Under watchful eyes and sensors: Michael Gübert, Dr. Gitta Erdmann and Daniel Fabian (left to right) assess wheat plants in the greenhouse. They are increasingly being supported by computer-aided phenotyping technology.
Fitness strategy for wheat, soybeans and other crops

The world’s population is growing rapidly. In order to secure our food supply, we need to produce more crops on the same amount of farmland. Around the world, scientists at Bayer are working to obtain maximum performance from arable crops such as wheat and soybeans. Using state-of-the-art genetic analyses, high-tech cameras and physiological and biochemical expertise, these experts are decoding plant life in minute detail, yielding valuable knowledge for new breeds, innovative crop protection agents and a successful future for farming.
The threat develops slowly, from inside the wheat plant. Under stress conditions, the plant’s cells switch into emergency mode: a biochemical chain reaction is triggered. With the plant now struggling to survive, producing a high yield is of secondary importance. At first glance, the small wheat plant still looks healthy, but on a cellular level, it is already on red alert. “The wheat plant is under stress from lack of water. And this puts the entire harvest at risk,” says Dr. Hans-Jürgen Rosslenbroich from Agronomic Development at Bayer CropScience. He and his team investigate the behavior of the wheat plant using sensor technology and try to optimize its ability to withstand the abiotic environmental factors that affect every plant, such as climate, soil and light conditions. “These are all factors that we cannot specifically address with conventional crop protection solutions,” explains Raphael Dumain, Global Head of Crop Efficiency. The plant specialists at Bayer CropScience use the term “Crop Efficiency” to refer to all of the various fields in which they are seeking to systematically optimize the yield potential of crops through research. They work with all technologies available, such as breeding, traits, chemistry and biology.

In the field, beetles and caterpillars chew on the leaves and roots of the plants, weeds compete with them for light and nutrients and fungi attack them with diseases. “And those are not the only challenges that crops face,” says Dumain. “Drought, heat, frost and lack of nutrients are other factors affecting plant health, and thus yields as well.” Take wheat, for example: an average temperature increase of just one degree equates to harvest losses of some 10 percent in developing countries. In order to combat these losses, plant researchers worldwide are working to breed more robust and productive varieties and develop new crop protection agents in what has become a race against time. The world’s population is growing constantly, but the available farmland cannot be continually expanded to accommodate it. In 1950, the amount of cropland per person was nearly as large as a soccer field. Now it has shrunk to the size of an ice hockey rink – and is continuing to decrease.

“The crops of the future will have to deliver top performance if we want to be able to continue feeding the world’s population,” says Dumain. This is why researchers at Bayer CropScience are using a variety of strategies to optimize crops for greater yields.
and better resilience. “The goal is to strengthen the plants so that they can better utilize nutrients and successfully cope not only with pests, but also with unfavorable environmental conditions such as drought,” explains Dumain. Bayer scientists are therefore developing solutions that enhance the genetic potential of the crops, reduce negative environmental influences such as drought stress and improve conversion of natural resources into harvests – for example through better utilization of nutrients. “First, however, we have to understand the plants and their metabolic processes, and discover where we can intervene,” says Dumain, who maintains an overview of all cross-departmental research projects run by his colleagues worldwide.

The researchers aim to strengthen crops’ ability to withstand weather and pests

His fellow researchers carefully study how the plants manage their processes to produce grains, and how these can be improved. Accordingly, the Bayer specialists must also closely examine their DNA. “In wheat, for instance, we want to identify and understand which genes are responsible for higher yields,” explains Dr. Marc Bots, Trait Research Head of Crop Efficiency (see also research 28, “The wheat makers”). The focal points of his research include photosynthesis, i.e. how plants metabolize energy. Plants use this process to convert light and air into biomass and sugar, which then flow into the ears of wheat and other parts of the plant. “One of the key molecules involved is the RuBisCO enzyme, which binds carbon dioxide from the air that is then converted into sugar,” explains Bots.

RuBisCO can also bind oxygen. This reaction is undesirable, because it creates toxic molecules. The detoxification process, referred to as photorespiration, robs the plant of valuable energy. “So we cannot simply suppress photorespiration, as it also serves as a detoxification mechanism for the plant,” says Bots. The Bayer scientists do think they can make it more efficient, though. “Photorespiration is a complex multi-step process. We are trying to insert a shortcut,” explains Bots. His team is collaborating with researchers from the University of Hanover on activating certain genes in wheat and introducing special enzymes that convert an early intermediate product of photorespiration in fewer steps. “This enables the plant to conserve a great deal of energy that can instead be used to build up the fruit and increase the harvest,” explains the biologist. “If we are successful at this in wheat, we can transfer the principle to other crops, such as canola.” Once a technology has been identified, the researchers

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Plant specialist: Dr. Jan Dittgen (photo left) compares young wheat plants which have been grown under different conditions. His colleagues Dr. Marc De Block and Dr. Korneel Vandenbroucke (photo right, left to right) check how well canola plants have taken up a dye which allows them to examine the plants’ transpiration.

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250 million tons

of wheat will be needed by 2050 to meet the growing demand. Source: FAO
and breeders will develop an application for the most suitable crop. This is the area of expertise of Breeding & Trait Development, where Colin Cavanagh works for Crop Efficiency as an expert representative.

In addition to improving the genome, Bayer’s specialists are also focusing on the plants’ nutrient balance. Calcium plays an especially important role here. Among other things, this important micronutrient supports pod formation in soybeans after the plant has blossomed. “Our partner company, Plant Impact in the United Kingdom, has developed a technology that improves the distribution of calcium in soy plants,” says Anne Suty-Heinze, Global Strategy Segment Manager for Crop Efficiency at Bayer CropScience. “Soy farmers in Brazil can use this technology to increase their harvests by 6 percent on average – that’s approximately 180 kilograms more soybeans per hectare.” Bayer scientists want to take advantage of symbiotic relationships between plants and microorganisms as well, to not only maximize nutrient uptake but also optimize the crop’s genetic potential. Certain microbes modulate plant physiology and biochemistry, such as root architecture and photosynthesis, leading to increased grain number and yield. But inserting the beneficial organisms into an effective seed dressing is a unique challenge. “The interactions between microbes and plants are often much more complex than we think,” says Dr. Magalie Guilhabert, Head of Crop Efficiency for Biologics Research at Bayer CropScience in Sacramento, California. “As a result, positive effects from laboratory tests cannot always be simply transferred to large field studies.” The Biologics Team is therefore continuously working to better understand the processes in beneficial microorganisms and their interactions with crop plants using state-of-the-art genetic and physiological analyses and high-tech microscopy techniques. In the future, the researchers want to develop tools such as predictive systems for identifying promising fungal or bacterial strains earlier on.

Man and technology: in the Crop Performance Lab, Andrea Zimmermann-Gross and Manfred Wagenbach (photo left, left to right) survey their trials with young wheat plants. The seedlings are particularly interesting to the scientists: in the physiology laboratory, multispectral analysis provides an insight into mechanisms that play a role in stress tolerance and subsequent yield formation (photo right).

“Optimized DNA saves the plant energy, bacteria help with the nutrient supply”

A good balance of nutrients and efficient energy metabolism make crops more resistant to pests. Bayer scientists are also looking for solutions to drought stress. “Our goal is to reduce harvest losses caused by drought. We want plants not to shift into survival mode as quickly under dry conditions but to continue focusing on forming grains,” explains Bayer chemist Dr. Hendrik Helmke. In their laboratory, the researchers can precisely adjust the climatic conditions to simulate a hot summer, a chilly and damp spring or an extreme drought. Helmke is working together with Dr. Gitta Erdmann, Head of Crop Efficiency Biology Small Molecules Research, and her team in the laboratory to look for substances that help plants cope better with drought stress. The

Raphael Dumain, Global Head of Crop Efficiency

“The crops of the future will have to deliver top performance.”
Inner values in the stress test

With the help of phenotyping technologies, specialists at the Crop Performance Lab can register subtle changes in test plants such as wheat after, for example, exposure to new chemical substances. The researchers then use these biological data to derive conclusions about plant health and thus their stress levels – and how yields could develop over the course of the plants’ lives.

Environmental factors such as light intensity, air and soil humidity – and of course the effects of crop protection agents – can be precisely adjusted in the fully automated greenhouse.

Using innovative phenotyping technologies, the researchers collect plant data around the clock and then evaluate them after the harvest.

The gas exchange at the leaf is a measure of how effectively the plant is carrying out photosynthesis.

If the leaves get too hot, the plant suffers from heat stress.

Infrared light makes the distribution of water in the plant visible, revealing where they are on the point of wilting.

The development and branching of the roots provides information about the growth and health of the plant.

The chlorophyll content is an indicator of how well the plant is supplied with nutrients.
substance in its roots and leaves. “Among other things, the plant hormone causes the aperture structures – also known as stomata – on the leaves to close,” explains Fabien Poree, an expert in biochemistry. The plant breathes through these tiny pores, taking in carbon dioxide and giving off oxygen and water vapor. “During a drought, a plant closes these openings in order to retain as much water as possible and ensure its survival. However, this interrupts the exchange of gases, which inhibits photosynthesis. This ultimately means less biomass and smaller harvests,” explains Poree. Bayer scientists are therefore developing molecules that can intervene in this signal path, regulating the stress reaction in plants that reduces yields.

The active substances must first prove what they can do in extensive tests conducted by Erdmann and her team in the Crop Performance Lab under heat, drought and climatic stress conditions. “The effects on the yield do not become apparent until after harvest, which takes more than 100 days. But we collect data over the entire lifecycle of the plant. In the future, this information will help us predict much earlier which compounds will have positive effects on the harvest.” With some 6,000 active substances tested each year, that would be a significant help. The Crop Performance Lab is much more than just a climate simulation chamber, however. Camera systems and sensors analyze each of the individual cereal plants lined up in dozens of pots on endless conveyor belts – from seedlings to mature plants ready for harvest. This discipline is known as precision phenotyping. Such technologies allow researchers to precisely quantify plant structures and physiological functions, including photosynthesis and transpiration. “These biological data then enable us to draw conclusions about the health status and fitness of the crops,”

A plant’s dietary plan

One essential nutrient is nitrogen. Plants absorb this element from the soil in the form of salts. Soybeans get some help here, from symbiotic nodule bacteria that live on the roots of the plant. “They absorb nitrogen from the air, convert it into usable salts and make these available to the plants. In return, the bacteria receive energy-rich molecules,” explains Dr. Magalie Guilhabert. Together with colleagues from Biagro, a company recently acquired by Bayer, the researchers developed a seed coating containing special nodule bacteria. Soybean seeds treated with this coating get special start-up assistance: the bacteria quickly colonize the plant cells within the root nodules on the first roots set out by the seedlings, which can then absorb as much nitrogen as they need. The soybean fields are filled with strong plants that generate large harvests. Even the protein content of the beans increases, making them more nutritionally valuable.

Cold, drought, heat: crops should produce large yields even under extreme conditions

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Comparison of surface area

There are some 535 million farms worldwide. The average surface area managed by a farmer in Asia is approximately 1.6 hectares in size. In contrast, European farmers manage an average of approximately 27 hectares each, while a farmer in North America is responsible for more than 121 hectares.

One objective: find links between plant physiology and subsequent yields

In the Crop Performance Lab, all of the plants begin their journey at the check-in center. Here each pot receives a label with a number and a barcode, and the researchers specify how often it should detour from its conveyor belt route for a trip to the analysis chambers. In one of the chambers, for example, the researchers take 3D pictures of the plants to aid in detailed depiction. “In the test chambers, we measure parameters such as biomass and color intensity, which provide us with information on the plants’ growth and vigor,” explains Dr. Jan Dittgen from Efficacy Testing Crop Efficiency Research at Bayer CropScience. In yet another box, the researchers measure the water distribution in the plants using infrared light: “This shows us when a plant is on the point of wilting,” says Dittgen.

This test marathon yields a huge quantity of data. Using special image processing and analysis software, the researchers then interpret and compare their results. “The greatest challenge is to extract the relevant information from the mountain of data,” says Vandenbroucke.

Greenhouse tests cannot replace field studies under real-life environmental conditions

“Together with the experts from Computational Life Sciences, we are looking for interrelationships between the plant data measurements and actual crop biology.” If the researchers can do this, they will be able to tell at a very early stage whether or not a new Crop Efficiency technology can increase yields. “In the future, it is possible that leaf temperature or chlorophyll levels in the leaves will provide us with information on what the harvest could be like. That would make development of improved crop varieties or new active substances much easier,” says Vandenbroucke. But as valuable as the various tests and analyses in the greenhouse are, researchers must still conduct field trials as well. “That is where the plants are confronted with real-life environmental conditions such as wind and weather, soil quality, shifting pH values and nutrient contents or microorganisms in the soil,” says Andreas Nicol, who works in Bioimaging at Bayer Technology Services. Together with his team, the biophysicist develops precision-phenotyping technologies that are robust enough for the agricultural industry for his research colleagues at Bayer CropScience. “You could say we design the secret weapons of...
Ser scanners take precise measurements of the crops. The system is also coupled with high-resolution satellite geo-reference data with a precision of approximately two centimeters. Other important measuring criteria include the exact color of the leaves and ripeness of the fruits. “Discoloration can indicate a lack of water or the presence of pests,” says the biophysicist.

At the same time, the sensitive equipment must be able to tolerate the rough conditions in the field, supplying reproducible data even in the midst of dust, tractor exhaust fumes, vibration and dampness. Nicol and his colleagues have also developed a second-generation system, the PhenoTracker, that recently began making its rounds on a HyperCare farm owned by Bayer. “These experimental field stations are used to further develop phenotyping technologies and test, with high resolution, crop efficiency solutions such as high-performance varieties and chemical or biological substances under field conditions,” explains Greta De Both, Crop Efficiency Manager for Global Breeding & Trait Development at Bayer CropScience in Belgium. For example, a rotating infrared camera has been mounted 15 meters in the air on a stand in a wheat field. Every few seconds it takes a picture of the plants underneath it, and documents the temperature. Just like a thermometer, this indicates under what conditions the plants feel heat stress. The camera can cover up to five hectares. “However, the image quality decreases towards the edge of the photographic range, so we are working together with a specialized company to determine how to optimally evaluate the pictures,” says De Both. These farms will also be used by Colin Nicol’s colleagues at Bayer Technology Services are already hard at work on a mobile phenotyping system called the Field Profiler. “It’s a kind of mobile laboratory in the form of a fold-out tractor arm equipped with built-in measuring technology,” explains Nicol. As the tractor drives at walking pace through the field, high-resolution cameras and laser scanners take precise measurements of the crops. The system is also coupled with high-resolution satellite geo-reference data with a precision of approximately two centimeters. Other important measuring criteria include the exact color of the leaves and ripeness of the fruits. “Discoloration can indicate a lack of water or the presence of pests,” says the biophysicist.

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Cavanagh and his colleagues in Breeding & Trait Development to understand which technologies can be translated into future breeding activities.

Three HyperCare farms are already in operation: in France, the focus is on winter wheat, while Texas is the perfect location for drought stress trials, and Minnesota provides researchers with an especially good site to study spring wheat as well as soybeans and corn. “Data are collected from the time that the plants emerge right through to the harvest,” says James Tallman, an agricultural scientist at the HyperCare farm in Minnesota. “We correlate the measurements and analyze the data in close consultation with the researchers.” In 2016, additional HyperCare farms are scheduled to open in Germany and Canada, and in California and Nebraska in the United States. Data-collecting operations will also be added in other climate zones, such as in South America and Australia, in the coming years.

To be able to evaluate the mountains of data, the analysts have to understand plant biology

Vast quantities of data are generated in the field here as well. Bayer specialists from Computational Life Sciences (CLS) are therefore working to create the appropriate infrastructure for sorting through these data and extracting the relevant information. “You might say we are the interface between the plant researchers and the mountains of data collected,” says Laurent Viau, Computational LifeScience Senior Project Manager. The diversity of the information poses a special challenge for his team. After all, the documented data include not only factors such as the growth and temperature of the plants but also the results of extensive genetic studies, all of which must be prepared and put into relation with each other. “In order to evaluate these data usefully, we have to know how chemical and biological substances function, be familiar with the processes taking place in plants and naturally understand the issues the researchers are examining,” explains Viau. Each of his CLS colleagues therefore has a background in biology as well. With the help of data specialists, scientists at Bayer are studying all stages of a plant’s life in great detail. This is the only way they can understand how wheat, corn and other crops respond to stress situations, which genes are responsible for high yields and how plants make optimum use of the resources available to them. “We are then better equipped to optimize the plants for high performance,” says Global Head of Crop Efficiency Dumain in summary. He and his research colleagues are thus ensuring “that crops are able to supply adequate, high-quality harvests even under unfavorable weather and climate conditions – in order to help secure the world’s future food supply.”

Digital agriculture

Already today, satellite-guided agricultural machines navigate fields while collecting data on topography and soil conditions and linking weather data and measurements from the past season with the current situation. “Nowadays, we can collate data in the field and measure plant characteristics without touching or damaging the crops,” says Michael Schlemmer, Project Development Manager Field Phenomics. Precise real-time data on the condition of the plants or analyses of soil health can be used, for example, to help farmers in their decision-making. These detailed field observations are expected to soon become standard. Field phenotyping can be used to gather physiological data on crops and then extrapolate them to the entire field. Based on this information, farmers can administer crop protection agents at the best possible time. “The next big step is integrating all of these data sets into a system that automatically generates and manages the information intelligently,” explains Schlemmer.

Digital analysts: Greta De Both and Dr. Marc Bots (photo left, left to right) evaluate infrared images of trials conducted in wheat fields. The plots colored blue in the image are cooler and the crops there can grow better. Laurent Viau (photo right) and his team develop software solutions that permit better processing, visualization and analysis of collated plant data such as these infrared images.