates in an unsteady condition that can lead to higher fuel consumption (Lindgren, 2005). The daily fuel consumed for idling is strongly correlated to the daily idling duration (Pearson's correlation is 0.99) caused by the limited variability of the fuel consumption on idling. The average value of the daily consumed fuel for idling is 2.1 l, but in the day where the daily idling duration was 222 min, the daily fuel consumption was 10.9 l. In the 34 days of the tractor use, 3009 l of fuel were consumed and 2.5 % was consumed for idling (equivalent to 78 l) and 61 % of this (equivalent to 48 l) was a waste of fuel due to the fact that the three-point hitch or any auxiliary valve were not used.

4. Conclusions

Real-world data is of utmost importance for designing vehicles optimised for the real usage of the drivers. In the last twenty years, many studies based on real-world data were carried out on on-road vehicles, and thanks to them, the sources of inefficiencies have been identified and solutions were proposed. The usage of real-world data for agricultural tractors is a pretty new topic and it is necessary for quantifying the inefficiencies of tractors. This study was focused on the idling activity of an agricultural tractor and its main reasons for idling, which for agricultural tractors, is usually estimated through anecdotal data or rule of thumb. Two approaches were used, one where idling activity was monitored with a dash-cam and one where idling activity was monitored with a CAN-Bus data-logger. Results of both experiments are quite comparable; indeed, a similar amount of idling was observed in both experiments. From the analysis of data, very low usage of the three-point hitch and of auxiliary valves in idling stops was found, therefore the workday idling was limited. Under these conditions, the tractor under study are let idling not for a real need.

The idling activity wasted 48 l of fuel in 142 h of tractor usage, which could be avoided with more attention of drivers. Tractors of this class operate for up to 850 h per year (Mattetti et al., 2019), so a yearly consumption of 287 l of fuel for idling can be estimated. That is equivalent to a yearly cost of 270 € (using a diesel cost of 0.94 €l^{-1}), not an insignificant quantity in a sector where the economic margins are very small. Moreover, considering that in Italy, around 150 thousand of tractors of this class are used (equivalent to 8.3 % of the total fleet of tractors in the country) (FEDERUNACOMA, 2019), more than 43 million of liters of fuel are consumed for idling every year. This quantity is not negligible and it has to be reduced in order to limit the environmental impact of agricultural mechanisation. This fuel waste could be reduced with tractors with lower fuel consumption during idling or with idling-stop devices. The fuel consumption during idling could be reduced with tractor auxiliaries electrification, which permits better utilization of the energy consumed by auxiliaries since their load can be adjusted to the real demands, which are usually low during idling (Hahn, 2008). Instead, idling-stop devices could permit a reduction of the idling activity of the tractor. However, in order to better design the tractor with electrified devices and to better estimate the fuel waste caused by idling, additional research studies should be carried out with the proposed methodology in a fleet of tractors of different classes and used in farms with different farming practices where there might be different reasons for idling than those reported in this study.

References

Brodrick, C.-J., Dwyer, H. A., Farshchi, M., Harris, D. B., & King, F. G. (2002). Effects of Engine Speed and Accessory Load on Idling Emissions from Heavy-Duty Diesel Truck Engines. *Journal of the Air &; Waste Management Association*, *52*(9), 1026–1031. https://doi.org/10.1080/10473289.2002.10470838

FEDERUNACOMA. (2019). Documenti e dati statistici. Recuperato da https://www.federunacoma.it/it/informati/federunacoma_monitor.php

Frey, H. C., Kuo, P.-Y., & Villa, C. (2009). Effects of Idle Reduction Technologies on Real World Fuel Use and Exhaust Emissions of Idling Long-Haul Trucks. *Environmental Science & Technology*, *43*(17), 6875–6881. https://doi.org/10.1021/es900186e

Gaines, L., Vyas, A., & Anderson, J. (2006). Estimation of Fuel Use by Idling Commercial Trucks. *Transportation Research Record: Journal of the Transportation Research Board*, *1983*(1), 91–98. https://doi.org/10.3141/1983-13

Heiß, A., Paraforos, D. S., & Griepentrog, H. W. (2019). Determination of Cultivated Area, Field Boundary and Overlapping for A Plowing Operation Using ISO 11783 Communication and D-GNSS Position Data. *Agriculture,* *9*(2), 38. https://doi.org/10.3390/agriculture9020038

ISO. (2012). *ISO 11783-7:2012 - Tractors and machinery for agriculture and forestry - Serial control and communications data network - Part7: Implement messages application layer — Implement messages application layer*.

Jenkins, A. J. (1960). Power and life investigation of the farm tractor drive components. *SAE Technical Paper*, *600322*, 1–17.

Khan, A. S., Clark, N. N., Thompson, G. J., Wayne, W. S., Gautam, M., Lyon, D. W., & Hawelti, D. (2006). Idle Emissions from Heavy-Duty Diesel Vehicles: Review and Recent Data. *Journal of the Air & Waste Management Association*, *56*(10), 1404–1419. https://doi.org/10.1080/10473289.2006.10464551

Lewis, P., Rasdorf, W., Frey, H. C., & Leming, M. (2012). Effects of Engine Idling on National Ambient Air Quality Standards Criteria Pollutant Emissions from Nonroad Diesel Construction Equipment. *Transportation Research Record*, *2270*(1), 67–75. https://doi.org/10.3141/2270-09

Lewis Phil, Leming Michael, & Rasdorf William. (2012). Impact of Engine Idling on Fuel Use and CO2 Emissions of Nonroad Diesel Construction Equipment. *Journal of Management in Engineering*, *28*(1), 31–38. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000068

Lindgren, M. (2005). A Transient Fuel Consumption Model for Non-road Mobile Machinery. *Biosystems Engineering*, *91*(2), 139–147. https://doi.org/10.1016/j.biosystemseng.2005.03.011

Lutsey, N., Brodrick, C.-J., Sperling, D., & Oglesby, C. (2004). Heavy-Duty Truck Idling Characteristics: Results from a Nationwide Truck Survey. *Transportation Research Record*, *1880*(1), 29–38. https://doi.org/10.3141/1880-04

Mattetti, M., Maraldi, M., Sedoni, E., & Molari, G. (2019). Optimal criteria for durability test of stepped transmissions of agricultural tractors. *Biosystems Engineering*, *178*, 145–155. https://doi.org/10.1016/j.biosystemseng.2018.11.014

Mattetti, M., Molari, G., & Sereni, E. (2017). Damage evaluation of driving events for agricultural tractors. *Computers and Electronics in Agriculture*, *135*, 328–337. https://doi.org/10.1016/j.compag.2017.01.018

Molari, G., Mattetti, M., Perozzi, D., & Sereni, E. (2013). Monitoring of the tractor working parameters from the CAN-Bus. *AIIA 13*. Presentato al Horizons in agricultural, forestry and biosystems engineering, Viterbo.

Paraforos, D. S., Hübner, R., & Griepentrog, H. W. (2018). Automatic determination of headland turning from auto-steering position data for minimising the infield non-working time. *Computers and Electronics in Agriculture*, *152*, 393–400. https://doi.org/10.1016/j.compag.2018.07.035

Perozzi, D., Mattetti, M., Molari, G., & Sereni, E. (2016). Methodology to analyse farm tractor idling time. *Biosystems Engineering*, *148*, 81–89. https://doi.org/10.1016/j.biosystemseng.2016.05.007

SAE. (2006). *Agricultural and Forestry Off-Road Machinery Control and Communication Network* (N. j1939-2). Recuperato da https://saemobilus.sae.org/content/j1939/2_200608

SAE. (2013). *Vehicle Application Layer* (N. j1939/71).

Takada, Y., Ueki, S., Saito, A., Sawazu, N., & Nagatomi, Y. (2007, aprile 16). *Improvement of Fuel Economy by Eco-Driving with Devices for Freight Vehicles in Real Traffic Conditions*. Presentato al SAE World Congress & Exhibition. https://doi.org/10.4271/2007-01-1323

Van den Berg, A. J. (1996). Truckstop electrification: Reducing CO2 emissions from mobile sources while they are stationary. *Energy Conversion and Management*, *37*(6), 879–884. https://doi.org/10.1016/0196-8904(95)00271-5

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