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Title:

**Moisture Measurement
on
Forage Harvesting Machines**

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Summary:

For precision farming yield measurement systems for all harvesting machines are needed. During the last years several approaches on yield measurement on forage harvesting machines were made. In these studies no working moisture measurement unit was mentioned.

Within a research project several moisture measurement principles were examined. A testing routine including laboratory and field testing was developed.

The results show a big influence on accuracy given by various material densities and non-homogeneity of the material flow. The best results in the laboratory could be reached using NIR sensor systems: standard deviation 0.9 % and correlation of 0.98. The big problem during field testing is how to take a "real" representative sample for sensor calibration and evaluation. Nevertheless good results are given by NIR and capacitive sensors.

Further testings are necessary for different crops and sensor mounting positions. To improve the results an adjustment of the material flow to the requirements to a sensor technology must be done.

Introduction

For precision farming and quality control within food production a lot of knowledge about the whole farming process is needed. Also because of the increasing competition between food producers all over the world detailed information about their work is needed. The precision farming strategy offers a lot of useful tools for productivity monitoring, fleet management and accounting. Therefore a lot of technology is needed, that is not available so far.

To ensure a closed data flow documenting all working steps in farming, yield measurement systems are needed for all harvesting machines. Today field proved yield detection systems are available for combines, potato and sugar beet harvesters. Information about the productivity and the variation within the rotations is also needed for forage production.

Therefore a yield measurement system containing data handling, location sensing, area sensing and throughput measurement is needed. For throughput measurement the mass flow and the moisture content are required. So far no solutions on that problem are available on the market.

State of the art

During the last ten years several examinations on yield measurement on forage harvesting machines were made. Most of the time the research work was focused on mass flow measurement (Auernhammer et al., 1995; Barnett et al, 1998; Ehlert, 1999; Vansichen et al., 1990; Wheeler et al., 1997; Wild et al, 1997). Moisture measurement was mentioned as one needed feature for future developments (Wild et al, 1997). Barnett et al. (1998) used a modified conductance moisture sensor from a combine harvester. The results were not satisfying in case of a wide moisture range.

Gasteiger (1992) was one of the first who published the possibility to use a continuously working NIR moisture sensor over a conveyor belt. With this system moisture measurement is possible for grass, cubes, grain, dough, spent hops and silage. Rode et al. (1999) uses a NIR system for moisture detection on plot harvesting machines. They got good results under defined conditions.

For moisture measurement several physical principles are known. Table 1 shows a summary of continuously working and reference moisture measurement methods.

Table 1: methods for moisture measurement **Fehler! Verweisquelle konnte nicht gefunden werden.**

| | | | | |
|------------------|-----------------------|----|----------------------------|---|
| direct methods | absolute methods | 1 | drying oven method | * |
| | | 2 | distillation method | |
| | | 3 | separation by absorption | |
| | wetchemical methods | 4 | calcium-carbide – method | |
| | | 5 | Karl – Fischer – method | * |
| indirect methods | electrical methods | 6 | conductance measurement | * |
| | | 7 | capacitance systems | * |
| | | 8 | microwave – sensors | * |
| | spectrometric methods | 9 | infrared method | * |
| | | 10 | nuclear magnetic resonance | |
| | | 11 | optical refraction method | |

*) used in practical applications

Most of those systems are used in laboratories or for process control. Mostly there are no experiences on mobile use of those sensors on a vehicle.

Problem

As shown many attempts for mass flow detection were made on forage harvesting machines. But there is no system available for moisture measurement. But this information is also needed for yield determination in forage.

Now a sensor unit should be found that matches all the requirements caused by being mounted on a forage harvesting machine: accurate, robust, easy to use and affordable. Therefore an existing sensor system should be adjusted to the environment on a harvesting machine – that means, no new development of a moisture sensor should be made.

Solution

In a first step the requirements on a sensor for mobile use on a forage harvesting machine were defined:

- Continuously working sensor adapted to the mass flow (no massflow interruption)
- Harvesting materials: hay, straw, hemp, grass silage, maize silage
- Moisture range: 8 % to 90 % (absolute)
- Required accuracy: $\pm 1 \%$ for moisture range 8 % to 40 %
 $\pm 2 \%$ for moisture range 40 % to 70 %
 $\pm 3 \%$ for moisture range 70 % to 90 %
- Very robust sensor for mobile use on agricultural machines
- Ambient temperature: -10°C to 60°C

- Material temperature: 0°C to 50°C
- Material speed: up to 40 m/s
- Material density: 0,05 - 0,5 kg/dm³

Based on this list over one hundred sensor manufacturers were asked for a test sensor unit. About twenty suppliers offered a system, that should fulfil the requirements. As there were no experience on mobile use of the sensors for moisture detection in organic materials, also basic trials were necessary. The following sensors were tested within three years (Table 2).

Table 2: Evaluated sensor units

| manufacturer | system name | labtest | | | fieldtest | | |
|--|---------------------|---------|------|------|-----------|------|------|
| | | 1997 | 1998 | 1999 | 1997 | 1998 | 1999 |
| microwave reflectance systems | | | | | | | |
| Franz Ludwig | FL H ₂ O | | x | | | | |
| Hydronix | Hydro Mix | | x | x | | | |
| Strandberg Eng. | Type 6711 | x | | | | | |
| microwave transmittance systems | | | | | | | |
| BERTHOLD | Micro Moist | x | | | | | |
| pro/M/tec | | | x | | | | |
| near infrared reflectance systems | | | | | | | |
| mesa electr. | MM55 | x | x | | x | x | (x) |
| Perten Instr. | DA 7000 | | x | x | | x | x |
| Rütter | Quadra Beam 6500 | x | | | | | |
| capacitance moisture sensors | | | | | | | |
| ARNOLD | FSV | | x | x | | | x |
| Liebherr | Litronic FMS | x | x | | x | x | |

The best results in the laboratory showed the NIR moisture measurement systems with a standard deviation of 0.9 % and a correlation of 0.99. Microwave reflectance and capacitance moisture sensors had a standard deviation of about 4 % and a correlation up to 0.8. A big influence on the accuracy of these systems could be recognised for various densities and different layer thickness. Both microwave transmittance systems didn't work properly. The result was dependent on the environment. Reflections from metal parts and moving people changed the results.

For field trials a self propelled forage harvester and a round baler were equipped with mass flow and moisture sensors. For yield mapping also a DGPS receiver was mounted.

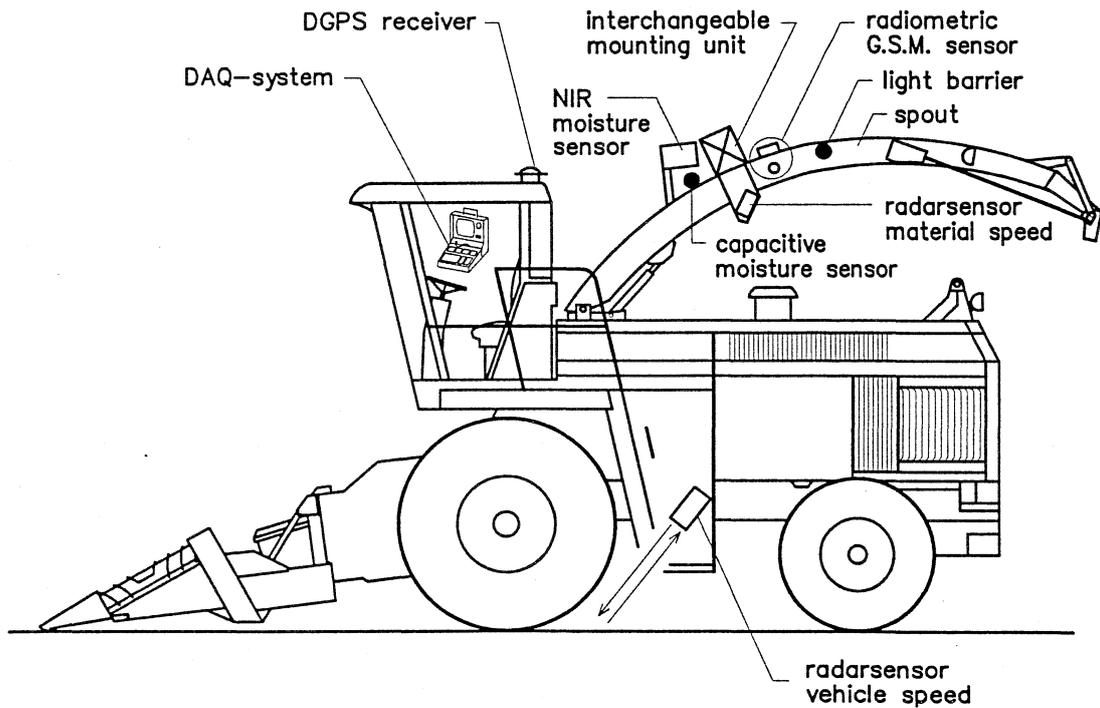


Figure 1: Self propelled forage harvester with moisture sensor setup

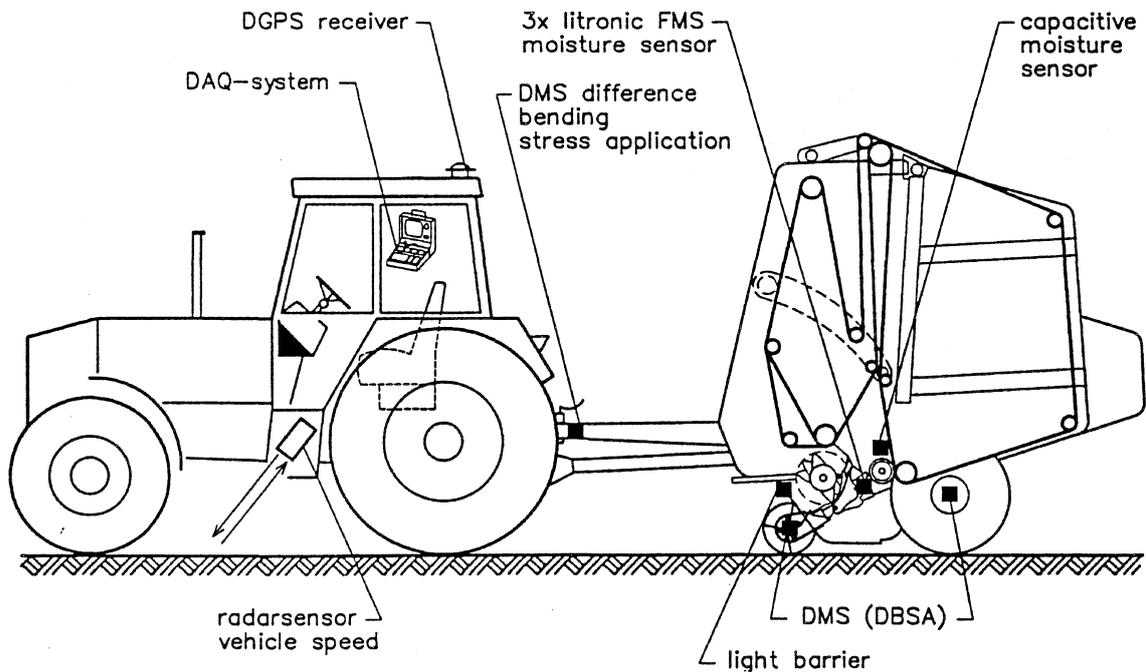


Figure 2: Experimental setup of a round baler for moisture sensor testing

During field trials the biggest problem was grabbing a “real” representative sample from a “big” load of 3 t or more. The results from several oven dried samples (temperature: 105°C) from a single load varied in a range of $\pm 5\%$. In spite of these problems the best results were shown again from NIR systems.

(number of loads: 133, total weight: 411 t, maize silage, 1998)

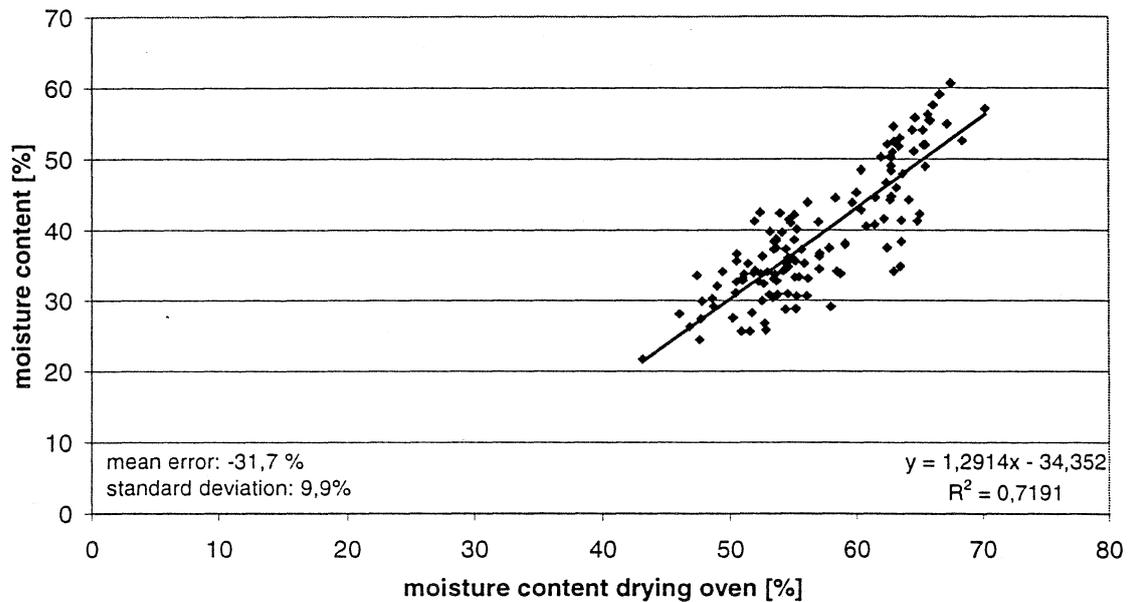


Figure 3: Results from MESA MM55 NIR moisture sensor on a chopper

So far no suitable mounting position for moisture sensors on a round baler was found. The various densities and the restricted space for mounting were the most avoiding parameters.

Conclusions

There are several sensors available on the market that could be integrated on forage harvesting machines. Therefore more tests with different crops are needed. The material flow also needs to be adjusted to the sensor requirements. Because the total moisture calculation is based on a weighted average from the mass flow, a very accurate mass flow sensor is a assumption for moisture measurement.

Economic aspects of this technology must be examined in the future, because the very accurate moisture sensors based on near infrared technology are quite expensive. This technology will also be able to detect ingredients. If it is possible to adjust such a system to the rough conditions on a harvesting machines, it won't be any longer too expensive to be used on agricultural machines.

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