Development of energy requirements of tractors and 
implements

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Abstract
The efficient use of the limited supply of resources and the reduction of harmful greenhouse 
gases are key challenges in the 21st century. To reach sophisticated climate directives 
stated by legislative power, the search for saving potentials throughout all branches is nec- 
essary. Finding technologies and strategies along the process chain in agriculture is the aim 
of the joint research project “EKoTech – Efficient fuel use in agricultural technology”. The 
进一步 aim of the project is to give recommendations for action towards farmers and manu-
facturers for a further application of saving potentials. To show already reached savings and 
to build up a database for the project, a comprehensive research of literature is done at the 
Institute of Agricultural Engineering at the University of Hohenheim. This article shows an 
extract of the research and discusses first results of the evaluation.

Motivation
Global population has been increasing crucially since the middle of the 20th century expect-
ing ten billion humans in 2050 with need for food [1]. Furthermore, the usage of conventional 
 commodites e.g. oil and gas as our primary source of energy, has also been increasing for a 
considerable time. Significant changes within this development in both fields are not ex-
pected in the near future. To provide food for the growing humanity, the need for another 
increase in productivity, and following expenditure of resources, is inevitable. However, as-
associated with the consumption of conventional commodities are the emissions of climate-
relevant gases. These so-called anthropogenic greenhouse gas emissions have effects on 
the natural greenhouse effect. The accumulation of additional greenhouse gases caused by 
humankind is presumable one factor of climate change [2]. Therefore, conventional natural 
resources are limited in their usage, making the search for reasonable alternatives signifi-
cant. Until traditional carriers of energy are going to be substituted comprehensively by alter-
native sources, the aim should be the efficient usage of available conventional resources. In 
2008, the legislative power of the European Union prescribed core demands for a Europe-
wide climate and energy policy. The aim is to increase the energy efficiency until 2030 by
27 % and to lower greenhouse gas emissions by 40 % referred to 1990 [3]. To reach the proclaimed aims, it is necessary to find saving potentials throughout all industries. The forecasted saving potential in agriculture is at 1.1 to 4.3 GtCO\textsubscript{2}e per year [4].

In recent years, the focus of agricultural engineering has been on the engine of tractors and self-propelled machinery. The effort was to fulfil the regulatory limitations of exhaust gas emissions, limiting innovations in other areas and further reductions of harmful emissions through other technologies. Finding further technologies and strategies along the process chain to reduce the fuel and energy consumption of tractors and implements, is the focus of the joint research project “EKoTech” funded by the Federal Ministry of Food and Agriculture in Germany. The joint venture of manufactures of farm machinery and several research institutions are trying to determine already reached reductions in fuel consumption and to find potentialities of further savings, using conventional farms and a simulation model. The aim is to define and analyse options for further reductions of the specific fuel consumption in agriculture and to develop recommendations for action towards farmers and manufactures for further savings.

**Procedure in EKoTech**

The project is subdivided in several working packages with different tasks and aims. An accurate literature research is done to detect already reached savings in fuel consumption since 1990 and to get the latest data of energy and fuel consumption of current project-relevant machines. Average farm models in nine selected soil-climate regions over Germany and six all over Europe are built up through extensive interviews and group discussions. The aim is to develop representative farms with region-specific characteristics and conditions. The consideration of Europe-wide regions helps to gain expertise and to avoid inefficient recommendations for actions for farmers. To detect further saving potentials within the cultivation systems of wheat, maize and grassland until 2030, single-machine models of project-relevant machines are built up, as well as a process model to simulate different sub steps in the process chain of the selected cultivation system. The further task of the simulation model is to fill detected gaps in the database. Potential future savings are qualitatively and quantitatively detected in another working package that consists of several manufactures.

**Data collection in EKoTech**

The conduction and responsibility of the data collection within the EKoTech project is done at the Institute of Agricultural Engineering of the University of Hohenheim. The KTBL (Advisory
board of Technique and Construction in Agriculture), the ‘Johann-Heinrich von Thünen-Institute’ and the manufactures who participate support the work. The working package aims to detect energy requirements and fuel consumptions for project-relevant machines of 2016 (content data collection) and to show the development since 1990 (empiric data collection). With the collected data, a database is built up using the software tool Microsoft Access. Figure 1 shows the graphical illustration of the working package together with several inputs from other project partners and working packages. The overview displays the further usage of the collected data in the single-machine model, the general model and the extension of already existing databases located at project partners e.g. the KTBL.

![Fig.1: Graphical illustration of the working package “Data collection”](image)

A core demand of the working package is the anonymization of the collected data. By using average tractors and implements in the following simulation model, the back tracing of an implement to a certain manufacturer is not possible.

**Development of the fuel consumption of tractors**

The fuel consumption of a tractor is an essential factor of variable costs, which refer to a farm’s machinery costs. Therefore, the fuel consumption can be used as a parameter to compare different machinery. Furthermore, the importance of environmentalism and the endeavour to a further reduce of different harmful emissions has been increasing. With the long-term comparison of tested tractors, it is possible to make statements about the development in technology and efficiency.
On a worldwide perspective, there are different test procedures in action. The OECD Code 2 standard test is one of the most used test procedures for a tractor's approval. The procedure consists of a power take-off test and three different tests, which are necessary for approval:

- Main power take-off and five extra points for calculating fuel consumption characteristics
- Hydraulic power and lifting force
- Drawbar power and fuel consumption (unballasted tractors)

A one-hour lasting test is conducted to verify the claimed maximum performance. The engine is heated up over an adequately lasting warming-up period for the power of the engine to become stabilised. The allowed variation of power during six readings is set at 2 %. After the maximum power test, a test at full load and varying speed is performed (full load curve), following a test at varying loads (limiting curve). In order to make statements about the engine's fuel consumption, five additional points in partial load operation are conducted [5]. In a summary of 926 tested tractors under conditions of the OECD Code 2 standard at the Nebraska-Tractor-Test laboratory, KIM [6] shows the development of the specific fuel consumption from 1959 to 2002. The curves in Figure 2 show a swaying progression throughout all power classes, but also a general reduction from about 15 % from 1959 until the beginning of 1990. After 1990, the curves show an almost steady course.

![Figure 2: Development of specific fuel consumption tested with OECD Code 2 standard [6]](https://doi.org/10.51202/9783181023006-237)
The illustrated Figure 2 also indicates that along with an increasing power of the tested tractors comes a higher reduction of the specific fuel consumption. In reality, the operation points of the engine near the full load or limiting curve can be graded as rare. To make statements about real life fuel consumptions of tractors, part load areas of the engine characteristics are important. The so-called PowerMix of the German Society of Agriculture (DLG) consists of twelve different part-cycles. They are derived from different tasks that occur in process chains of several agricultural systems all over Germany. The aim is to obtain nearly realistic specific fuel consumptions of tractors to compare them under different operating conditions. By use of a draught power measuring vehicle, different load profiles under similar conditions are imprinted on the tractor. Imprinted parameters are tractive power, power take-off and hydraulic power in single mode and in combination. Figure 3 shows the evaluation of 45 tested tractors with the DLG PowerMix. The figure displays the specific fuel consumption over power classes and emission standards.

Fig. 3: Development of specific fuel consumptions over EU emission standards for non-road engines

The evaluation shows an almost similar trend as Figure 2. With higher power classes comes a lower specific fuel consumption. In the power class from 75 to 130 kW is from EU stage IIIB to EU stage IV almost none reduction visible.
Development of the energy requirements of implements

To display the development of energy requirements of implements, tractive force or tractive power as parameter for comparison is chosen. However, to compare different measurements, other parameters like soil type or soil moisture are needed in addition. Those secondary parameters are often described superficially. Gaps in the database are the consequence, making consistent evaluations difficult. To fill the gaps in the database, different approaches on tractive force or tractive power calculations are researched. In the next step, calculated values are compared with measurements. Researched calculation models are models from the ASABE, Gorjatschkin and the KTBL. The approach described in this article is by Gorjatschkin and it is used to calculate tractive forces for ploughs [7]:

\[
F_z = b \cdot t \cdot (k + e \cdot v^2)
\]

The working width \(b\) is a fixed factor with 1 meter, as measured values of tractive force are also converted into a specific tractive force per meter. The working depth \(t\) varies with different measurements. Working speed \(v\) is weighted by square. \(k\) and \(e\) are empirically determined values. Parameter \(k\) (kN/m\(^2\)) covers the soil as a factor, \(e\) (kNs\(^2\)/m\(^4\)) characterises the applied working tool.

Fig. 4: Comparison between calculated specific tractive force (kN/m) with the equation of Gorjatschkin \((k = 50\ \text{kN/m}^2, e = 2.5\ \text{kNs}^2/\text{m}^4)\) and real measurements [8]
Figure 4 shows a comparison between the calculated values from the Gorjatschkin equation and measurements with ploughs on silty loam in different working depths. Different forms of workings tools on the utilised ploughs are not considered. \( k \) is fixed at a value of 50 kN/m\(^2\) covering the silty loam, \( e \) is fixed at a value of 2.1 kNs\(^2\)/m\(^4\). The graphic shows the calculated constant lines of working speed compared with 22 data points recorded during different experiments. The mean deviation between calculated and measured data is at 0.48 kN/m at a speed of 5 km/h. Greater deviation cannot be explained due to missing stated boundary conditions (soil type, soil moisture) in the test reports.

 Besides the equation of Gorjatschkin, further approaches like ASABE and KTBL are researched and compared with measurements within the EKoTech project. Furthermore, different implements like cultivators and (short) disk harrows are considered. To compare calculated values with real data, databases of currently 91 data points for ploughs, 76 measurements for cultivators and 22 data points for (short) disc harrows are available. Most of the data was collected at the DLG in Groß-Umstadt. Within the EKoTech project, test reports from the repository where gathered and digitalised.

**Summary and outlook**

Defining options for a further reduction of fuel consumption in agriculture and giving recommendations for action for farmers and manufactures is the aim of the joint research project EKoTech. At the Institute of Agricultural Engineering at the University of Hohenheim, a comprehensive research of literature is done to show already reached potentials of saving and to build up a database to make a statement about energy requirements and fuel consumption of project-relevant tractors and implements. Different worldwide-engaged test standards are used to compare tractors regarding their specific fuel consumption. To fill up gaps in the database of the implements, different approaches for calculating tractive force are considered and compared with researched measurements. The next step within the project is the planning of field tests to measure missing data detected in the implements’ database.

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References


