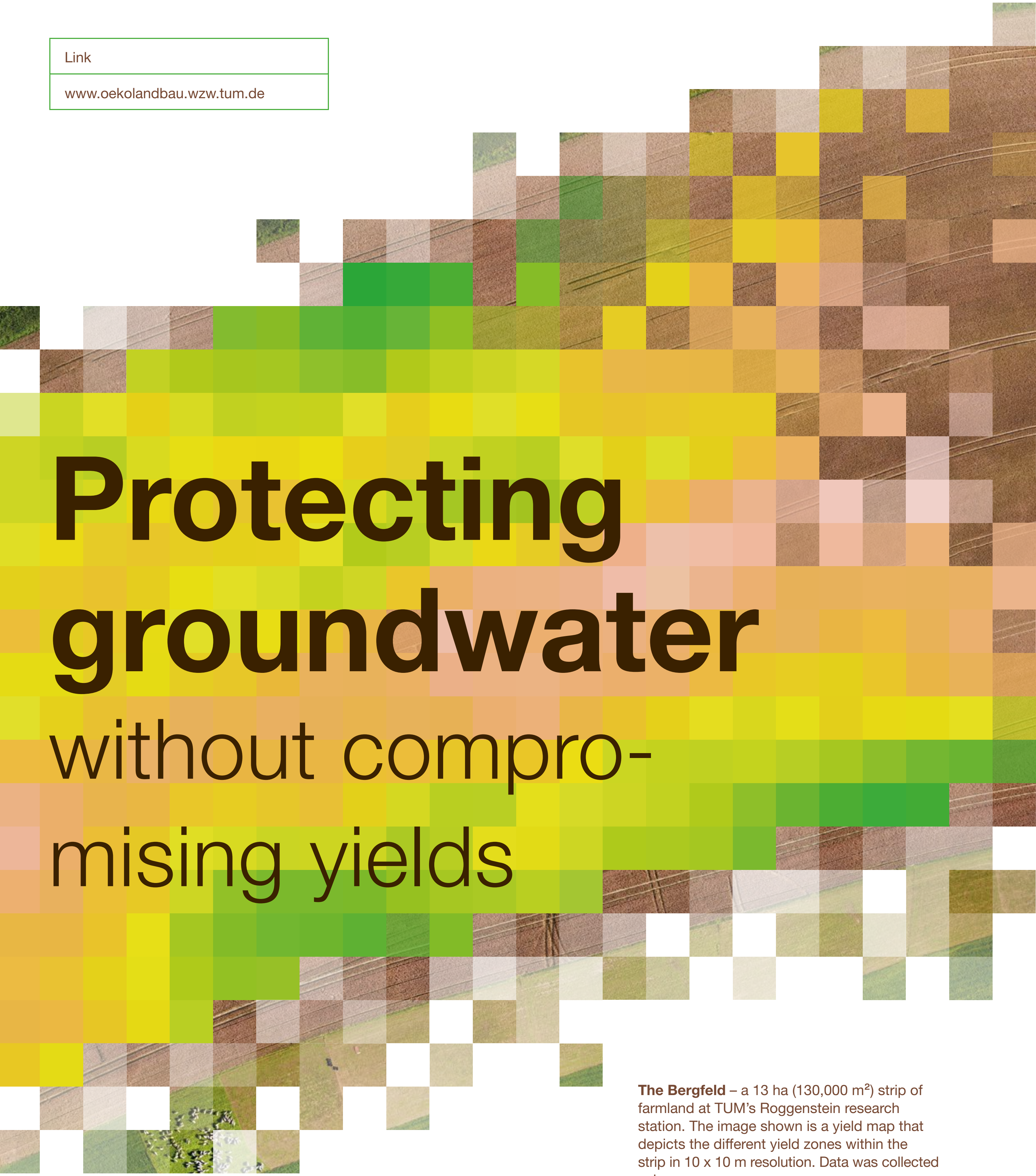
Link

www.oekolandbau.wzw.tum.de

Protecting groundwater

without compromising yields

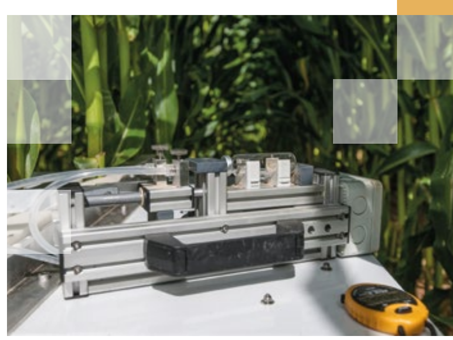


The Bergfeld – a 13 ha (130,000 m^2) strip of farmland at TUM's Roggenstein research station. The image shown is a yield map that depicts the different yield zones within the strip in 10 x 10 m resolution. Data was collected using sensors.

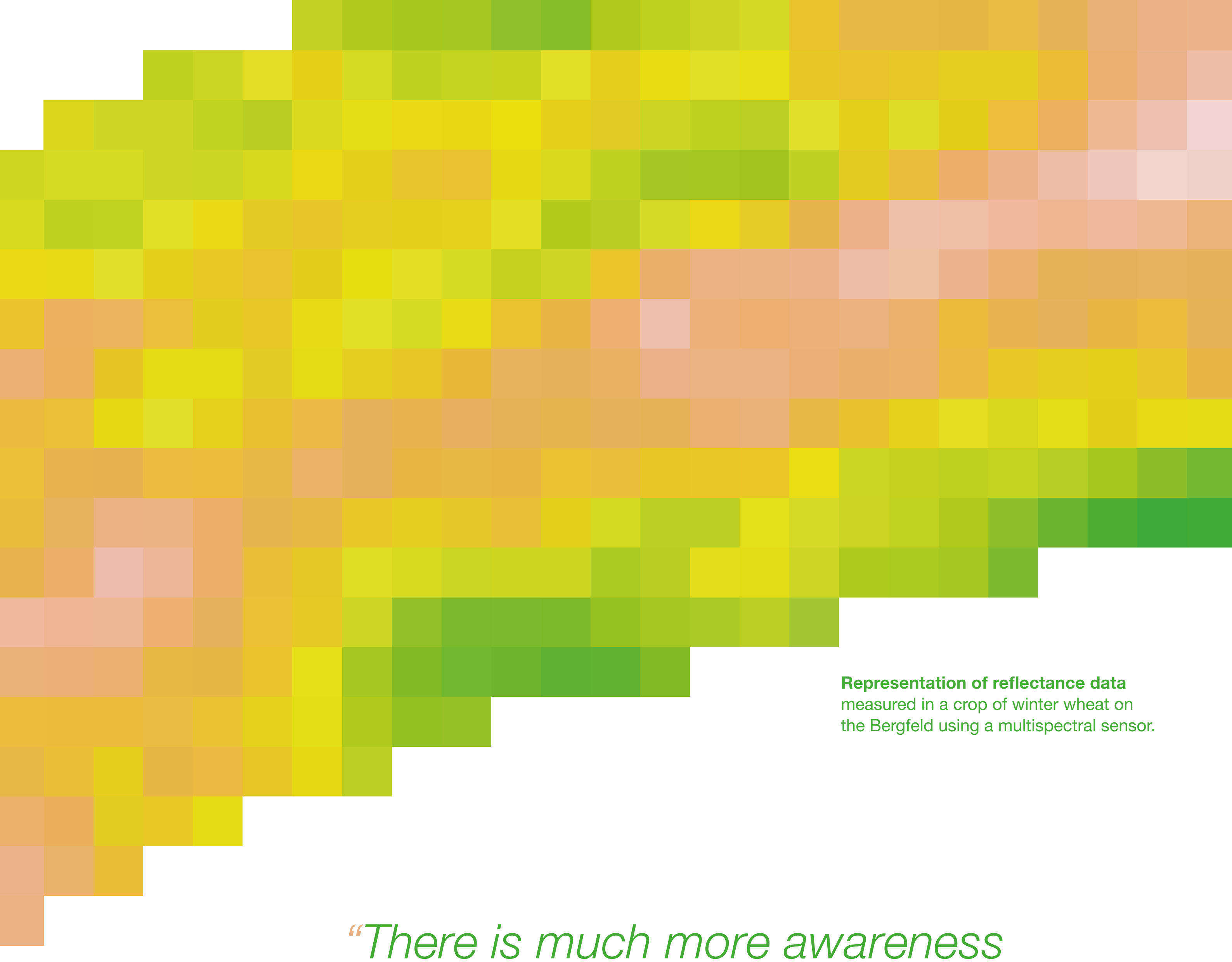
Picture credit: Kurt-Jürgen Hülsbergen; Graphics: ediundsepp

The more fertilizer, the better? This is rarely a good idea. Good harvests depend on different factors and too much nitrogen fertilizer can contaminate groundwater. Prof. Kurt-Jürgen Hülsbergen and Dr. Franz-Xaver Maidl from TUM School of Life Sciences in Weihenstephan have set themselves the goal of giving farmers the digital tools to determine optimal fertilizer quantities. In doing so, the TUM researchers are making it possible to achieve good yields without polluting groundwater with excess nitrate.

The respiration chamber, which is placed over the soil, measures the quantities of nitrous oxide emitted by the soil. The pump (right) is used to fill test tubes (above) that are then analyzed in the lab.



You could say they're working in the eye of the storm. Kurt-Jürgen Hülsbergen and Franz-Xaver Maidl are researching the efficient use of nitrogen in agriculture – a highly topical field of research. In June 2018, the European Court of Justice censured Germany for breaching the EU Nitrates Directive. This obligates countries to comply with a limit of 50 mg per liter of groundwater. Since 2008, however, at least 16.9 % of measurement sites in Germany have failed to meet this limit each year. High nitrate concentrations in groundwater are mostly caused by agriculture. While Germany has reviewed and amended its Fertilizer Ordinance, it is apparent that this legislation will not suffice. Hülsbergen holds the Chair of Organic Agriculture and Agronomy at the School of Life Sciences in Weihenstephan. The agronomist has worked on the topic of nitrogen management in agriculture for more than 20 years. This includes developing the REPRO model – a digital system to analyze, evaluate and optimize nutrient and energy flows.



Representation of reflectance data measured in a crop of winter wheat on the Bergfeld using a multispectral sensor.

> *“There is much more awareness of the importance of nitrogen efficiency now, but that wasn’t always the case.”* Kurt-Jürgen Hülsbergen

Picture credits: Kurt Bauer; Graphics: ediundsepp (source: TUM)

Professor Hülsbergen and his team collect data on parameters such as utilized agricultural area, crop yields, animal husbandry, soil quality and the use of mineral fertilizer and liquid manure; using this data, they develop models of nutrient cycles that – in the case of nitrogen – highlight surpluses and deficits and indicate potential areas of improvement. For example, the amount of mineral fertilizer used should be adjusted accordingly if liquid manure has been applied, as this means less additional nitrogen fertilizer is needed.

The algorithms used for analysis contain the knowledge gathered from years of field experiments. How do the type and quantity of fertilizer and the timing of its application affect yields and product quality? How much nitrogen is lost to the air or seeps into the water? What influence do soil properties and weather conditions have on nitrogen turnover in the soil? “Looking back, I’m happy that we persevered with the topic of nitrogen management for so many years,” says Hülsbergen. “There is much more awareness of the importance of nitrogen efficiency now, but that wasn’t always the case.” ▷

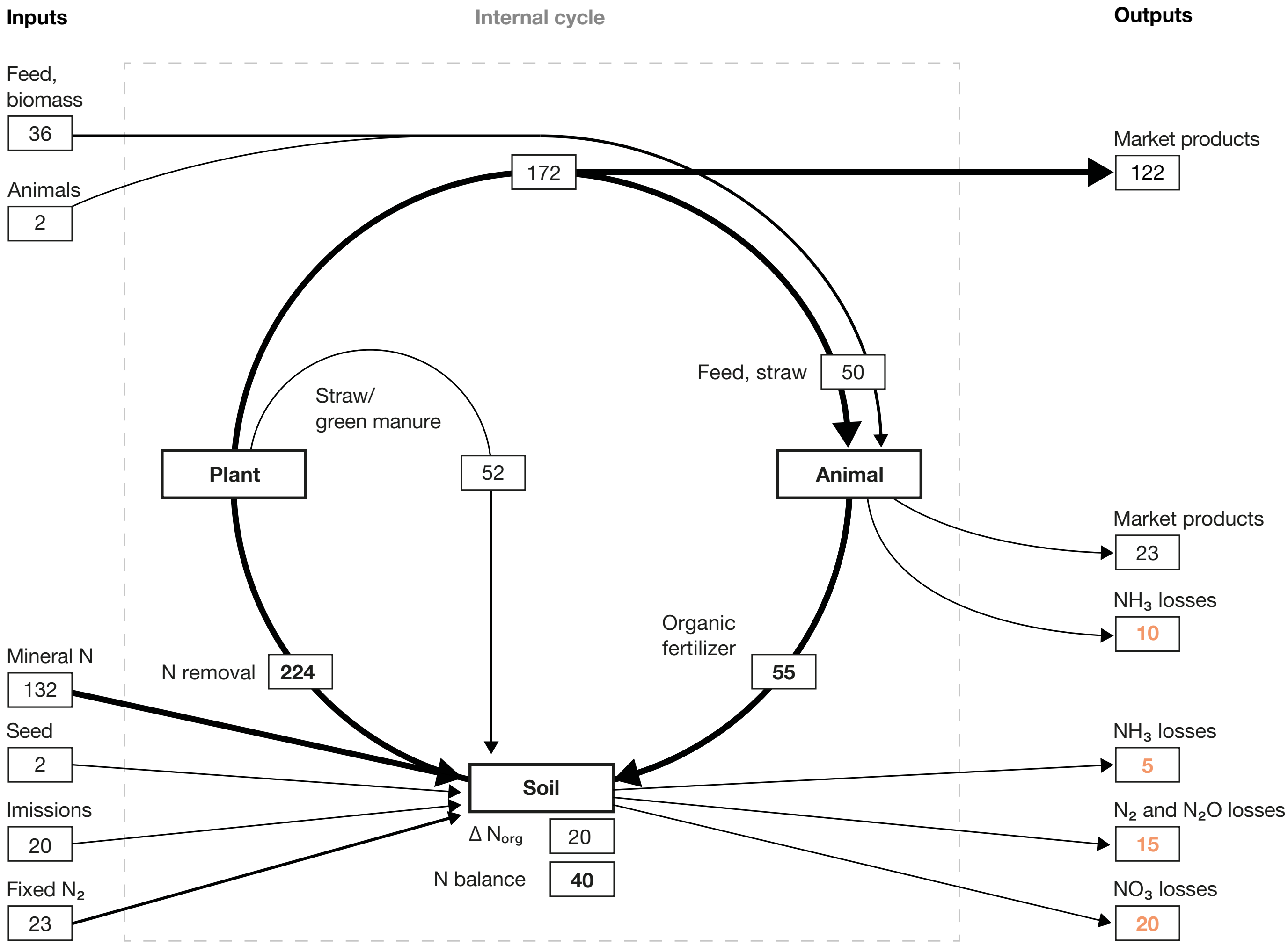
An online tool for digital nutrient management

Advances in sensor technology also benefit the REPRO model. Digitalization in agriculture and the adoption of precision farming methods – methods taking differences within individual fields into account – mean more data will be available. This requires new IT solutions to integrate data from many different sources into one overall system. REPRO is currently being developed further as a nutrient management system called Web-Man. This digital tool is now ready to be put into practice. The researchers hope that specially trained farmers and farm advisors will use the tool to analyze their farms and develop optimization measures. It has been designed to be used on both organic and conventional farms. This work is being funded by the German Federal Environmental Foundation (DBU) and the Federal Office for Agriculture and Food (BLE).

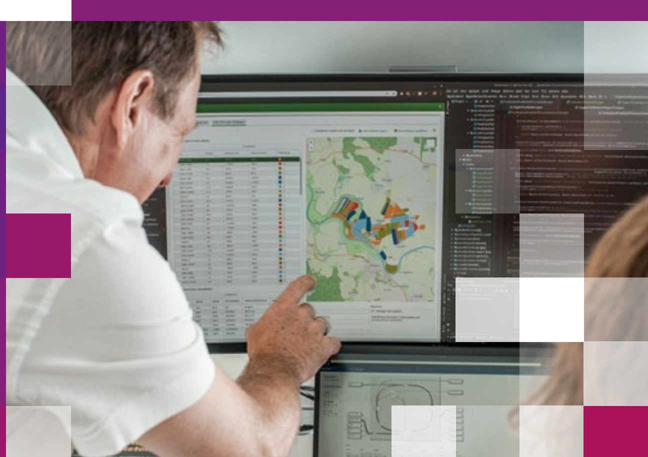
As well as calculating nutrient cycles, Web-Man also contains powerful data analysis algorithms that generate information to assist with decision-making. It provides advice to the user and makes specific optimization suggestions. At present, however, the tool is still a prototype that Hülsbergen and his team of specialists use to advise farmers. "We can't just hand farmers the results and leave them to it," says Professor Hülsbergen. IT specialists at the university are, however, currently developing automatic decision-making algorithms based on expert knowledge and artificial intelligence. Other computer scientists are working together with agricultural experts to create user-friendly, self-explanatory user interfaces to ensure that users can use the finished tool without needing assistance from scientists.

▷

To keep the soil data in their database up to date at all times, the researchers regularly collect soil samples using a small auger. The soil cores are then analyzed.



Above: The nitrogen cycle on a farm, calculated with the REPRO model: The figures represent the volume of nitrogen in kilograms per hectare per year. Figures in red are areas needing improvement.
Below: Kurt-Jürgen Hülsbergen demonstrates the digital Web-Man tool. The pixelated image represents the nitrogen footprint of the Bergfeld at Roggenstein in 2018.

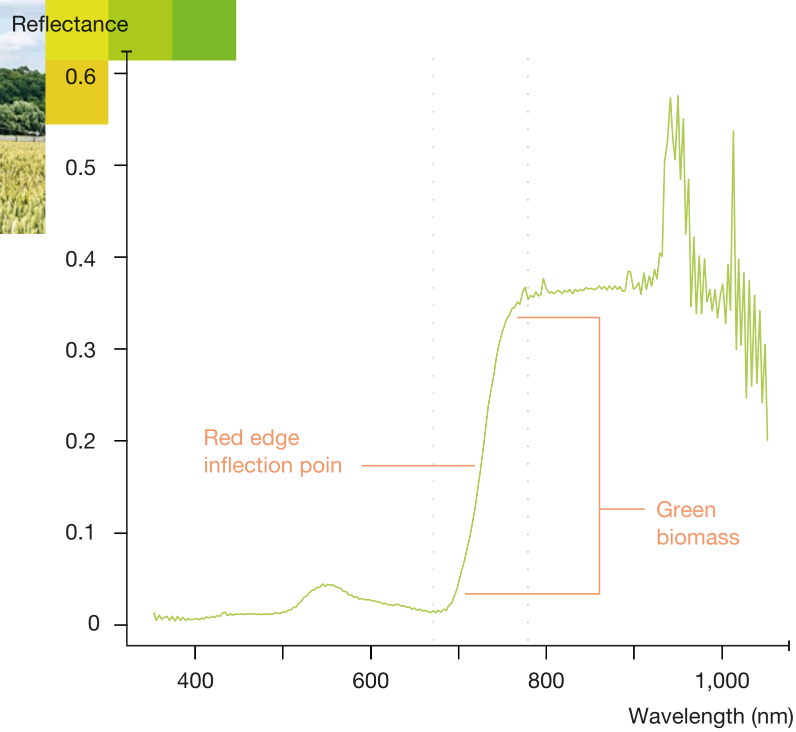


“We can’t just hand farmers the results and leave them to it.”

Kurt-Jürgen Hülsbergen

Picture credits: Kurt Bauer;
Graphics: ediundsepp (source: TUM)

Measurement at the front, fertilization at the back: Sensors mounted on the frame on the front of the tractor record reflectance values; the computer analyzes these in real time and uses the values to control the rear-mounted fertilizer spreader with pinpoint accuracy. At right is the reflectance spectrum of a crop plant.



How sensors determine plant fertilizer requirements

Commercial sensors for fertilization according to crop requirements measure the light reflected by the plants. They use only two to four wavelengths and are suitable for only a limited number of crops. Maidl hopes to expand the technology for use with other crops, such as maize, and to include other plant properties. Each plant has a different reflectance spectrum, which changes as it grows and is also dependent on the weather and the time of day. Different wavelengths make it possible to record different plant properties. Maidl's multi-spectral sensor measures 220 different wavelengths and precisely records the properties required for different crops, times of day and weather conditions. This sensor was developed using spectral measurements from a wide range of trial plots. In addition, crop biomass and yield measurements are taken in the field and crop nitrogen content determined in the laboratory; the protein content in the kernel is also analyzed for cereal crops. Over the years, he has compiled an enormous treasure trove of data. By examining the correlation between different spectral measurements and plant analyses, Maidl can derive a fingerprint for the respective crop and the parameter in question. This is then used to develop fertilizer algorithms.

Save nitrogen using precision farming

Parallel to developing Web-Man, Hülsbergen's colleague Franz-Xaver Maidl is researching efficient nitrogen usage with sensors according to the principle of "Ask the plant what it needs". Sensors directly measure the nitrogen nutrition status of plants, which is then used to calculate the optimal quantity of fertilizer – taking into account the plant's growth stage, soil quality and the desired product quality. This technology is now being integrated in Web-Man.

This process is based on the reflectance behavior of plants. Plants absorb visible light for photosynthesis and strongly reflect light in the near-infrared spectral range at longer wavelengths. If spectrally resolved measurements of the reflected light are taken, different wavelengths return different reflectance values. These reflectance curves then allow researchers to compute specific parameters, such as the amount of biomass or nitrogen intake.

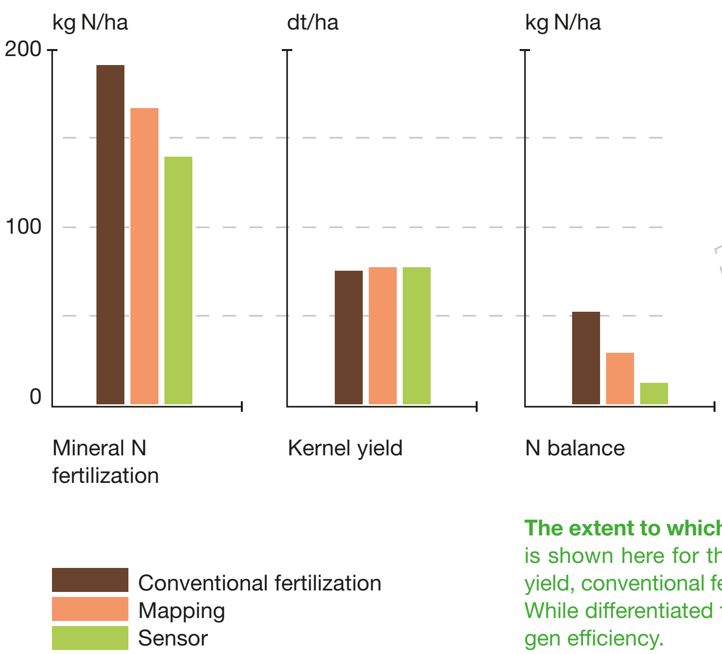
Farmers have already started using this technology, mostly using satellite measurements. Maidl's solution, on the other hand, is far more direct – specifically, a system mounted on a tractor coupled with the fertilizer system. This method is far more precise – also because measurement and fertilization coincide. In a single pass, the system measures plant nitrogen content, calculates in real time the correct quantity of fertilizer, and delivers this quantity with pinpoint accuracy.

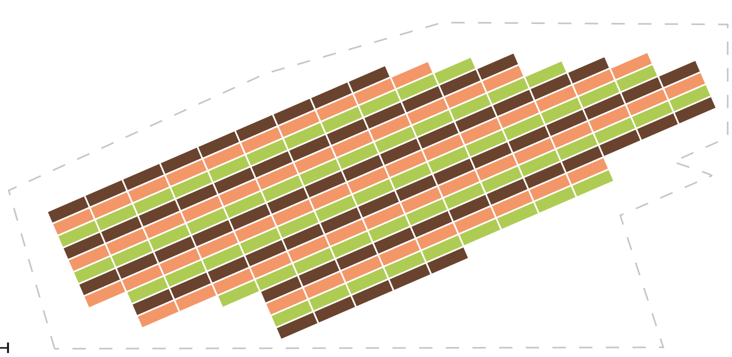
This process opens the door for much more precise fertilizer application than has been the case to date. At present, farmers generally calculate the quantity of fertilizer for a field based on the average yield and average soil quality. In reality, however, soil properties, yield potential and fertilizer requirements also vary within a single field. Consequently, crops in areas with properties that deviate from the average values for the field either receive too much or too little fertilizer. Excess nitrogen remains in the soil, accumulates over years and, at some point, is discharged into the environment, such as groundwater. Sensor-assisted fertilization can prevent this. Trials conducted with winter barley at TUM's Roggenstein research station produced the same yields with almost a quarter less nitrogen. The scientists achieved similar results using winter wheat and winter rape.

Flying drones over a field is also an effective way of recording yields. Drones can carry sensors with an optical or thermal imaging camera.

Sensor measurements give farmers peace of mind

The methods used by the researchers in Weihenstephan have also impressed farmers themselves, for example in the Hohenthann research project in the Landshut district. The region is home to numerous intensive livestock holdings; due to the high volumes of liquid manure this involves, the region is battling rising nitrate levels in groundwater. Hülsbergen and Maidl analyzed nitrogen flows in farms that are typical for the region. They identified where and why nitrates were leaching into groundwater and derived groundwater protection measures, such as the timing of liquid manure applications and modifying animal feed. Field experiments testing fertilization using sensor data have also been conducted; this proved to be effective at increasing nitrogen efficiency. The measurements showed that soils that had been fertilised for years with manure had high nitrogen levels. In these areas, the application of additional fertilizers needs to be reduced significantly in order to comply with nitrate limits. ▷





The extent to which the Web-Man digital tool can improve nitrogen efficiency in the field is shown here for the Bergfeld at Roggenstein. The comparison shows that, for the same yield, conventional fertilization uses the most fertilizer and leaves the most nitrogen in the soil. While differentiated fertilization is better, fertilization using sensor data has the highest nitrogen efficiency.

Picture credits: Kurt Bauer, Uli Benz; Graphics: ediundsepp (source: TUM)

“With appropriate fertilizer algorithms, farmers can maintain yields and society would benefit from good water quality.”

Kurt-Jürgen Hülsbergen

The Bergfeld at Roggenstein is shown again here. The colors represent crop nitrogen uptake in 2018.

Optimizing crop rotations

Many organic farmers face a very different problem: they use organic fertilizers such as liquid and solid manure but do not use nitrogen from mineral fertilizers. Organic guidelines also limit the number of animals per hectare of agricultural land. This means nitrogen is a scarce resource, which often limits yields. It is therefore crucial that farmers use the nutrient efficiently. Leguminous crops – plants such as red clover, lucerne and soybeans – are therefore an important tool as they can add nitrogen to the soil via atmospheric nitrogen fixation. It then undergoes mineralization processes that make it available for subsequent crops. Some of the nitrogen is bound in soil organic matter over the long term. The speed of this process depends on soil quality and weather conditions. Plants, on the other hand, take up different amounts of nitrogen during different growth stages. The challenge is, therefore, to coordinate crop rotation and organic fertilization so that, taking into account soil processes, crops always receive an optimal supply of nutrients. There are currently no models that depict these processes or that include suitable fertilization algorithms for organic farming. Hülsbergen and Maidl hope to integrate this as an additional module in Web-Man.

Dr. Franz-Xaver Maidl

When he isn’t researching at TUM, Franz-Xaver Maidl runs the family farm in Lower Bavaria. “The farm is, in a way, also an experimental station,” he says. He claims he can tell straight away which methods might be relevant to farmers and can be implemented in practice: “It can be difficult to see how scientific research could be applied in the field, this is only possible if you have a lot of contact with farmers.” Maidl is a man in demand in his community. Many turn to him for advice, currently in relation to revisions to the Fertiliser Ordinance.

Maidl studied agricultural sciences at TUM and did his doctorate on nitrogen dynamics. A research project at the German Aerospace Center (DLR) aimed at recording the nutrition status of plants using measurements from aircraft attracted his attention and led him to his current research topic of fertilization according to crop requirements using sensor measurements. A system he developed and patented is available on the market in the Isaria and Crop Sense sensors.

Protecting groundwater using nutrient management

The researchers are motivated by the idea that "our work can minimize the amount of nitrogen used and reduce environmental contamination," explains Hülsbergen. "With appropriate fertilizer algorithms, farmers can maintain yields and society would benefit from good water quality." Taking this one step further, the fertilizer algorithms could be used to optimize drinking water quality instead of crop yields. The model can simulate these scenarios and calculate expected yield reductions. It would then be possible to derive potential compensation for farmers.

The next generation of farmers might even take these concepts for granted. Maidl and Hülsbergen are doing their best to make this happen by engaging heavily in teaching. "Today, many people study agricultural sciences because they want to make the world a better place with the help of modern technologies," says Hülsbergen. "That's ideal for us, because we want to make students enthusiastic about environmentally friendly farming. Digitalization and precision farming are important and innovative ways of achieving this."

Christine Rüth

Prof. Kurt-Jürgen Hülsbergen

Hülsbergen grew up on a farm in the Magdeburger Börde and studied agricultural sciences at the University of Halle-Wittenberg. After being awarded his doctorate in 1990, he helped establish organic agriculture as an area of study at the university. Hülsbergen qualified as a professor in 2002 and, in 2003, was appointed to the Chair of Organic Agriculture and Agronomy at the TUM School of Life Sciences in Weihenstephan.

Moving to Freising, the researcher also switched to agriculture with a completely different structure: "In Bavaria, the average field size is 1.8 hectares; at home, there are fields of 50 to 150 hectares. One field there is many times the size of an entire farm here." Hülsbergen lives in the Hallertau, the world's largest contiguous hop-growing area – so work is just outside his front door: "Nitrates are a hugely important issue for hops."

Nitrogen in agriculture

Plants need nitrogen to grow and can only absorb it in certain forms – mainly as ammonium or nitrate. Mineral fertilizers make nitrogen directly available to plants in a form they can quickly absorb. In liquid and solid manure, and compost, organic nitrogen predominates. It remains in the soil for years or even decades as it is slowly mineralized. Leguminous crops capture nitrogen from the air, hold it in the soil and thus make it available for subsequent crops. If too much organic nitrogen is present, such as from liquid manure, this can remain in the soil for decades. The excess nitrogen can then seep into groundwater, rivers and lakes. It is therefore a threat to ecosystems and potable water. Liquid manure emits ammonia, which disperses in the air and thereby "fertilizes" areas where this is not desirable. As a result, nitrogen also contributes to loss of biodiversity. Specific turnover processes also cause nitrogen to be emitted as nitrous oxide. This is a highly potent greenhouse gas and is therefore critical even in very small quantities.

Picture credits: Kurt Bauer, Uli Benz; Graphics: ediundsepp (source: TUM)