# Particulate filters on rotary cultivators

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**Summary**
Single-axle hand-operated rotary cultivators are used by vegetable growers and nurseries for soil tillage in greenhouses and polytunnels. The use of diesel engine equipment leads to increased pollution of the ambient air with diesel particulate. The specifications for a diesel particulate filter were defined on the basis of logger data recorded during real operation and test bench measurements. As the exhaust gas temperatures in real use are very high, a Baumot Type BA5666 passive particulate filter system was selected. The first step was to fit the filter to the test bench engine and run around 25 hours of tests and measurements in various cycles. Filtration effects of over 99 % were obtained in relation to particle number. On completion of the bench tests the filter was fitted to a rotary cultivator for testing under practical conditions. So far the cultivator with the particulate filter has put in around 20 hours of market garden operation and continues to be used for the collection of long-term experience.

**Introduction**
Rotary cultivators are used for soil tillage in greenhouses and polytunnels because of their small size. Free air exchange is prevented due to the fact that greenhouses and polytunnels are generally of enclosed construction. The exhaust gases emitted are therefore unable to escape from the greenhouse, resulting in a build-up of exhaust emissions inside. Rotary cultivators are hand-operated machines, so the user walks immediately behind the motorised equipment and has no protection against exposure to the increased exhaust gas pollution.
Diesel exhaust particles in particular are damaging to health, as they are so small (1/10'000 mm in section) that they are able to penetrate deep into the lungs and are ranked as carcinogenic substances (Swiss Confederation 2009). Single-cylinder diesel engines are generally used to drive the more powerful rotary cultivators. These have gained ground because of their ruggedness and service life. Rotary cultivators for professional use have a rating of between five and ten kilowatts. These engines are not therefore subject to exhaust gas legislation, since exhaust gas limits for diesel engines in the off-road sphere are only stipulated above 18 kW (Federal Office for the Environment FOEN 2008a). The emissions of such engines are correspondingly high. This consequently produces high levels of health-damaging diesel particulate pollution inside greenhouses. As the fitting of particulate filters is only compulsory on building machinery with a rating of over 18 kW and applies only to new machines from 2010 onwards, no experience is available in this field. (Federal Office for the Environment FOEN 2008b).
Information from Swiss importers indicates that approximately every third rotary cultivator sold is fitted with a diesel engine, more powerful machines with diesel engines being sold primarily for professional use.

According to statistical surveys by the Swiss Farmers' Union (SBV 2007), 13,542 self-propelled rotary cultivators were employed throughout agriculture in 1990, with no distinction made between petrol- and diesel-driven equipment. No more recent figures are available. Because the machines are so rugged it is assumed that the majority of single-axle rotary cultivators are still in use.

In Switzerland 386 hectares of land were covered by greenhouses and polytunnels in 2007. Horticultural crops were grown on a covered-over area of 247 ha (SBV 2007). The Association of Swiss Vegetable Producers reported that vegetables were cultivated on 971 ha of land in 2007. The higher cultivation area as opposed to the covered area is due to several consecutive crops being grown on the same land. Since the 1980s, moreover, a steady increase in greenhouse area has been noted. (Association of Swiss Vegetable Producers VSGP 2009). The increased area under cultivation requires the use of more rotary cultivators or an increase in the operating time of existing cultivators.

## Methodology

### Recording load status under real operating conditions

In order to adjust a particulate filter system to an engine, the operating conditions are crucial. A heavy engine load results in a high exhaust gas temperature. An exhaust gas temperature in the 300 to 600 °C range facilitates automatic regeneration, i.e. the combustion of black carbon to form $CO_2$. In order to obtain more accurate data, a “Goldoni Super Special 140” rotary cultivator was fitted with a data logger optimised for the application by ART. Every ten seconds the data logger saved the current exhaust gas temperature and exhaust back pressure. The rotary cultivator was operated with the data logger for four days in summer 2008. During that time the hoe ran for 4.7 operating hours under practical conditions.

High exhaust gas temperatures are generated, as tillage uses the equipment to full capacity. Maximum temperatures of 850°C were measured.

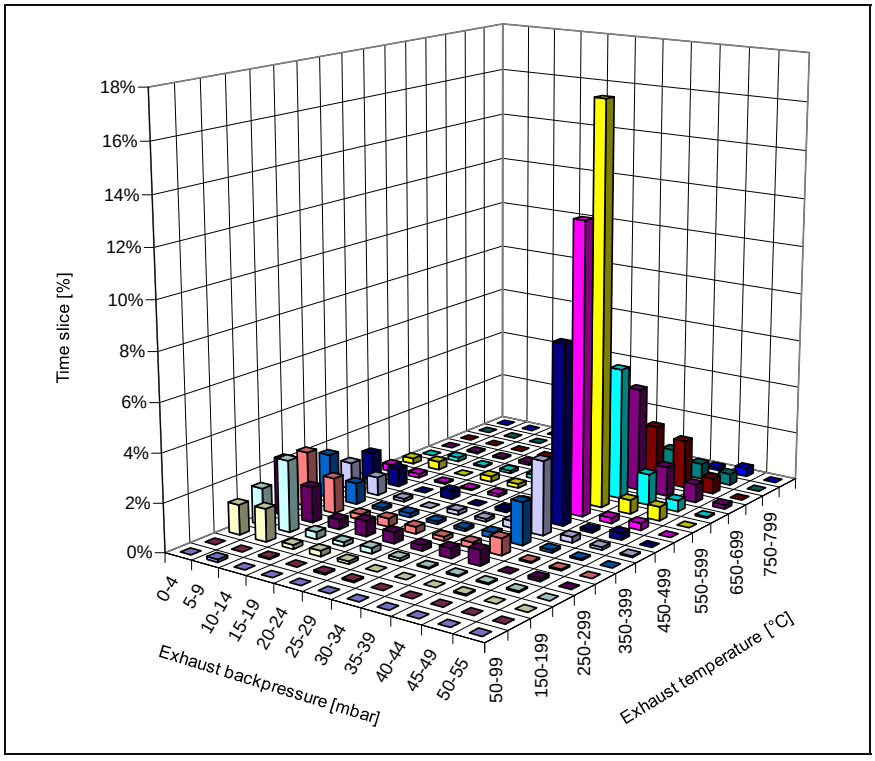


*Figure 1: Logger data for the Goldoni Super Special 140 rotary cultivator*

**Bench tests**

A single-cylinder Lombardini 4LD 820 diesel engine was set up on the ART Research Station engine test bench. This made it possible to determine the emissions specified in the ISO 8178-4, G1 measurement cycle (ISO 2007) and other measurement points. The particulate map (Figure 2) shows high particulate emissions in the range of maximum torque. Exhaust gas temperature and exhaust gas back pressure were recorded in addition to power, consumption and emissions. An equipment operating profile was assigned to the rotary cultivator with the data from the map and the data collected in practical use. The volume of exhaust gas under real operating conditions could thus be more accurately quantified and the filter dimensioned accordingly. Several measurements recorded oscillation loading and vibration loading. The data obtained formed the basis for the design of our own filter mounting.

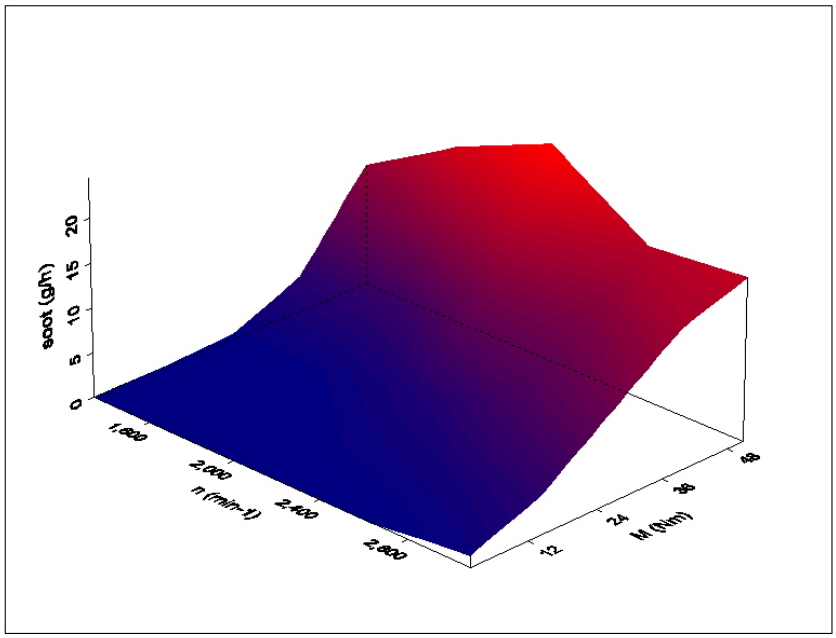


*Figure 2: Soot map based on Lombardini 4LD 820 engine plotted against engine speed (n) and torque (M)*

## Results

### Particulate filter tests on test bench engine

The particulate filter was tested during standardised measurement cycles as well as during real cycles recorded by logger data collection. Filtration efficiency exceeded 99 % in all cycles.

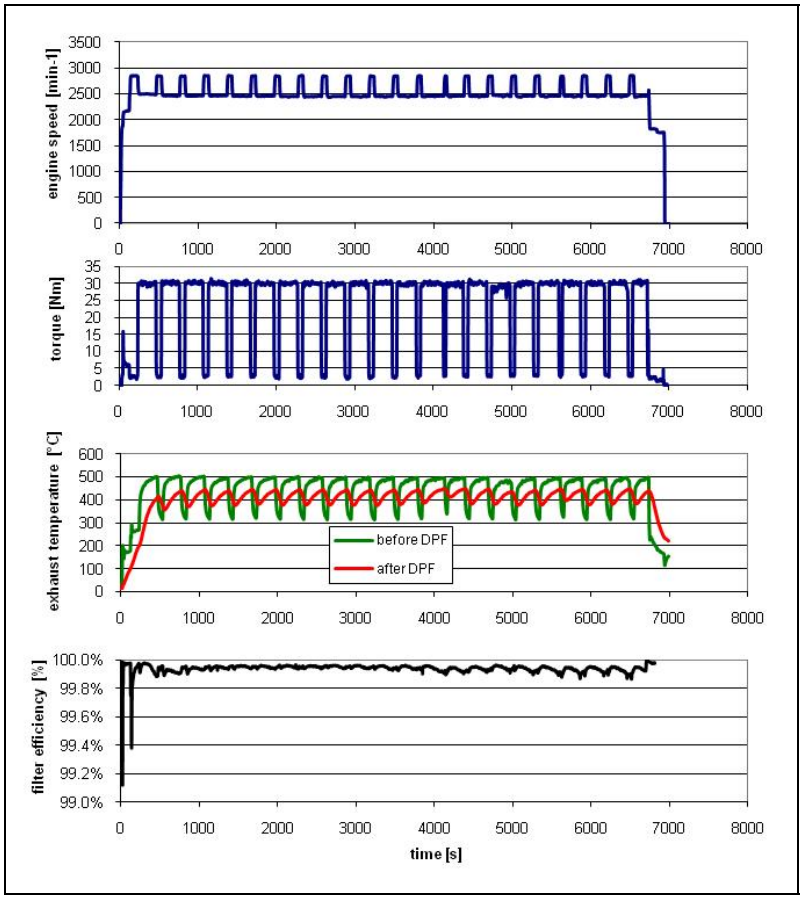


*Figure 3: Test bench measurement results: engine speed and torque during test cycle, exhaust gas temperatures before and after DPF, filtration efficiency of particle filter in relation to particle number.*

### Fitting the particulate filter to the rotary cultivator and field testing

The bench-tested particulate filter was fitted to a Goldoni Super Special 140 rotary cultivator. Installation was not a simple matter, as the space available for the particulate filter was very small: the fuel tank had to be moved forward so that the filter could be fitted in its place. The filter was attached to the chassis of the rotary cultivator by means of vibration-reducing flexible rubber dampers. The exhaust gas ducting and filter were provided with protection against accidental contact in order to protect the user from the DPF's hot surfaces. The rotary cultivator with the retrofitted filter is being put to practical use in a market garden in order to gather further experience. In addition to rotary cultivator emission measurements, comparative immission measurements inside greenhouses with rotary cultivators (with and without particulate filters) are planned so that information can be provided on their effect on the air breathed by operators.

*Figure 4: Rotary cultivator with retrofitted diesel particulate filter (cutter unit missing)*

## Conclusions

Test bench measurements and an initial prototype of a rotary cultivator retrofitted with a diesel particulate filter system yielded positive results. The emission of harmful diesel particulate can be reduced by over 99 % in a rotary cultivator with a single-cylinder diesel engine. The long-term behaviour of the filters is currently being investigated in field operation.

When equipment is operated in semi-enclosed buildings, the health protection of users can be increased considerably by the use of diesel particulate filters.

## References


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## Introduction

Single-axle hand-operated rotary cultivators are used for soil tillage by vegetable growers and nurseries. They are often operated in greenhouses and polytunnels. The cultivators are generally powered by single-cylinder combustion engines with a rating between five and ten kilowatts. High engine emissions combined with low air exchange in greenhouses lead to a build-up of black carbon particles in the air and hence to the exposure of users to health risks .

## Methodology

### Load status of rotary cultivators under real operating conditions

In order to obtain more accurate data on the practical conditions under which rotary cultivators operate, a “Goldoni Super Special 140” cultivator was fitted with a data logger, which recorded exhaust gas temperatures and back pressure every 10 seconds. Analysis revealed very high exhaust gas temperatures up to a maximum of 850°C, with mean values in the 600°C range

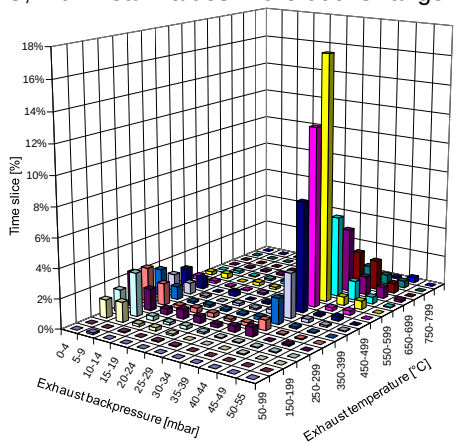


**Figure 1: Exhaust temperature and back pressure during rotary cultivator operation**

### Bench tests

The fundamental emissions of a single-cylinder “Lombardini 4LD 820” engine were measured on the ART engine test bench. Emissions of around 10 to 15 g black carbon per hour were calculated based on the particulate map and typical operating areas.

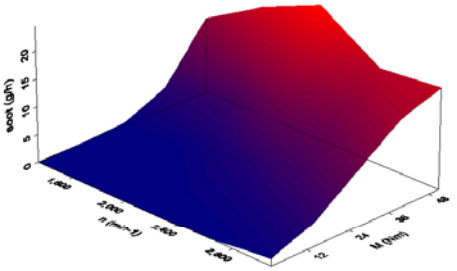

**Figure 2: Particulate map of the Lombardini 4LD 820 engine**

A Baumot Type BA5666 passive particulate filter system was then installed and the separation effect investigated by means of various measurements. Standardised measurement cycles such as the stationary ISO 8178-4 G1 cycle were used as well as dynamic cycles based on the collected logger data. In all the cycles separation effects of more than 99 % were obtained in relation to particle number.

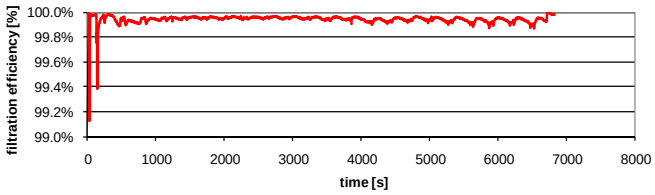


**Figure 3: Particulate filter efficiency in relation to particle number on the test bench.**

### Fitting a filter to a rotary cultivator

The particulate filter, which had been tested by means of test bench measurements, was fitted to a rotary cultivator. Due to the constricted space the diesel tank had to be moved to make way for the DPF. The rotary cultivator is currently undergoing field testing for the collection of long-term experience.

**Figure 4: Rotary cultivator with retrofitted diesel particulate filter**

## Summary

- The use of diesel-operated combustion engines in greenhouses leads to high, health-damaging concentrations of particulate in the air.
- A Baumot BA5666 particulate filter fitted to the rotary cultivator reduces particulate emissions by over 99 %.
- Test bench results and previous field experience have yielded positive outcomes.
- Actually long-term field trials are undergoing.