Fuel Efficiency in Stage V Tractors: The Role of Engine and Transmission

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Abstract. The specific fuel consumption of Stage V-compliant tractors is investigated in detail herein, considering the influence of engine type, transmission configuration, and nominal engine speed. A total of 34 OECD Code 2 test reports conducted at the TAMTEST Test Centre were analysed, showing that tractors with E-type engines registered the lowest average specific fuel consumption, at 267.4 g/kWh. At the same time, the highest was recorded for the D-type engine, at 298.167 g/kWh. In terms of transmission type, B-type transmissions showed the highest efficiency.

Assuming Turkey's tractor fleet is 1,598,659 units and using an average nominal power of 45 kW, the maximum fuel savings from using the most efficient engine type would be about 2.63 million litres per hour at the national level. Assuming these findings as a basis for the estimated global fleet of 50 million tractors, the theoretical global fuel-savings potential rises to about 81.44 billion litres per hour, equivalent to a reduction of 218.26 million metric tons of CO_2 emissions per hour.

These results emphasise that selecting engines and transmissions is a direct, technologically feasible strategy to reduce greenhouse gas emissions from the farm sector. The present research offers actionable insights for manufacturers, farmers, and policymakers by demonstrating that efficiency-focused improvements can yield substantial economic and environmental benefits at the national and global levels.

Keywords: effect of engine power on fuel consumption; fuel ratio in diesel tractors; fuel ratio in stage V tractors; fuel in agricultural machinery; fuel efficiency; specific fuel consumption.

INTRODUCTION

The agricultural sector is one of the industries that is continuously evolving to meet the increasing global demand for food. Agricultural machinery, especially tractors, has become indispensable in this industry. The use of such machinery has several environmental implications. The diesel-powered tractors significantly affect air quality and contribute to climate change through exhaust emissions [1, 7].

As of early 2025, the number of tractors in Turkey reached 1,598,659 [3]. On a global scale, more than 50 million agricultural tractors are in use [10]. Fuel efficiency in agriculture is an important component of environmental sustainability and of operational cost management. Tractor fuel consumption depends on many factors, such as engine technologies, transmission systems, and overall design features [5,8]. Improvements in fuel efficiency have multidimensional implications for economic costs, energy security, and environmental sustainability. Reduced fuel consumption decreases greenhouse gas emissions and helps to fight climate change, contributing to strategic energy management.

From an economic standpoint, fuel is a significant cost input in agricultural activities. More fuel-efficient tractors reduce operational costs and raise margins in large-scale farming. Ecologically, improved fuel efficiency reduces carbon emissions and helps mitigate climate change. The idea also contributes to better utilisation of energy resources and lessens reliance on fossil fuels.

Consequently, the economic and ecological imperatives require that tractor fuel consumption be carefully analysed and optimised. The environmental impact is further emphasised by the potential reduction in greenhouse gas emissions from widespread adoption of fuel-efficient tractors at both national and global scales.

In Europe, a series of progressive emissions standards for diesel engines has been developed to limit the environmental impact of farm machinery. The first stage (1999-2001) established limits on CO and HC emissions, while the second stage (2001-2004) introduced reductions in NOx and PM emissions. More sophisticated technologies, such as DPF and EGR systems, became widespread after the introduction of Stage IIIA/IIIB standards (2006-2013). In Stage IV (2014-2019), substantial reductions in NOx and PM emissions were achieved by combining SCR technology with DPF in high-power engines. Stage V standards (first step, 2019) maintained even higher levels of environmental performance for tractor emissions, particularly from smaller engines, by introducing PN emissions limits [14].

The European Union's Stage V emission standards call for stricter limits on PM and NOx emissions from non-road mobile machinery [2]. To comply with Stage V standards, NRMM will need to be fitted with a DPF or, as an alternative, advanced exhaust aftertreatment technologies such as SCR, which can affect engine performance and fuel consumption.

Internationally accepted procedures include OECD Code 2 tests used to benchmark tractor performance and fuel consumption under standard conditions [4]. These tests have been proposed to measure power output, fuel efficiency, and other variables; specific fuel consumption is considered a better index for energy-efficiency comparisons. Since 1965, the OECD standards have provided a unified method for testing tractor reliability and performance [6].

In Turkey, the Agricultural Machinery and Equipment Testing Centre (TAMTEST) was established within the Central Anatolian Regional Agricultural Research Institute in 1962 under the Ministry of Agriculture. TAMTEST provides tests in accordance with OECD criteria for agricultural and forestry tractors, prepares test reports, and, when required, obtains OECD approval to ensure international validity [9].

The OECD developed nine test codes to assess the performance, safety, and environmental impact of agricultural tractors, covering technical parameters such as traction performance, fuel consumption, power take-off components, safety equipment, and emissions. These tests enable comparability of results between countries and allow agricultural machinery to be assessed transparently in global trade [11].

In 1965, the OECD initially developed a series of standard test codes for agricultural tractors, aiming at a common basis on which tractors would be tested for their performance, reliability, and safety in all member states; subsequently, all the member countries agreed to use these standardised test procedures, hence unifying the assessment methodologies of tractors irrespective of the country of manufacture and/or use [12,13]. Expanding this regime, TAMTEST currently carries out an extensive series of tests on agricultural and forest tractors in rigorous conformity with the official OECD test codes, keeping a thorough record of the test results in voluminous reports, which, after formal approval by OECD, are considered valid and legally effective within all member nations and allow international comparisons and guarantee that tractors perform according to internationally accepted norms on performance and reliability [9]

In this paper, the dependence of fuel consumption in Stage V emission-compliant tractors on engine type, tractor type, and nominal engine speed is investigated. The results provide stakeholders with a scientific basis for informed tractor selection and for optimising fuel efficiency in future designs. By quantifying achievable emission reductions at both the national and global levels, the study also contributes to increased sustainable agricultural practices.

METHODS

A broad dataset was used to evaluate the fuel consumption performance of tractors that meet Stage V emissions standards. The dataset includes engine and transmission features, nominal engine speeds, and SFC (g/kWh) values for 34 tractor models with different commercial denominations. The dataset encompasses six transmission types (A, B, C, D, E, F) and four engine types corresponding to different regulatory standards (D, E, A, K) (Table 1). This diversity

forms a solid basis for analy**s**ing the influence of tractor configurations on fuel consumption.

Table 1 − Classification of Test Tractors

Transmission Type	Gear Ratios	Engine
A	16+16 / 16+8 PS	D / E
B	24+24 / 12+12	D / A /E
C	16+16	K / D / A / E
D	12+12 / 8+8	K
E	16+16 / 16+8	K / D / A
F	8+8	K

The fuel consumption was measured in accordance with OECD Code 2 (Organisation for Economic Co-operation and Development Test Code 2), the internationally accepted guide for testing agricultural tractors for performance and reliability. Adopted in 1965, the OECD Code 2 unified tractor testing methodologies across member countries. Testing under this code enables objective, comparable studies of fuel consumption and other performance characteristics of tractors manufactured or tested in various regions. This test procedure defines the main performance parameters, such as specific fuel consumption, under specific load and engine speed

conditions, improving transparency and reliability in the agricultural machinery sector. The results will provide manufacturers with data to help them develop their products and give farmers a scientific basis for their purchase decisions.

In this paper, the SFCs were investigated for each tractor model concerning engine type, transmission characteristics, and nominal engine speed. Data visualisation-both tabular and graphical-was used to indicate differences and trends in fuel consumption among tractor models. Each model's SFC was analysed with its specific engine and transmission configuration to determine which combinations result in lower or higher fuel consumption. Moreover, it was interesting to investigate the influence of nominal engine speeds on fuel efficiency.

The present analyses aim to provide a scientific basis for improving fuel efficiency in agriculture, thereby supporting the economic performance and environmental sustainability of the sector.

RESULTS AND DISCUSSION

Specific Fuel Consumption According to Transmission Type. The tractors analysed in this study were equipped with transmissions from six manufacturers, classified by model (Table 2).

Table 2 − Average Specific Fuel Consumption and Power at Nominal Engine Speed by Transmission

T	Number	Egine	Gear Ratios	Power at Nominal Engine Speed (kW)	Specific Fuel Consumption at Nominal Engine Speed (g/kWh)
A	7	D / E	16+8 / 16+16	60,20	312,50
B	10	D / A /E	24+24 / 12+12	52,90	269,30
C	6	K / D / A / E	16+16	45,23	294,83
D	5	K	12+12/8+8	34,12	284,00
E	4	K / D / A	16+8 / 16+16	42,72	290,25
F	2	K	8+8	32,60	275,50

Fuel consumption analysis by transmission type revealed some remarkable differences. The lowest average SFC was recorded for the B-type transmission at 269.3 g/kWh, while the highest was observed for the A-type transmission at 312.5 g/kWh. Among the other transmission types, C, D, E, and F had average values of 294.83 g/kWh, 284 g/kWh, 290.25 g/kWh, and 275.5 g/kWh, respectively. These results clearly indicate that the transmission system, including gear ratios and overall efficiency, is critical in fuel

consumption. Especially in agricultural use, selecting appropriate gear ratios and ensuring efficient operation are crucial for fuel savings.

Specific Fuel Consumption According to Engine Type. By analysing average SFC values by engine type, some engines were found to be more efficient than others. For example, engine type E had the lowest average SFC of 267.4 g/kWh, while engine type D had the highest average SFC of 298.167 g/kWh. The A and K types of engines had averages of 283.286 g/kWh and 285.667

g/kWh, respectively. This indicates that with changes in engine technology, fuel efficiency varies.
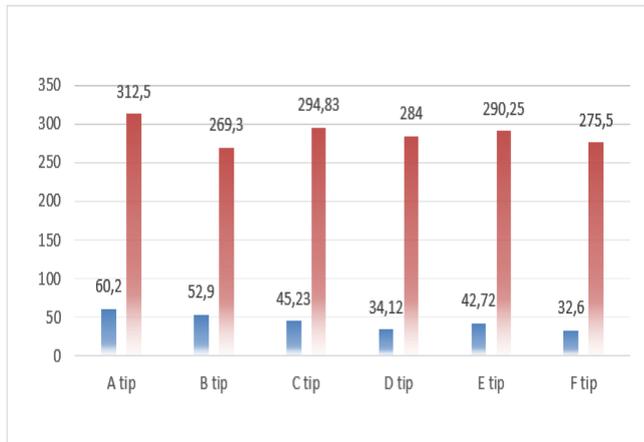

Figure 1 – Average Specific Fuel Consumption by Transmission Type

It was calculated that the E engine consumes 30.767 g/kWh less fuel per tractor compared to the D engine. Considering the average power at nominal engine speed of the 34 tested tractors (45 kW) and the total number of tractors in Turkey as of early 2025 (1,598,659), the potential hourly fuel savings using the most efficient engine instead of the least efficient one can be estimated using Equation 1:

$$F = \frac{A \times B \times C \times D}{E}, \qquad (1)$$

where A – Fuel consumption reduction by each tractor (g/kWh); B – The Number of tractors in the country; C – Conversion factor from grams to kilograms; D – Average power at nominal engine speed (kW); E – Fuel density (kg/L); F – Hourly fuel saving (L/h).

F=30.767*1598659*0.001*45/0.85=2.603 l/h

Given that there are roughly 50 million tractors worldwide, the theoretical fuel savings in one hour using the most efficient engine can be calculated using Equation 2.

$F_{global} = (\text{Fuel Consumption}*P_{avg}*N_{tractors})/P_{fuel}, \quad (2)$

Fuel Consumption = 30.767 g/kWh (reduction per tractor); P_{avg} = 45 kW (average power at nominal engine speed); $N_{tractors}$ = 50,000,000 (global tractor population); P_{fuel} = 0.85 kg/L (fuel density).
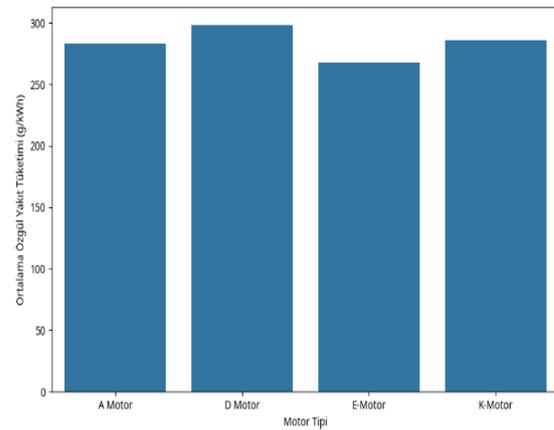

Figure 2 – Average Specific Fuel Consumption by Engine Type

Substituting the values, the estimated global fuel-saving potential is around 81.45 million litres per hour. The reduction in CO_2 emissions, on the back of a fuel carbon emission factor of 2.67 kg CO_2/L, works out to around 217.37 million kg CO_2 per hour, underscoring the importance of the engine choice from a global environmental perspective.

Relationship Between Nominal Engine Speed and Specific Fuel Consumption. The relations between nominal engine speed and SFC were also analysed. In general, the SFC decreased with increasing engine speed up to a point, beyond which it began to rise again. This trend implies that engines are most efficient within their operating speed range and that fuel efficiency declines when operating outside it. Thus, performing field operations by running tractors at optimal engine speed can yield substantial fuel savings.

Furthermore, since exhaust emissions (PM, NOx) are closely related to fuel consumption and engine speed, operating tractors within the nominal engine speed range optimises fuel use and minimises environmental impacts. These findings highlight the importance of selecting not only an efficient engine type but also ensuring proper transmission use for maximum fuel efficiency and emission reduction.

CONCLUSIONS

The study shows that engine type, transmission configuration, and nominal engine speed significantly affect the specific fuel consumption of Stage V-compliant tractors. The results from 34 OECD Code 2 test reports conducted at the TAMTEST Test Centre indicate that tractors with

the E engine type had the lowest average specific fuel consumption, 267.4 g/kWh, while the highest was from D engine types, 298.167 g/kWh. In terms of transmission type, the B-type transmission performed best.

On a national scale, assuming an average nominal power of 45 kW per tractor and a fleet of 1,598,659 tractors, the estimated fuel savings from adopting the most efficient engine type could be about 2.63 million litres per hour. It is also possible to enhance fuel efficiency by operating tractors within the optimal engine speed range, thereby adding to the economic and environmental benefits.

Global Impact and Carbon Footprint Reduction Potential. Extrapolating these findings for the Turkish tractor fleet to an estimated 50 million tractors worldwide, the theoretical global fuel-savings potential rises to around 81.44 billion litres per hour. This translates into a theoretical reduction of about 218.26 million metric tons of CO_2 emissions per hour, using the internationally accepted diesel CO_2 emission factor of 2.68 kg CO_2/L. These figures indicate that engine and transmission optimisation represents one direct, technologically feasible, and highly impactful pathway to mitigating greenhouse gas emissions in global agriculture.

Significance Relative to Other Agricultural Emissions. The potential CO_2 reduction through optimised engine and transmission choice is particularly remarkable when set against other major sources of greenhouse gases in agriculture, namely N_2O from soil management and CH_4 produced by enteric fermentation. CO_2 reduction through machinery efficiency, unlike biological emissions, which depend on complex alterations in agricultural practices and livestock management, stands out as a direct technological intervention. Thus, adopting highly efficient tractor configurations is one of the most immediate and practical measures to support global climate change mitigation while complementing efforts to reduce biological emissions.

This study strongly encourages policymakers, manufacturers, and farmers to prioritise highly efficient engine and transmission configurations, underlining their critical role in advancing economic and environmental sustainability at both national and global levels.

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