Stenon GmbH

Stenon FarmLab

with software version d-1.3.0 and calibration model p-2.1.0

NO_3 content, N_{min} content, soil moisture

Overview

A test mark „DLG-APPROVED for individual criteria“ is awarded for agricultural products which have successfully fulfilled a scope-reduced usability testing conducted by DLG according to independent and recognised evaluation criteria. The test is intended to highlight particular innovations and key criteria of the test object. The test may contain criteria from the DLG test scope for overall tests, or focus on other value-determining characteristics and properties of the test subject. The minimum requirements, test conditions and procedures as well as the evaluation bases of the test results will be specified in consultation with an expert group of DLG. They correspond to the recognised rules of technology, as well as scientific and agricultural knowledge and requirements. The successful testing is concluded with the publication of a test report, as well as the awarding of the test mark which is valid for five years from the date of awarding.

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STENON FARMLAB
WITH SOFTWARE VERSION D-1.3.0
AND CALIBRATION MODEL P-2.1.0
✓ NO_3 content
✓ N_{min} content
✓ soil moisture
DLG Test Report 7197

This type of test was applied to the Stenon FarmLab soil sensor with software version d-1.3.0 and calibration model p-2.1.0. The prediction accuracy of this mobile soil tester was tested regarding the following soil parameters:

- NO_3 content
- N_{min} content
- Soil moisture

For assessing the accuracy of the predictions provided by the device it is determined whether the system is able to provide information on the soil condition which is of practical relevance for growers and their nutrient and water management decisions. In addition to this, the testers intentionally committed a number of operator errors to test the accuracy of the meter’s error and troubleshooting prompts.

All results presented in this report relate solely to those devices that were actually tested.

No further criteria came to the test.

Assessment in brief

Measuring the parameters listed below, the Stenon FarmLab soil sensor with software version d-1.3.0 and calibration model p-2.1.0 meets the prediction accuracy as required by DLG for sensors on mobile soil testers.

- NO_3 content
- N_{min} content
- Soil moisture

The device detects operator errors and prompts appropriate warnings and instructions.

Table 1:
Recognised parameters – results at a glance

QUALITY PROFILE TO DLG STANDARDS	Assessment*
Soil parameters	
NO_3 content (mg/100 g)	✓
N_{min} content (mg/100 g)	✓
Soil moisture by percentage weight	✓
Error detection and system warnings	
Calibrating without calibration cap	✓
Calibration cap not removed before probing	✓
Measuring air	✓
Plant residues in front of the Sensor	✓
Measuring soil but calibration cap still in place	✓
Measurements out of range	✓

* Assessment explained: Meets the requirement (✓)/Does not meet the requirement (✗)

The product

Applicant and manufacturer

Stenon GmbH, Hegelallee 53, 14467 Potsdam

The product:
Stenon FarmLab
Software version d-1.3.0
Calibration model p-2.1.0

Description and technical data

The Stenon FarmLab is an integrated hardware and software solution that carries out soil analyses and delivers real-time results. The system consists of several components: a meter with a sensor probe which has several optical (e.g. NIR) and electrical sensors that measure the soil properties. In addition, climate sensors are inside the control unit. The meter is a handheld device that is charged via a USB-C port. The battery life is more than 8 hours according to manufacturer information. The meter connects to an internet-connected device via WiFi and includes a GPS module for positioning.

The data collected are transmitted to a cloud-based application which processes the data on demand. The Stenon Artificial Intelligence (AI) uses the sensor data to calculate the following parameters: NO_3, N_{min}, N_{total}, PO_4, K, Mg, and Corg levels as well as soil moisture and pH levels plus soil temperature and texture. The algorithm is constantly and dynamically adapted as new data are being added to the database. After the calculation is completed, the results are stored to a specific user account from where the data can be retrieved by logging into the web portal. The measurements are presented as measuring points on a GPS map. But users can obtain additional information on each measuring point by logging into the web portal. As a platform-agnostical development, the web portal can be accessed from a smartphone, tablet or PC at any time.

How the measurements are taken

As a first step, the user calibrates the device using the calibration cap provided. The probe is then inserted into the soil by stepping one's foot on it. Measuring is then triggered by tapping on the touchscreen of the control unit. After each measurement it is necessary to clean the probe. One measuring cycle consisting of 3 individual measurements comprises the results of all parameters listed above. Then the data are transmitted to the cloud application from where the results are returned within seconds. The measurements can also be taken while offline; in that case, the data are saved to the internal memory and synchronised automatically when an internet connection is established.

Scope of measurements

The measuring range depends on the type of soil and the measurements apply to a depth of 0 - 30 cm. The Stenon FarmLab is suitable for use in sandy, silty and loamy soils. Table 1 shows the measuring ranges for all parameters tested.

*Photo 2:
Inserting the Stenon FarmLab into the soil*

*Table 2:
Stenon FarmLab measuring ranges (manufacturer information)*

Soil parameters	Measuring range	Unit
N_{min}	> 1 to < 4.5	mg/100 g
NO_3-N	> 0.5 to < 4.0	mg/100 g
N_{total}	> 0.05 to < 0.3	%
P	> 2.5 to < 25	mg/100 g
K	> 7 to < 17	mg/100 g
Mg	> 2.5 to < 22	mg/100 g
Corg	> 0.75 to < 3	%
pH	> 6.0 to < 7.8	
Humus	> 1.25 to < 5.25	%
Soil moisture	> 5 to < 25	% weight
Soil temperature	> 0 to < 50	°C
Soil texture	loamy/sandy/silty	

The method

Prediction accuracy

The testing method

The predictive accuracy on each of the three soil parameters is verified by comparing the data supplied by the sensors with data that are obtained by analysing appropriate soil samples in various labs. Then the results of these comparisons are assessed by applying the current DLG assessment scheme.

For each test parameter and each measuring range, the manufacturer must provide data on the measuring precision of the sensor. They must also state which method was applied to measure these precision levels.

The scope of the tests

The tests are carried out in 40 different fields.

The fields chosen represent the widest possible range of soil and crop situations in which the product is potentially used:

- A variety of sandy/silty/loamy texture
- High/medium/low N_{min} levels
- High/medium/low humus levels
- Typical crops (e.g. asparagus, strawberries, lettuce)
- Fields under cropping to ensure the relevance of the results

The test design

An approx. 2 m by 2 m plot is marked out in each of the 40 fields.

In each of these 4 m^2 test plots, measurements are taken in five different sub plots following a specific design. Each measurement is taken with two soil sensors.

All sensor measurements per test parameter are taken for a 0-30 cm depth and are then recorded and logged.

As a next step, soil samples are taken in the immediate vicinity of the individual sub plots. These samples are used for reference analyses at various labs.

These soil samples are labelled and immediately deep frozen. The frozen samples are stored until they are sent by express mail to the labs for reference analysis.

The reference labs

The reference analyses are carried out by five different accredited labs according to recognised scientific methods.

Evaluation

The NO_3, N_{min} and soil moisture levels are grouped into practice-oriented classifications (see tables 3 to 5).

To measure agreement, a procedure was developed in cooperation with the Julius Kühn Institute, the German Federal Research Centre for Cultivated Plants. This procedure evaluates the agreement between the sensorbased class predictions with the mean lab results (the class which the mean lab result is grouped in) on the one hand and the agreement

Table 3:
NO_3 classes

NO_3 classes	Lower limit [kg/ha] ≥	Upper limit [kg/ha] <
A	0	5
B	5	45
C	45	85
D	85	125
E	125	165
F	165	205
G	205	

Table 4:
N_{min} classes

N_{min} classes	Lower limit [kg/ha] ≥	Upper limit [kg/ha] <
A	0	10
B	10	50
C	50	90
D	90	130
E	130	170
F	170	210
G	210	

Table 5:
Soil moisture classes

H_2O classes	Lower limit [%] ≥	Upper limit [%] <
A	0.0	2.5
B	2.5	5.0
C	5.0	7.5
D	7.5	10.0
E	10.0	12.5
F	12.5	15.0
G	15.0	17.5
H	17.5	20.0
I	20.0	22.5
J	22.5	25.0
K	25.0	

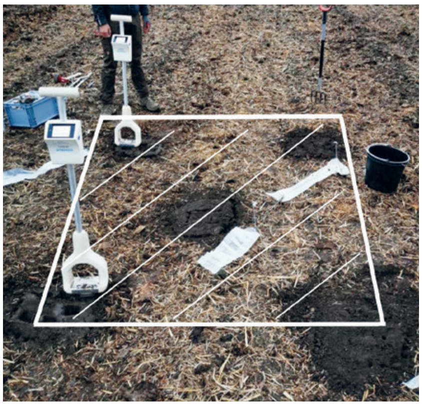

Photo 3:
A typical plot and its sub plots

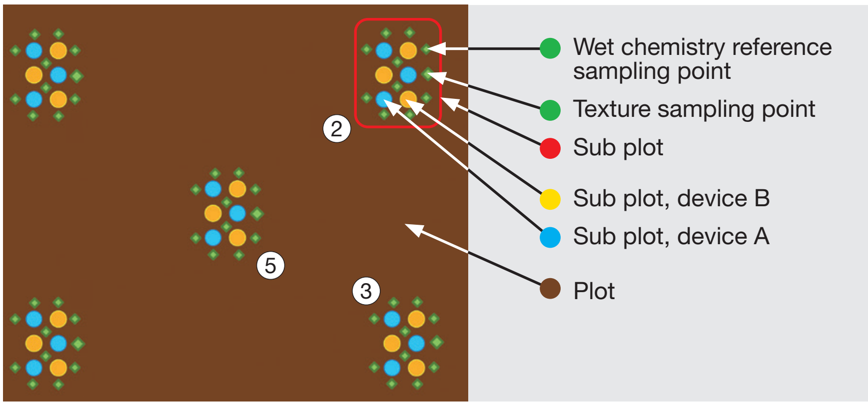

Photo 4:
The soil sampling design

between the individual lab results with the mean lab result class on the other hand. This procedure is applied to each plot and soil parameter.

The classification results per field are collected and entered into a confusion matrix which is used to calculate agreement.

Cohen‘s kappa and weighted Cohen‘s kappa serve as parameters to describe the predictive accuracy of the soil sensor.

Cohen‘s Kappa quantifies agreement without taking the level of misclassification into account (class distance). The values that are scattered around 1 indicate considerable agreement whereas the values scattered around 0 and those smaller than 0 indicate poor agreement.

The weighted Cohen's Kappa quantifies agreement by taking into account the level of misclassification. To do this, the level of misclassification obtained by comparing the sensor measurements to the mean lab result is calculated. Such misclassifications are due to variations in soil quality and conditions which occur even in sub-fields, for example.
To assess the results, the level of misclassification by the sensor is related to the level of misclassification by the labs.

Assessment

The results are assessed by applying a system that was developed by the DLG expert group together with the Julius Kühn Institute. The following diagram (Figure 5) shows the assessment workflow and required prediction accuracies.

Error detection and system prompts

Error and instruction prompts following an operator error, which also form a claimed feature of the device, were tested by provoking errors systematically in the field test.

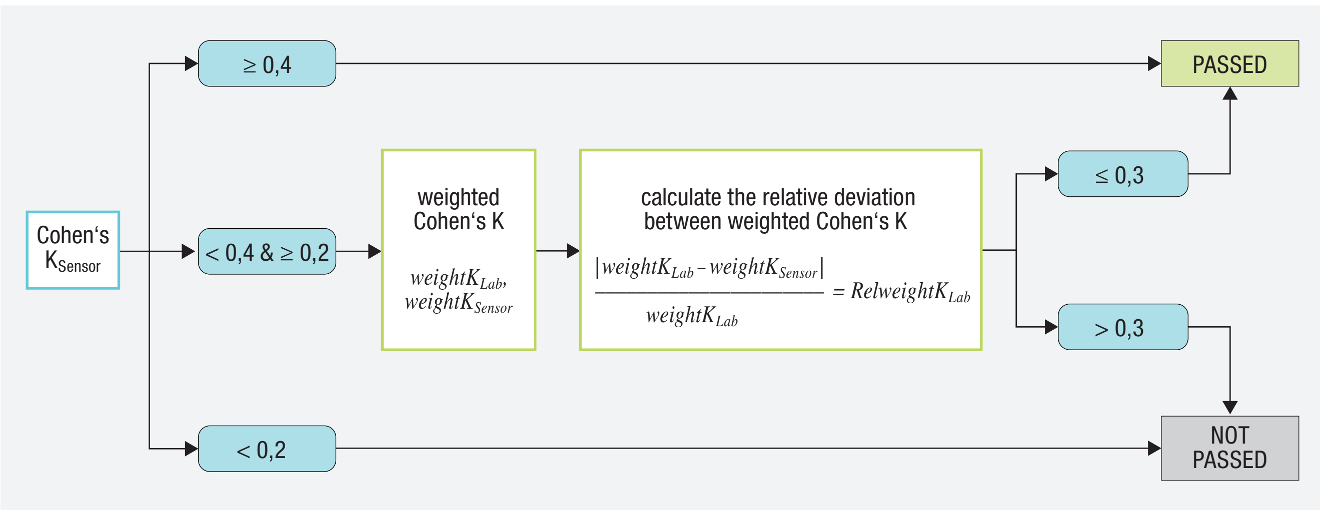

Figure 5:
Assessment system and requirements

Detailed account of the test results

The Stenon FarmLab is an integrated hardware and software solution that carries out soil analyses and delivers real-time results. The test verified whether the system provides information on the soil condition which is of practical relevance for growers and their nutrient and water management decisions. In addition, it was tested whether the system detects operating errors and prompts appropriate warnings and instructions.

The field measurements were carried out in the Darmstadt-Dieburg area (Hesse) in May 2021 by using five handheld devices that used identical software versions and were calibrated to identical models. All devices were operated in typical field conditions.

Soil properties in the test fields

The fields measured and sampled with the Stenon FarmLab soil sensor were chosen and selected with the help of the Hesse State Office for Agriculture (LLH).

The number of 40 different test fields reflects a relatively wide range of different soil properties and meets the aim of the test design, which is covering the widest possible spectrum of soil conditions. The individual spectrums are shown in Figures 6 to 9.

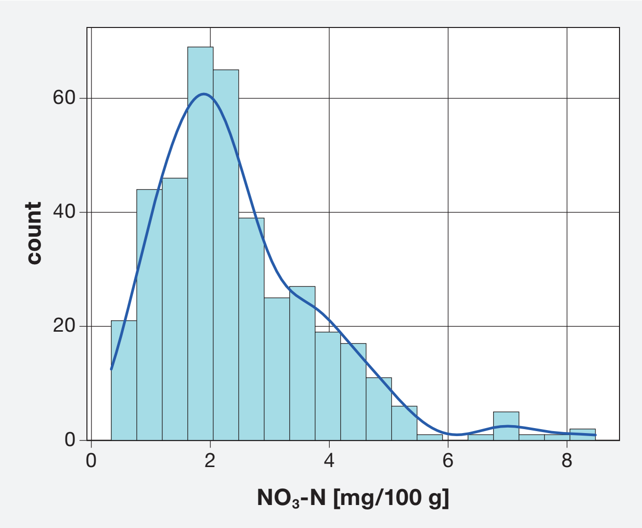

Figure 6:
NO_3 distribution of measured plots

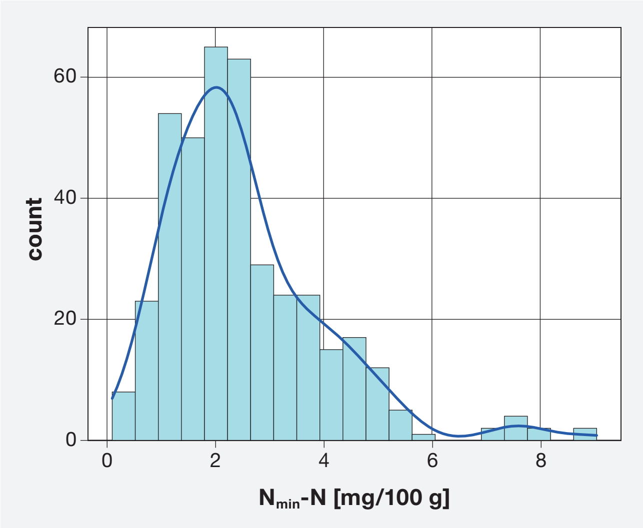

Figure 7:
N_{min} distribution of measured plots

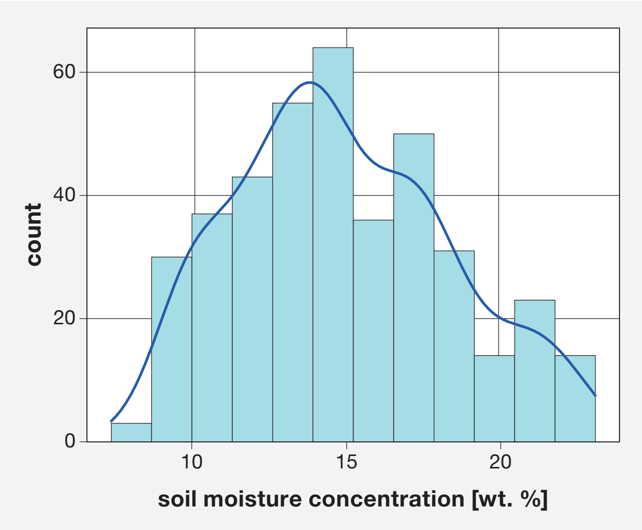

Figure 8:
Soil moisture distribution of measured plots

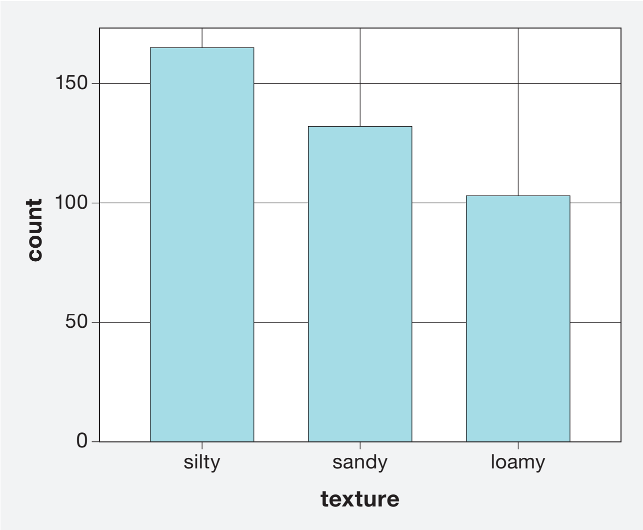

Figure 9:
Texture distribution of measured plots

Measurement imprecisions

The manufacturer specifies measurement imprecisions per parameter and range, which are listed in the tables 6, 7, 8 below. The degree of precision is expressed by the root mean square deviation (RMSE) and the median absolute error (MedAE). The measurement imprecision value per measuring range served as a basis for extrapolating the measuring range of the device as claimed by the manufacturer.

Table 6:
NO_3 measurement imprecisions

	NO_3 (mg/100 g)					
Measuring range	0.0 - 0.5	0.5 - 1.3	1.3 - 2.1	2.1 - 3.0	3.0 - 4.0	4.0 - 6.0
RMSE	0.72	0.55	0.68	0.97	1.09	1.99
MedAE	0.47	0.37	0.39	0.64	0.91	1.76

Table 7:
N_{min} measuring imprececions

	N_{min} (mg/100 g)				
Measuring range	0.0 - 1.0	1.0 - 2.0	2.0 - 3.0	3.0 - 4.5	4.5 - 7.0
RMSE	0.67	0.62	0.96	1.18	2.45
MedAE	0.43	0.36	0.71	0.92	1.98

Table 8:
Measuring imprececions for soil moisture

	Soil moisture in percentage weight				
Measuring range	0 - 5	5 - 10	10 - 15	15 - 20	20 - 25
RMSE	2.6	1.32	1.39	1.5	2.75
MedAE	2.59	0.94	0.98	0.92	2.45

Photo 10:
Measurements in potato planting

Prediction accuracy

The test presented here evaluated the predictive accuracy of the Stenon FarmLab for the soil parameters listed in table 9.

Table 9:
Soil parameters and reference methods

Parameter	reference method
NO_3 (mg/100 g)	VDLUFA Vol. I, A6.1.4.1 (extracted in a calcium chloride solution)
N_{min} (mg/100 g)	
Soil moisture as percentage weight	VDLUFA Vol. I, A2.1.1 (oven drying at 105 °C)

The evaluation and calculation of the figures was carried out by the Julius Kühn Institute, the German Federal Research Centre for Cultivated Plants.

Table 10 groups the Stenon FarmLab results on prediction accuracy for the NO_3 in mg/100 g and N_{min} in mg/100 g content classes and for the soil moisture in weight percentages.

The tables 13, 14, 15 show the corresponding confusion matrixes.

Table 10:
Stenon FarmLab prediction accuracy

Parameter	Cohen's Kappa		weighed Cohen's Kappa		rel. difference
	Labs	Soil sensor	Labs	Soil sensor	
NO_3 (mg/100 g)	0.51	0.21	0.87	0.66	24.1
N_{min} (mg/100 g)	0.49	0.22	0.87	0.70	19.5
Soil moisture (percentage weight)	0.72	0.29	0.97	0.84	13.4

Error detection and system prompts

The operator warnings listed in table 11 were provoked five times in the experiment (see page 10).

The Stenon FarmLab detected each error and prompted to the operator the appropriate warning on the display screen.

Photo 11:
Error message code 28

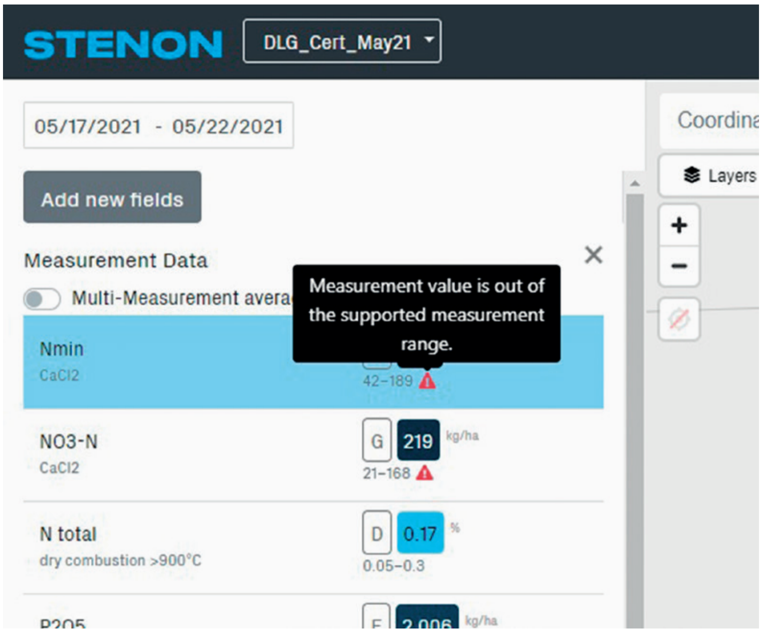

Photo 12:
Warning measuring range

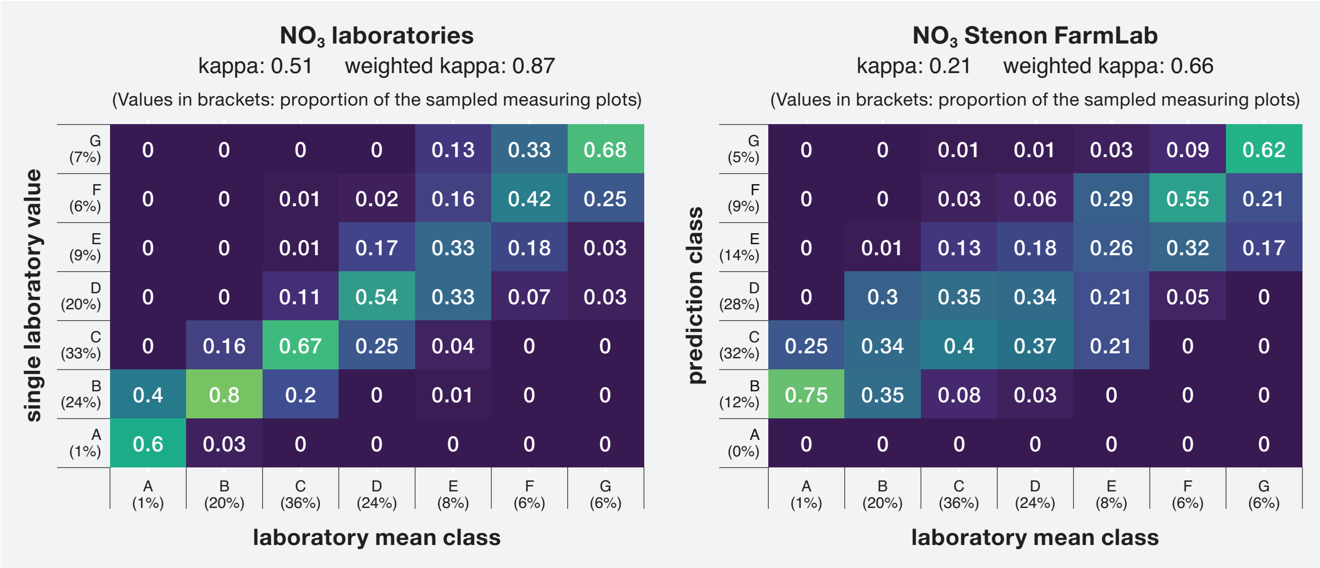

Figure 13:
Confusion matrix for NO3 concentration classes (left: laboratories/right: FarmLab)

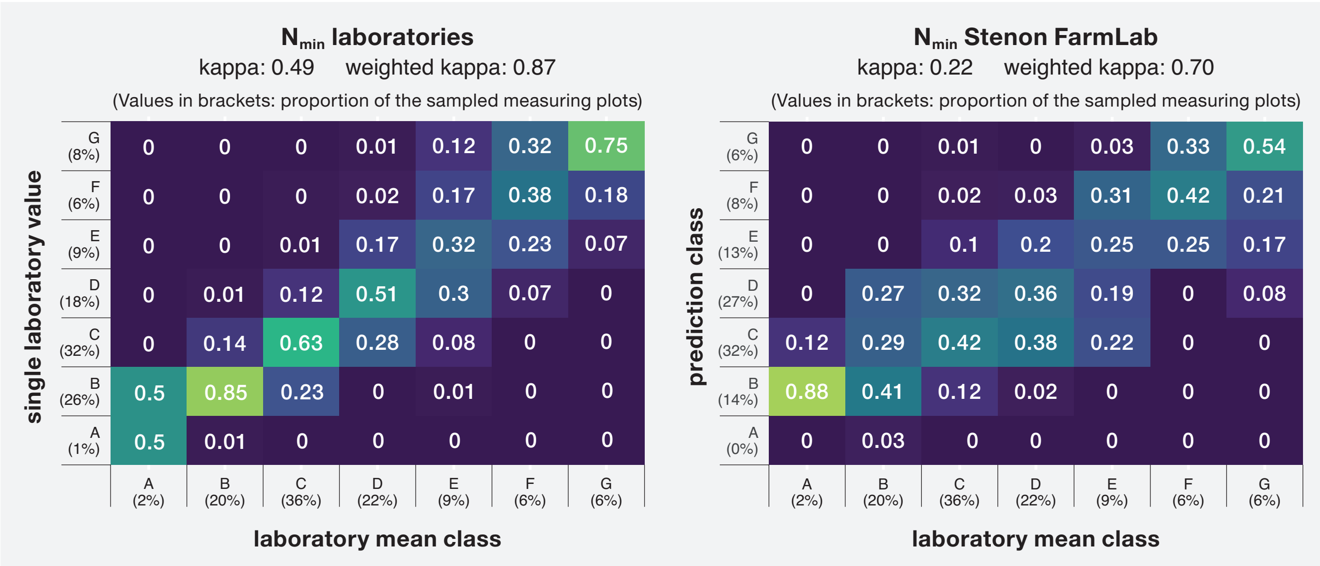

Figure 14:
Confusion matrix for Nmin concentration classes (left: laboratories/right: FarmLab)

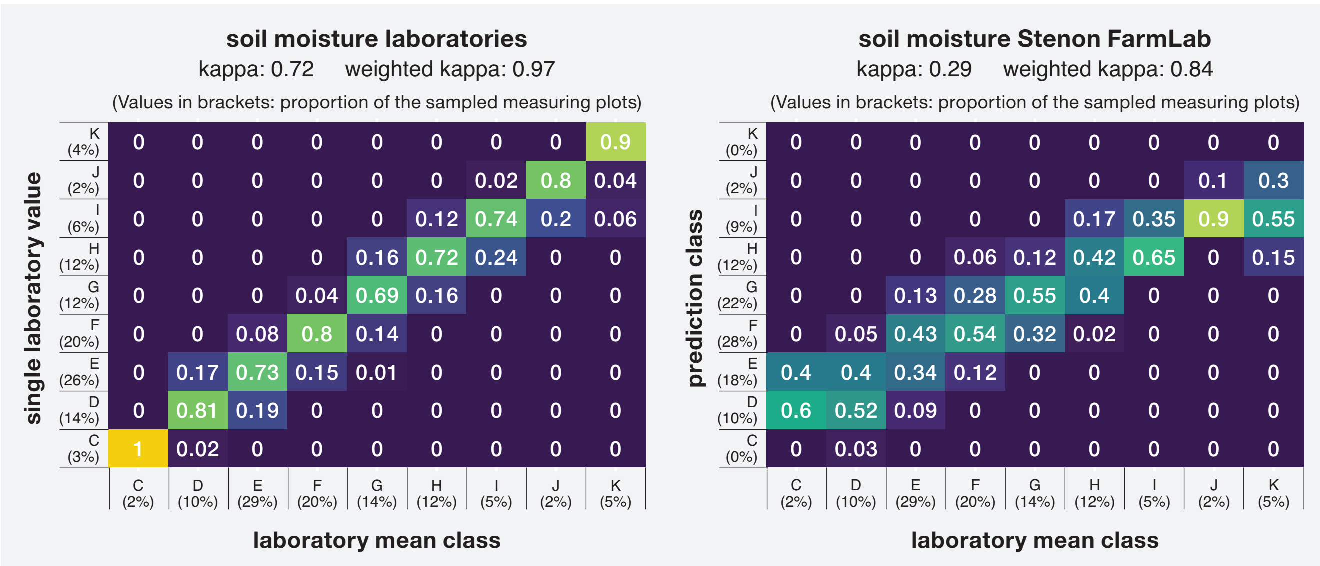

Figure 15:
Confusion matrix for soil moisture classes (left: laboratories/right: FarmLab)

Table 11:
Operator errors and error prompts on the discplay screen

Operator error	Error code	Warning
Calibrating without calibration cap	3b	**Bad calibration** (code 3b) Re-do calibration process until it is verified. Contact technical support, if the error persists.
Calibration cap not removed before probing	3	**Cap measurement** (code 3) Remove the calibration cap from the sensor head and place the device into the soil.
Measuring air	1	**Air or too dry soil was measured** (code 1) Only measure when the sensor head is placed properly into soil OR measure more moist spot.
Vegetation residues	28	**Vegetation residues** (code 28) To get proper results repeat measurements at another location and make sure to remove any plant residue from topsoil before placing the sensor.
Measuring soil but calibration cap still in place	6	**Unusual signal of the optical sensors** (code 6) Repeat measurement in another spot and make sure that the sensor is completely immersed in the soil. Avoid wobbling the unit after it is in the soil. Proof for stones in front of the sensors.
Measurements out of range	Prompt issued in the web app	**Measurements out of the supported range**

Summary

In the DLG test, the Stenon FarmLab soil sensor with software version d-1.3.0 and calibration model p-2.1.0 met the DLG requirements for prediction accuracy of sensors for mobile soil samplers. This applies for the following parameters:

- NO_3 content (mg/100 g)
- N_{min} content (mg/100 g)
- Soil moisture by percentage weight

Stenon FarmLab detected operator errors and issued the appropriate warnings and instructions.

The DLG APPROVED specific criteria quality seal is awarded to the Stenon FarmLab and its performance in measuring the following parameters: NO_3, N_{min} and soil moisture levels.

The DLG panel of experts

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Special thanks go to Dr Doreen Gabriel for her huge commitment in the development of evaluation and assessment procedures and statistical data processing.

Further information

Testing agency

DLG TestService GmbH,
Gross-Umstadt test site,
Germany.

The tests are conducted on behalf of DLG e.V.

The fields where the tests took place were selected with the support of the Landesbetrieb Landwirtschaft Hessen (LLH). The statistical analyses were carried out by the Julius Kühn Institute, the Federal Research Centre for Cultivated Plants.

DLG test framework

Prediction accuracy of sensors for mobile soil analysis (as of 09/2021)

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Photos and Graphics

DLG, JKI, Stenon

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