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Impact of emission standards on fuel consumption of tractors in practical use

The market for tractors – in Germany more than 28,000 new tractors are registered annually – is influenced by EU exhaust emissions legislation. Since January 1, 2011 all tractors and other mobile working machinery of 130 kW power rating upwards have had to comply with the requirements of EU exhaust emission standard stage III B. As from January 1, 2014 a new standard, EU stage IV, will apply to this power class, requiring still more emission reductions. In order to comply with these new thresholds, exhaust emission aftertreatment systems that have a significant influence on an engine's fuel consumption and power output will have to be applied. In the following study the effect of the required exhaust emission aftertreatment on fuel consumption was investigated and compared during practical operations using two identical models of the same tractor make with different exhaust treatment systems. The differences recorded during this trial showed that fuel consumption was reduced by around 7 % through intensive exhaust emission aftertreatment.

Keywords
Emission standards, stage III A and III B, SCR, exhaust gas recirculation EGR, economy

Abstract
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The conversion/combustion of fuel into movement energy results in pollutant substances being ejected along with exhaust gases with every combustion cycle. The most important pollutant substances are carbon monoxide (CO), hydrocarbon (CH), nitrogen oxide (NO_x) and particles (PM). Decisive in the reduction of pollutant emissions are regulation of combustion temperature and electronic fuel injection management. The higher the combustion temperature, the lower the particle load in the exhaust gas, although the proportion of NO_x then increases.

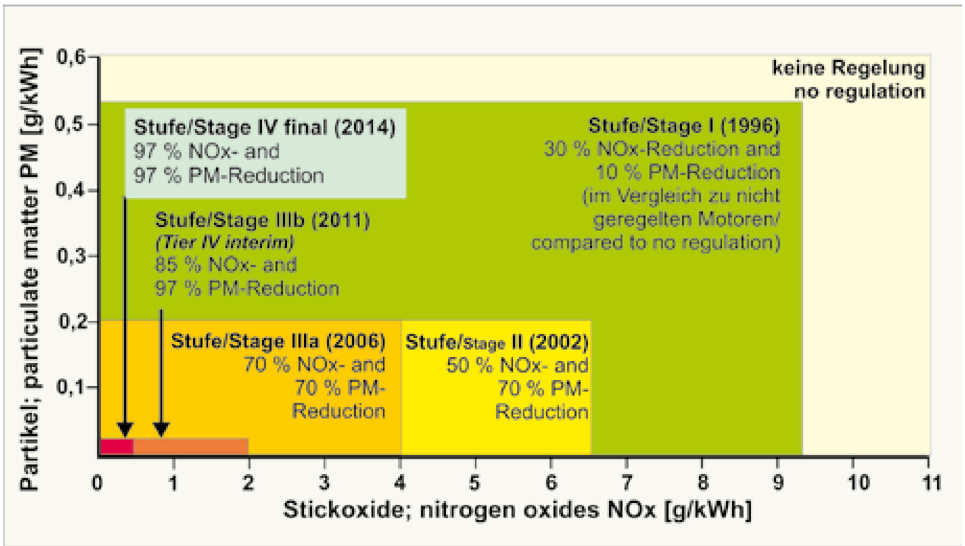
European exhaust gas legislation is subdivided into stages from I to IV. These also represent the US exhaust gas legislation divisions from tier I to IV. The thresholds up until now (**Figure 1**) in the stages I to III A can be achieved through technical adjustments to the engine. Alongside the improvement of combustion through electrical engine management and recirculation of cooled exhaust gases, the most important action towards reducing hydrocarbon, nitrogen oxide and particle emissions is direct injection of fuel.

The drastic reductions of particle and nitrogen oxide emissions required for the exhaust gas stages III B and IV can only be achieved through additional exhaust gas treatment. Possible technical solutions are exhaust gas recirculation with additional particle filter, NO_x adsorption systems and selective catalysators such as Selective Catalytic Reduction, also called SCR technology.

A technical solution exists through altering the engine settings. In order to keep exhaust gas emissions within the strict stage III B threshold, a diesel oxidation catalysator (DOC) together with a diesel particle filter (DPF) are used. The recirculated proportion of exhaust gases is cooled and mixed with fresh air drawn in for the combustion process. The resultant reduced oxygen content slows combustion speed and reduces temperature peaks in the engine. In this way less NO_x is produced, although there is an increase in soot particles. The diesel particle filter must, at the very latest, be regenerated after 25 hours. This involves spraying a small amount of fuel (< 1%) into the filter so that the particles are burned in the DPF.

With the SCR systems, exhaust nitrogen oxide content is reduced after passage through the DOC through addition of an aqueous ammonia solution. This is also known as the AdBlue system and requires an additional tank for the urea solution. The input of AdBlue depends on the amount of power required from the engine and therefore on the work being undertaken. In own tests the measured input ran from 2 to 7 % of diesel

Fig. 1



Emissions stages for the problematic exhaust gas components (nitrogen oxides and particulate matter) in tractors and mobile working machines in agriculture for engines with 130–560 kW [1]

Fig. 2

Case Puma CVX 225 during power measurement at the PTO shaft (Photo: Trefflich)

Fig. 3

Disc harrow Kverneland Qualidisc 5000 on field trial (Photo: Trefflich)

fuel input [2]. In return, the engine can be set-up for more efficient running so that, with the same fuel consumption, up to 10 % higher engine performance can be achieved. The price of AdBlue depends on the amount bought at any time and ranges currently between € 0.4 and € 0.7 for the conventional size of purchase in agriculture. If the AdBlue tank is allowed to run dry the engine power output is automatically reduced to approx. 60 %. The aqueous urea solution must not be allowed to freeze, a danger to be aware of especially on the farm. On the tractor, the AdBlue tank must be frost-protected through heat from the engine or some other way of heating because the solution forms a gel at minus 10 °C and at around minus 18 °C freezes solid. Frozen urea solution has to be "thawed" when an engine is started cold and during this action the engine power is also reduced to approx. 60 %.

Material and methods

Two Case IH tractors, a CVX 225 Puma and a CVX 230 Puma, were involved in the trial (**Table 1**). These were of identical design, differing only in the exhaust gas cleaning systems. Engines were 6.7 l turbo diesels with intercoolers and four-valve technology from FTP Industrial as well as continuously variable transmissions.

The CVX 225 Puma is equipped with exhaust gas recirculation and particle filter, meeting stage III A requirements. The CVX 230 Puma is fitted with SCR technology and meets the requirements of exhaust gas stage III B.

To achieve meaningful results the trial involved both test station and field tests. Firstly, both tractors went into the practical test station where an eddy current brake attached to the respective PTOs allowed delivered performance to be measured [3]. Simultaneously, exhaust gas output was tested with further equipment [4].

Table 1

Technical data of the tractors used in the test

Modell	Case CVX 225 Puma	Case CVX 230 Puma
Nennleistung/*Nominal power* [kW/PS][1)]	165/224 nach ECE R120	167/228 nach ECE R120
Höchstleistung/Maximum power [kW/PS][1)]	169/230 nach ECE R120	183/249 nach ECE R120
bei Drehzahl/*RPM* [U/min][1)]	1 800	1 800
Leermasse/*Empty weight* [kg][1)]	7 200	7 400
Max. Drehmoment/*Peak torque* [Nm/U/min][1)]	950/1 400	1089/1 500
Drehmomentanstieg/*Torque rise* [%][1)]	32	45
Getriebe/*Gear box*[1)]	stufenlos/*continuously*	stufenlos/*continuously*
Abgastechnik/*Exhaust technology*[1)]	Gekühlte Abgasrückführung mit Partikelfilter (DPF) *cooled exhaust gas recirculation with particulate filter (DPF)*	SCR
Abgasstufe/*Exhaust stage*[1)]	III A	III B

[1)] Herstellerangaben.

The recorded performance parameters (engine performance, torque, rpm, fuel consumption) in the practical testing station documented the current state of the trial tractors. Based on the measurement results it was then left for the field trials to confirm that the treatment of exhaust gas with AdBlue reduces fuel consumption, with emissions of particles and nitrogen oxide also decreased.

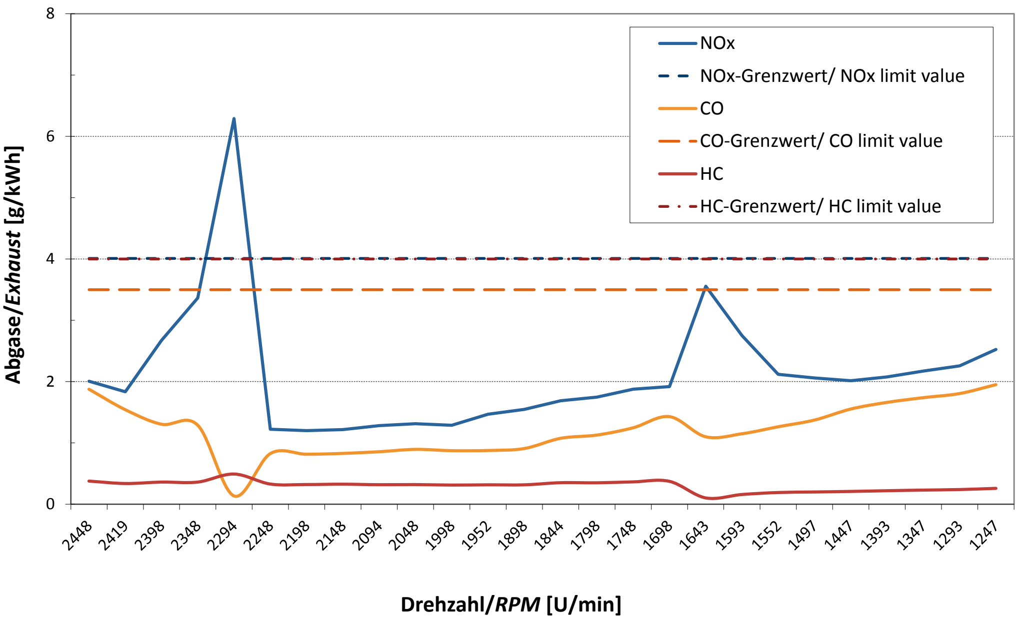
After practical testing station measurements both tractors were put to work in field trials with a 5 m disc harrow and a data logger was used to record all important parameters (GPS position, fuel and AdBlue consumption, driving speed and exhaust gas temperature).

Results

Figure 4 shows the NO_x, HC and CO exhaust gas contents for the CVX 225 during the practical testing station recording.

The recorded concentrations in the exhaust gas as shown in **Figure 4** show that the CVX 225 remains within the limits of the stage III A requirements given in **Figure 1**. Where the limits were exceeded – at 2 294 rpm – was when the nominal rpm of 2 198 was exceeded. This was only reached in the practical testing station, not in fieldwork. The testing station recordings should also be able to be reproduced out in the field. The mobile exhaust gas measurement systems required for this are already being worked on [5].

Fig. 4



Measured NO_x, CO and HC emissions in the CVX 225 in the practice test and the limit values of stage III A in comparison

In the field trials cost comparisons were calculated during stubble cultivations through position-based recording of further data: draught performance, area performance and fuel consumption. The results were assimilated using a geographical information system. In **Table 2** the average AdBlue and fuel consumptions are presented for both tractors.

The results confirm the expectations from the practical testing station. The Case CVX 230 used on average 3.79 l/h diesel less than the CVX 225. However, the CVX 230 required both fuel and AdBlue. Despite this extra input cost, total fluid consumption of the CVX 230 was still 1.71 l/h under that of the CVX 225. If the average for both tractors is put on a percentage basis allowing the result to be expressed in relative figures, the CVX 230 saved around 11 % diesel per hour compared with the CVX 225. Following evaluation of the field trial data, it could be established that the diesel consumption of the CVX 230 was significantly lower. The low consumption of AdBlue meant that even when this had to be tanked as well as diesel there was no economic disadvantage.

Only the components diesel and AdBlue were considered when comparing costs. Purchase prices and repair and maintenance costs were ignored because the trial design allowed no reliable conclusions to be reached on these aspects. Current purchase prices (without value-added tax) were applied for diesel and AdBlue [6].

The average consumption as measured in the field trials served as basis, from which costs per hour and per hectare for both tractors were calculated (**Table 2**).

Regarding fuel costs, the Case CVX 230 was more efficient than the CVX 225. The calculated fuel costs for the CVX 230 were, using current diesel and AdBlue prices, 41.86 €/h. The fuel costs for the CVX 225 were 44.90 €/h thus in the stubble cultivations with the aforementioned disc harrows the extra cost totalled 3.04 €/h. Per hectare there was a difference of 0.72 € to the benefit of the CVX 230. In relative terms, the CVX 230 offered a saving of 7 % per hour and 8.72 % per hectare compared with the CVX 225.

Table 2

Average AdBlue- and fuel consumption and cost calculation on the basis of data obtained in field trial

Modell	Case CVX 225 Puma	Case CVX 230 Puma
Diesel [l/h]	36.25	32.46
AdBlue [l/h]	0.00	2.08
Summe Verbrauch [l/h] *Total consumption*	36.25	34.54
Rel. Dieselverbrauch[1)] *Relative diesel consumption*	105.51	94.48
Diesel [€/h][2)]	44.90	40.20
AdBlue [€/h][3)]	0.00	1.65
Summe Prüfstand [€/h] *Total costs at the test stand*	44.90	41.86
Rel. Kosten[1)] *Relative costs*	103.50	96.50
Flächenleistung [ha/h] *Area performance*	5.2	5.3
Diesel [l/ha]	6.96	6.12
AdBlue [l/ha]	0.00	0.39
Summe Verbrauch [l/ha] *Total consumption*	6.96	6.52
Rel. Dieselverbrauch[1)] *Relative diesel consumption*	106.42	93.58
Diesel [€/ha][2)]	8.62	7.59
AdBlue [€/ha][3)]	0.00	0.31
Summe im Feldversuch [€/ha] *Total costs in the field trial*	8.62	7.90
Rel. Kosten[1)] *Relative Costs*	104.36	95.64

[1)] Index 100 = Durchschnitt beider Traktoren/*average of both tractors*.
[2)] Diesel: 1.2385 €/l ohne MwSt/*exclusive of VAT*.
[3)] AdBlue: 0.795 €/l ohne MwSt/*exclusive of VAT*.

Conclusions

Engine settings have a substantial effect on subsequent performance and the exhaust gases produced.

Legal requirements in this context require active measures in engine management and exhaust gas aftertreatment so that production thresholds for nitrogen oxide (NO_x), particles (PM), hydrocarbon (HC) and carbon monoxide (CO) are not exceeded.

A further problem for manufacturers and tractor operators is that meaningful recording of exhaust gas qualities during field operations is very difficult to achieve.

Our own trials results have shown that using the AdBlue system allows savings of more than 10 % in diesel consumption to be achieved, an advantage that makes the system more attractive to the farmer. In order to keep within the limits for exhaust gases defined in stage IV from January 2014, manufacturers are working on different concepts. The combination of both SCR and DPF exhaust gas treatment systems is seen as a very possible development.

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