The lead cow Alma (right) and the rest of her small herd, grazing on the Brunnenkopfalm in the Ammergau Alps. The Murnau-Werdenfels cattle keep the vegetation cropped and create gaps in the grass, in which e.g. rare species of orchid like the pink globe orchid (small image) can grow.

RELO-CATING THE SOIL

TEXT: TIM SCHRÖDER

In the future, Bavaria's climate could become warmer and drier. Experts fear that, as a result, the soils of meadows could lose fertile humus. To better gauge the impacts, researchers are trying to get one step ahead of climate change: they are transplanting soil from the cool and moist mountain regions into the warmer lands below – and observing the resultant changes. In this context, researchers and farmers are working hand in hand.

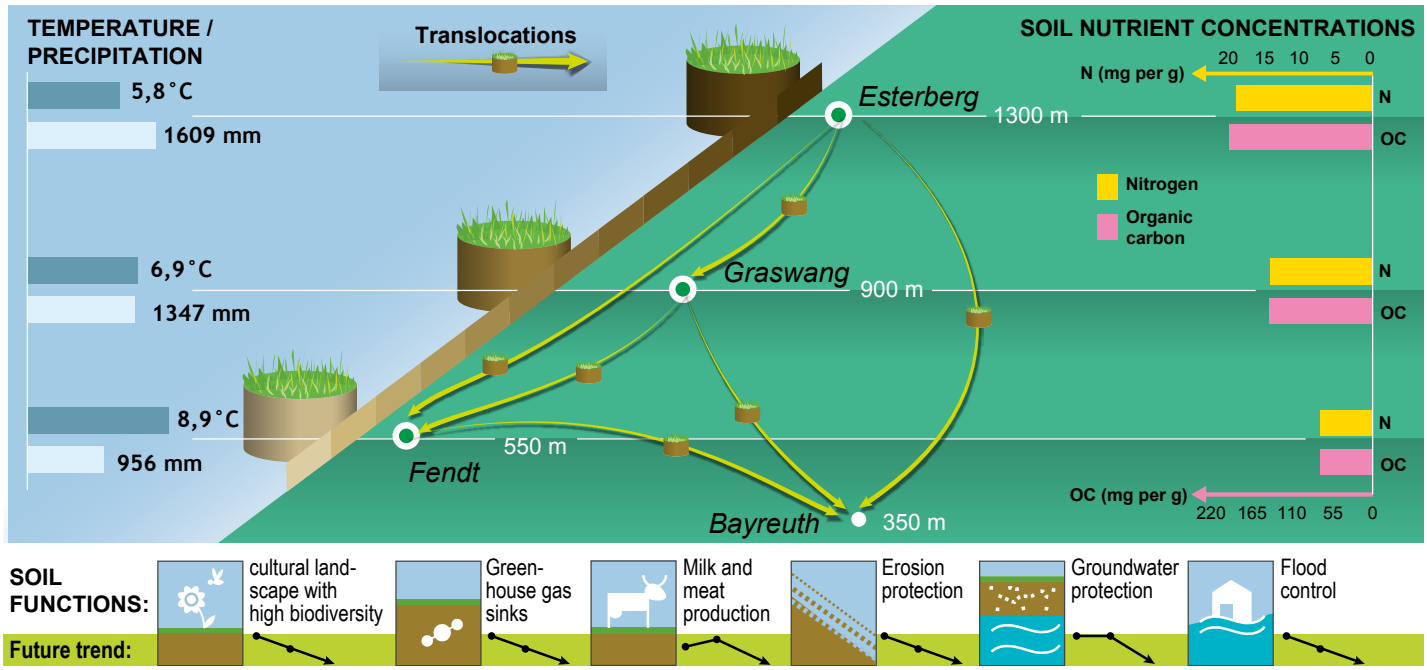
Open-air laboratory: project coordinator Michael Dannenmann and his team of environmental researchers have collected water and soil samples in the pastures and surrounding countryside, and can test their nutrient content directly onsite.

At the Brunnenkopfalm, small soil core samples are used to measure the nitrification, i.e., the production of nitrate by microorganisms in the soil. The extensively pastured soils are such effective filters that the groundwater remains nitrate-free.

Alma is one cool customer. When Michael Weiß needs to drive the cow, she goes where she's supposed to without any major complaints. And, more importantly, the younger cows follow her – and don't get lost. After all, the inexperienced animals could easily fall from the steep edges of the Brunnenkopfalm. Alma is 18 years old, and essentially a landscaper: together with the younger cows, she helps keep the grass in the pasture short. By grazing on the flowers and grasses of the Brunnenkopfalm in Bavaria's Ammergau Alps, she helps the pasture remain exactly what it has been for centuries: a picturesque meadow landscape where the flowers bloom every spring.

Reviving a tradition

For many years, the Brunnenkopfalm was essentially forgotten. Several decades ago, pasture farming was discontinued there - and in many other remote meadows – because the work was simply too difficult, and not very profitable. For all these years, the pasture was reduced to a hunting ground, and was at risk of reverting to woodlands. But farmers like Michael Weiß from the village of Schöffau want to preserve the pasture landscape, and with it, the diversity of species. After all, a carefully maintained pasture can be home to over 250 plant species. "I spent a lot of years looking for a pasture where I could fulfil my dream," says Michael Weiß. "But the government authorities weren't prepared to give me a plot of land for pasturing." Things looked bleak until he met Dr Michael Dannenmann. Dannenmann is a soil researcher at the Institute of Meteorology and Climate Research in Garmisch-Partenkirchen, part of the Karlsruhe Institute of Technology (KIT). He is currently investigating how climate change is affecting the soils of Bavarian meadows, and what these changes will mean for agriculture, biodiversity and water quality, as well as flood and erosion protection. "Michael Dannenmann was looking for a meadow to research, and I was looking for one to turn into pasture," says Weiß and laughs. And, with the goal of investigating ways to protect the neglected meadows from the impacts of climate change, a mutually beneficial solution was found: since 2018, Michael Weiß's cattle have had two Bavarian pastures to graze on -



The soil translocation study and expected future changes in soil functions, provided these trends are not counteracted using climate-smart management.

and Michael Dannenmann has had two pastures for his soil research.

Bavaria will become warmer

However, the meadows aren't Dannenmann's only concern. In the project SUSALPS he and experts from other research institutes are investigating several sites at various elevations throughout Bavaria – from the alpine pasture meadows to primarily dunged and mowed ones at moderate elevations, and in the comparatively flat Pre-Alpine foothills. "We now know that the alpine regions are warming at roughly twice the speed of other parts of the Earth in response to climate change," says Dannenmann. "In the future, we expect to see Bavaria's climate grow substantially warmer. Our goal is to find out what it will do to the soils, and what the consequences will be for the ground and for agriculture."

With regard to the meadows, what we're seeing is as follows: when it grows warmer, the treeline retreats uphill. If they're not used as pastureland, the meadows cleared from the forests centuries ago gradually fill with bushes and trees – an unfortunate development, since forests are home to far fewer plant species than meadows. To make matters worse, there are also manmade problems. Meadows that haven't been used as pasture for several years are home to long and thin grasses that barely decompose at all; instead they form dense mats of straw that prevent rainwater from soaking into the soil. In the event of heavy rains, which are likely to become more frequent as a result of climate change, the water rushes directly into the valley, increasing the risk of floods. Elsewhere, melting snows sweep these grass mats with them as they slide downhill, promoting soil erosion.

Heat destroys humus

For the meadows at lower elevations, the researchers expect to see a very different development: the warming climate isn't likely to be good for the soils there, either, Dannenmann explains, because the amount of humus in the increasingly warm and dry soils is likely to dwindle. Especially cool and moist soils contain a wealth of humus. These moist soils are poorly ventilated and oxygen-poor. In this cool, low-oxygen setting, microorganisms hardly have a chance to break down dead crop matter, since they need oxygen to do so, and the low temperatures further hamper their activity. As a result, the plant remains, which contains valuable plant nutrients, slowly but surely accumulate. Further, since the plant remains are only broken down very slowly, the humus-rich soils only release their nutrients at a snail's pace – which is precisely the speed that young plants need. Many of Bavaria's meadowland soils were fertilised with manure for centuries. This manure only partly decomposed, accumulated in the moist soils, and promoted the formation of humus.

"The fact that we often find soils in Bavaria that are so rich in plant nutrients is thanks to the centuries-long fertilisation methods," says Dannenmann. "Essentially this created the ideal reserve of nutrients for grasses, and it was preserved in the moist and cold soil." But climate change could mean the end of this reserve, since in warmer soils, those microorganisms that break down humus could become more active. If that happens, vital nutrients for dairy and meat production from meadowland agriculture will be lost.

LOOKING AHEAD

Ten years from now we hope to see our latest findings on how meadowland soils are responding to climate change translated into practice, in the form of climate-adapted agricultural methods. To help make that happen, we plan e.g. to develop decision-making support apps for farmers that they can access on their smartphone.

MICHAEL DANNENMANN
Environmental Researcher, Karlsruhe Institute of Technology (KIT)

At the TERENO observatory in Fendt, robots assess soil columns from different elevations to determine which greenhouse gases their microorganisms are releasing.

The more earthworms living in the soil, the better its quality is. Accordingly, in their studies on changes in the Pre-Alpine grasslands, the environmental researchers also record the number and biodiversity of these valuable organisms.

Granted, many farmers in Bavaria fertilise their meadows with liquid manure. "But our research indicates that more nutrients will be lost due to climate change than can be replaced with manure," says Dannenmann. "And that's not the only problem – less humus also means more emissions of greenhouse gases from the soils, and reduces the soil's capacity to filter out toxins; this increases the risk of water pollution, for instance from nitrate." Further, he explains, soils with less humus absorb less water, which can compromise their function with regard to preventing flooding and erosion. As such, climate change is jeopardising the most important soil functions in the pastures and meadows of the Pre-Alpine foothills.

A new home for mountain soils

Dannenmann is only able to forecast the future of soils so accurately because of a tremendous joint effort: together with several colleagues, he essentially transplanted soils, digging them up at higher elevations and transporting them to lower ones. By doing so, he's getting a step ahead of climate change: it's colder at higher elevations, so when he transplants a section of soil a few hundred metres downhill, it simulates the effects of a warmer and drier climate. The effort involved was immense, especially in terms of collecting the soil samples: to do so, the researchers had to drive more than 800 ca. 30-centimetre-long plastic pipes roughly half a metre into the ground, using them like cookie cutters to remove tubular sections of the soil. Then they dug up all of the pipes, so that they could transport them and their valuable contents to the warmer soils downhill. "As a result, we can measure how the soil develops quite accurately," says Dannenmann. "On the one hand, how it reacts to the warmer climate farther downhill, and on the other, which type, quantity and form of fertiliser is best suited to preserving the humus, and with it, important soil functions, despite climate change." Some of the transplanted pipes are equipped with small tubes at four different depths. These tubes suck up the water that trickles into the soil. Consequently, the researchers can analyse how much water penetrates the soil, and how the nutrient concentration changes. Experts refer to these measuring systems as lysimeters.

The liquid manure that the experts use to fertilise the soil in the lysimeters is enriched with stable nitrogen isotopes, which allow them to precisely trace how much of the manure is taken up by plants, and what happens to the remainder in the soil column.

A wealth of water samples

In addition, Michael Dannenmann and his colleagues had access to several dozen large-scale lysimeters that were set up across Bavaria and other parts of Germany prior to the start of SUSALPS, as part of the major Helmholtz project TERENO. Each of the large devices weighs over three tonnes and is bristling with measuring equipment. All told, the more than 800 small and large lysimeters deliver a wealth of data, which first has to be analysed.

The results of these analyses are a virtual treasure trove, and not just for Michael Dannenmann and many other REKLIM experts; the Bavarian State Research Center for Agriculture (LfL) uses them, too. "For the past 30 years we've maintained permanent soil monitoring areas in Bavaria, which we check for important changes, especially regarding humus, every five years," says Martin Wiesmeier from the LfL's Institute for Organic Farming, Soil and Resource Management. "The work done in SUSALPS is an excellent complement to these areas, since the effects of climate change can be studied much better in the transplanted soil samples than under normal conditions. Otherwise, identifying changes in humus content can only be done with a great deal of effort, and over extremely long timescales."

Back to the dung heap?

For Wiesmeier, two key questions are what the combined effects of climate change and agriculture have on the soil, and what recommendations can be provided to farmers on using the land in a climate-adapted manner. "We know from our own monitoring areas that, despite the effects of climate change and agriculture, not all soils are losing their humus. But in soils that are affected, it may prove necessary to counteract it with targeted fertilisation." According to Wiesmeier, one thing is certain: mineral-based artificial fertilisers are largely ineffective: they can be easily washed out of the soil, or can vaporise, leaving behind ammonia and the potent greenhouse gas nitrous oxide. In turn, liquid manure releases nutrients more gradually, but doesn't offer a long-term source of nutrients. His verdict: "It's quite possible that, in some regions, the best response to climate change is to return to stall manure, so as to stop the deterioration of the soil." For many regions, this would mean "going back to their roots", in similar vein to how Weiß has brought meadowland agriculture – a centuries-old tradition - back to the Brunnenkopfalm.

IN BRIEF

- **As climate change progresses, Bavaria will grow warmer. In turn, the soils of pastures and meadows could lose valuable humus. Accordingly, fertilising and pasturing practices will need to be adapted.**
- **To predict the effects of climate change on soils, samples from cooler, higher elevations are now being transplanted to warmer, lower regions, and the resulting changes are being closely monitored.**
- **The warming will also cause the treeline to retreat uphill, and species-diverse meadows could revert to woodlands as a result. Consequently, researchers are also exploring how meadow pasturing could be used to help preserve the current landscape.**