



Agriculture instead of forests. The natural vegetation in many parts of the world has been replaced by cropland and pastures. This has consequences for the climate.

Agriculture Is Plowing Up the Climate

Since the earliest beginnings of agriculture and livestock farming, mankind has been transforming areas of natural vegetation into cropland and pastures. However, the vegetation covering the continents influences our climate in a variety of ways. Humans thus may well have been responsible for changes in the climate long before they started to burn oil and coal on a massive scale. Scientists at the **Max Planck Institute for Meteorology** in Hamburg have studied the spread of agriculture over the past millennium. Their research shows that mankind had a significant impact on climate, especially on the local level, even before the advent of industrialization.

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The study of church registers is an activity that is generally associated with theologians and genealogists rather than with natural scientists.

Indeed, most people would find it very hard to imagine that such registers also contain important information for climate researchers. But these records, which go back many centuries, contain important information about population development and thus also about how much land area was used for agriculture. However, transforming natural vegetation into agricultural lands has consequences for the climate. We climate researchers are thus very fortunate that demographers have already done the work in recent decades and derived data on global population development from historical documents. Based on

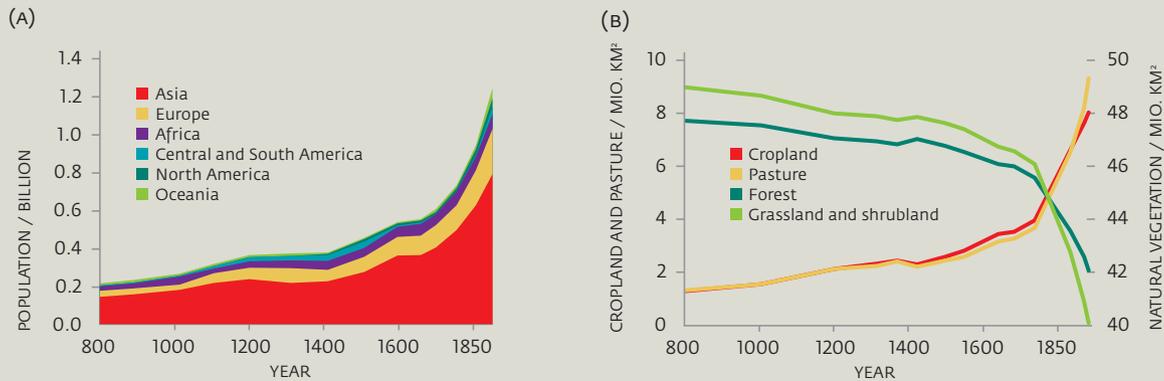
this data, we can deduce information about the human influence on climate many centuries into the past.

The pre-industrial era is particularly suitable for analyzing the consequences of land use on climate. Prior to 1850, the global expansion of agriculture was the only “manmade” disturbance to the global climate system. Since the expansion of agriculture often required the clearing of forests, the carbon stored in the wood eventually ended up in the atmosphere as part of carbon dioxide, a greenhouse gas. It was not until the mid-20th century that the amount of carbon dioxide that humans released into the atmosphere by burning fossil fuels significantly exceeded that caused by agricultural expansion. Since then, the global climate change that is now being

observed has been caused largely by emissions arising from the combustion of coal, oil, and gas.

CONTINENTS ACT AS CARBON RESERVOIRS

So the destruction of vegetation leads to the emission of carbon dioxide. At the same time, the Earth’s flora renders part of the carbon dioxide released into the atmosphere harmless again. Plants absorb carbon dioxide from the atmosphere through photosynthesis and bind the carbon it contains in organic compounds, releasing oxygen in the process. In the 1990s, for example, each year, the continents reabsorbed around one gigaton (one billion tons) of the approximately 6.4 gigatons of carbon that were released annually through



(A) There was continuous population growth between 800 and 1850 AD, particularly in Europe and Asia. (B) Change in area of different natural and agricultural types of vegetation throughout the world between 800 and 1850. Parallel to the growth in population, extensive areas of natural vegetation were already transformed into agricultural areas in pre-industrial times.

the combustion of coal, oil, and gas. The continents thus actually store 15 percent of fossil emissions each year. This phenomenon is referred to as the land carbon sink. In this way, the vegetation on the continents can counteract the increase in the global temperature, as global warming is directly linked to the increase in the concentration of carbon dioxide in the atmosphere: carbon dioxide reduces the permeability of the atmosphere to the thermal back-radiation of the Earth, and the lower atmospheric layers warm up as a result. Therefore, by absorbing carbon, the land carbon sink mitigates the increase in temperature that might otherwise be expected as a result of the combustion of fossil fuels and the expansion of agricultural areas.

However, vegetation is also relevant for climate in another respect. The different types of vegetation influence the exchange of energy, water and momentum between the atmosphere and the Earth's surface. This affects particularly the regional climate. For example, grassland typically looks brighter than forest from a bird's-eye view – scientists refer to this as a higher albedo. Grassland thus reflects sunlight better and warms up less. At the same time, forests evaporate more water through their leaves and needles, as they often have deep roots and can therefore cool themselves better than shallow-rooting grasslands. Which of these effects pre-

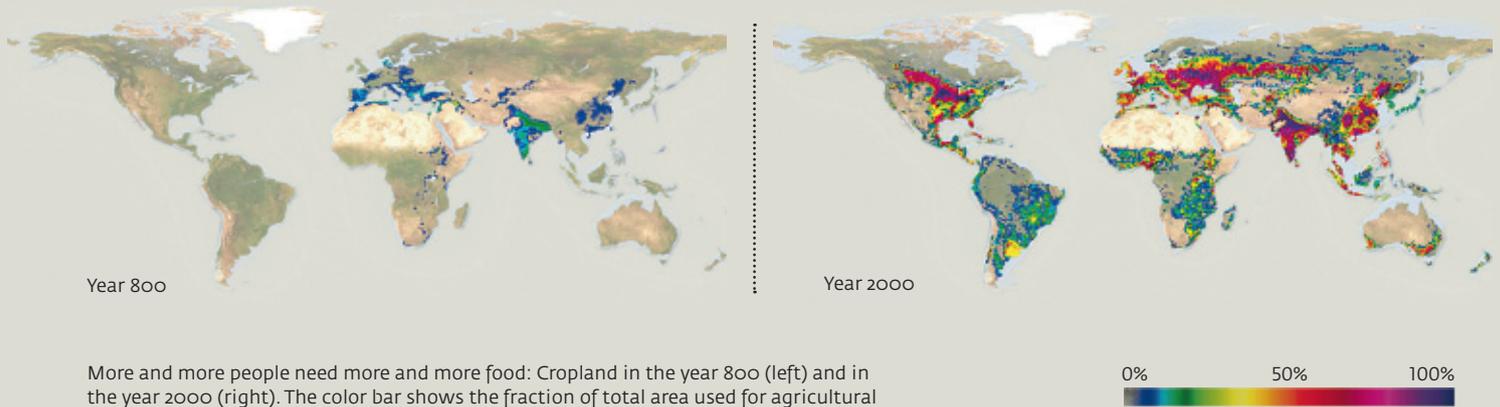
dominates – warming through solar radiation or self-cooling through evaporation – depends, among other things, on the position of the Sun, the availability of water in the soil, the level of atmospheric humidity and the type of vegetation involved. The vegetation cover thus shapes local climate in combination with the prevailing mean solar radiation, wind direction and precipitation. This is why we at the Max Planck Institute for Meteorology examine how strongly changes in vegetation influence the absorption of solar radia-

tion and their consequences for the carbon-dioxide exchange between the land masses and the atmosphere.

Climate has changed naturally since the end of the last ice age 10,000 years ago. As a result, new plant communities have formed and spread. But on top of these natural changes, human activities, such as agriculture, forestry and urbanization, have had a substantial influence on the interaction of the atmosphere and the vegetation on the continents. Calculations have shown that, today, around 24 percent



Graphics: MPI for Meteorology (z. top), photo: akg-images (bottom)



More and more people need more and more food: Cropland in the year 800 (left) and in the year 2000 (right). The color bar shows the fraction of total area used for agricultural purposes (gray: 0%, violet: 100%).

Graphics: German Climate Computing Centre (DKRZ) - MPI for Meteorology (z. above)
Photo: Fotolia (below)

of global plant growth is controlled by humans. In the millennia between 9,000 and 5,000 years before the present day, agriculture and livestock farming developed independently of each other in at least four regions: the so-called Fertile Crescent of Asia Minor, parts of China, and Central and South America. From there, the cultures that practiced agriculture spread and gradually replaced the historically older hunting and gathering societies. Unfortunately, there are very few detailed records available on how much land in a region was used for agriculture at a

particular point in time. This lack of data has hindered the study of changes in global vegetation distribution and their role in climate events to date.

A GLOBAL AGRICULTURE MAP

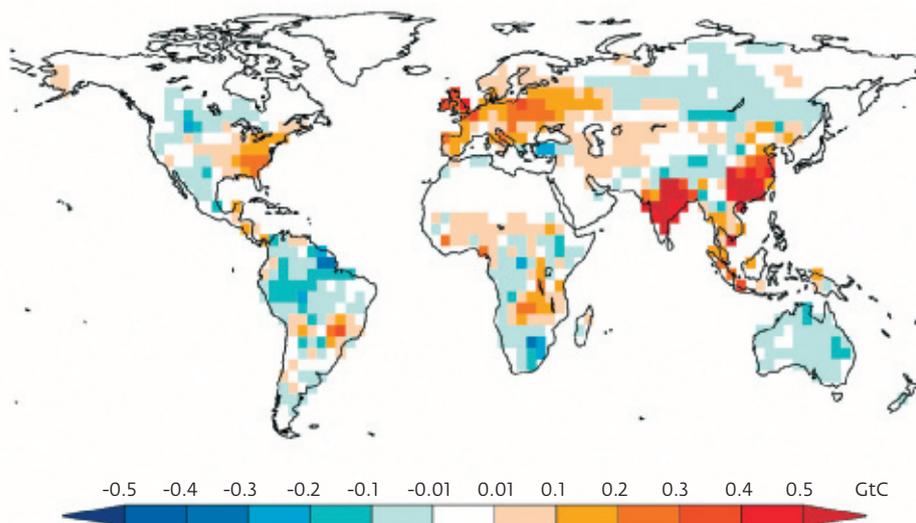
For this reason, we had to use other information sources for our study, namely the data on population development mentioned at the outset. Population size and agricultural area are closely linked. Before the industrial revolution, long-distance trade was limited to valuable goods such as spices; basic food-

stuffs could hardly be transported in sufficient quantities across long distances. The area of agricultural land required in the period between the Middle Ages and the Industrial Revolution can thus be inferred from the regional population figures. We used this correlation and generated a data set that traces the distribution of cropland and pastures throughout the world starting in the year 800. Uncertainties relating to the population data and the influence of changing agricultural methods are taken into account in the calculations. In addition, we reconstructed the changes in the distribution of forests and natural grass- and shrubland caused by the agricultural expansion. It emerges from this that natural vegetation had already decreased significantly in the pre-industrial era, making way for arable and livestock farming.

The last millennium is particularly interesting in this regard: between the year 800 and the early 18th century, the global population tripled, reaching one billion people. This increase must have

A burden from the pre-industrial era: People have used the plow to work their environment for many centuries. As a result, they influenced the heat exchange between the land and the atmosphere long before the large-scale combustion of oil and gas.





Between 800 and 1850, the agriculturally important regions lost carbon to the atmosphere (beige to dark red) while many natural regions tended to absorb carbon as a consequence of the agricultural losses (light blue to dark blue). Scale in billion tons of carbon (GtC) per grid cell of the climate model.

been accompanied by agricultural expansion on an unprecedented scale. If we do not find that anthropogenic climate change took place during this period, we must not expect it during the preceding millennia, either. In this case, and as is usually assumed, the anthropogenic influence on the climate would have begun only with the large-scale burning of oil and coal during the industrial revolution.

Our study, however, reaches a different conclusion. Today, climate models enable us to simulate the interaction between vegetation, the atmosphere and the oceans over extended periods on mainframe computers. Based on the reconstruction of land use in the last millennium and an Earth system model developed at our institute, we can estimate the impact of agriculture on the carbon cycle and the climate. Our results show that, in the centers of historical agriculture in Europe, India, and China, agriculture spread extensively between 800 and 1850 at the cost of forest area, and led to the loss of 53 gigatons of carbon worldwide. At the same time, 25 gigatons of carbon were sequestered in the land carbon sink.

Thus, almost half of the emissions were taken back up by the vegetation, especially in regions that were left to nature's devices, like tropical rain forests. This happens because plants grow faster under higher atmospheric carbon dioxide concentration. As a result, they can bind more of the greenhouse gas and compensate, at least in part, for the increase of the gas in the atmosphere. Scientists refer to this process as the "carbon dioxide fertilization" of plants.

LOCAL CLIMATE CHANGE EVEN WITHOUT INDUSTRIAL ACTIVITY

These figures prove that a net volume of around 28 gigatons of carbon was released into the atmosphere as a result of agricultural development in the pre-industrial period of the last millennium. These emissions remained very small for hundreds of years, and it was only during the period between the 16th and 18th centuries that they affected the concentration of atmospheric carbon dioxide beyond a level that could be explained by natural climate variations alone. As a result, it would appear that humans did not increase

the carbon dioxide concentration in the atmosphere until a relatively late point in time – albeit still prior to the advent of industrialization. However, this increase in carbon dioxide was too small to perceptibly alter the temperature at the global level.

At the regional level, in contrast, humans already influenced the climate prior to industrialization. Simulations show that, due to the changes in the albedo of the land surface through land use, mankind altered the energy balance in some regions as early as a thousand years ago. In Europe, India and China, in particular, the amount of absorbed solar radiation decreased by around two watts per square meter. A change of this magnitude at the regional level is just as large as the current global greenhouse effect; however, it has the opposite impact, as it causes cooling rather than warming.

Even historical events can leave their traces on the climate through such biogeophysical effects. For example, there was a clear reversal of the increasing human influence on Europe's energy balance in the 14th century. This change was brought about by the bu-



Bright grasslands reflect more solar energy than comparatively darker cultivated fields and forests. In this way, the type of vegetation influences the local climate.



Forest does not always equal forest. The reforestation of logged forest areas in the tropics and temperate zones has differing effects on the climate.

bonic plague, which claimed the lives of around one third of the population and in the wake of which large expanses of agricultural land were temporarily abandoned. The Mongol invasion of China in the 13th century and the diseases spread among the high cultures of the Americas by the invasion of the Europeans had similar consequences.

CLIMATE PROTECTION THROUGH FORESTATION?

We conclude that humans caused changes in the regional energy balance already in pre-industrial times and increased the carbon dioxide content of the atmosphere. They disrupted the carbon cycle and reduced the forest carbon sink through deforestation. All this created a legacy of the past by the time humans entered the industrial era, so the land use of the past continues to affect current and future climate conditions.

While the influence of land use on the climate was only an unintentional side-effect up to now, it is planned to make targeted use of this effect in the future to counteract climate change. As a result, various demands are made for the reforestation of agricultural areas to withdraw carbon dioxide from the atmosphere and mitigate current climate change. However, reforestation does not always have the effect of mitigating climate change – it can also accelerate global warming. Studies show that, in mid- and high latitudes, the reduction in albedo due to reforestation causes so much extra solar radiation to be absorbed that the cooling effect from the uptake of carbon dioxide has no impact. In the tropics, in contrast, the high level of evaporation in the forests plays a greater role and, combined with the uptake of carbon dioxide, has a net cooling effect. Preventing deforestation of the tropical rain forest, which is being

deforested to gain agricultural land, could thus be more effective than the reforestation in moderate zones. Therefore, also in the future, the development of the climate will depend on agricultural decisions. ◀

GLOSSARY

Albedo

Albedo is a measure of how strongly continents, oceans and clouds reflect sunlight. Lighter areas have a higher albedo than darker ones.

Carbon sink

The land masses and oceans can remove carbon from the atmosphere and bind it for long periods. On land, this process involves primarily vegetation, which absorbs carbon dioxide and forms organic compounds from it. However, carbon dioxide is also bound during geological processes, such as the formation of limestone.