Preparing Agriculture for a Changing World

PERRY RECH (K3829-14)

Range scientist Herman Mayeux checks a light-sensing bar that indicates solar radiation levels within plastic growth tunnels. Carbon dioxide concentrations inside the tunnels range from today's 350 parts per million to the 200 ppm present during the last ice age.

With every exhalation, we release carbon dioxide (CO_2) into the atmosphere. In the wondrous biological process of photosynthesis, plants use the sun's energy to convert this gas to the food we eat and the oxygen we breathe.

Yet this crucial gas may have a dark side. CO_2 and some other gases may be changing our climate.

Atmospheric CO_2 concentrations have risen from 280 to more than 350 parts per million during the last 200 years. At current CO_2 emission rates, that concentration will double again over the next century.

"The so-called greenhouse effect is a natural process that helps keep the planet surface at a comfortable temperature," says Herman S. Mayeux. "The concern is that concentrations of greenhouse gases are increasing in the atmosphere. As a result, the surface temperature of the planet may be rising." Mayeux is the ARS national program leader for rangelands and global change at Beltsville, Maryland.

Potential temperature increases and the changes in precipitation patterns that could occur because of the rise of greenhouse gas concentrations are known collectively as global climate change.

Scientists can measure an increase in atmospheric gas concentrations, but determining the effect of that rise is difficult because of natural variability in temperature and precipitation. Computer models that simulate atmospheric behavior indicate that global temperatures generally increase as greenhouse gas concentrations rise.

"Because climate and CO_2 play such important roles in agriculture, any long-term changes are of great concern," Mayeux says.

For that reason, ARS scientists nationwide are evaluating U.S. agriculture's contribution to the increase in greenhouse gases, the potential impact of climate change on how we produce food, and the industry's unique opportunities to help mitigate atmospheric change.

The following pages present a glimpse into the variety of state-of-the-art experiments under way in ARS. The projects range from basic studies that provide a foundation for our understanding of how plants interact with the atmosphere to applied research on the impact of specific farming techniques.

All of the work shares the goal of reducing uncertainty about how global climate change will affect agriculture and future food security. Information on how to contact each of the ARS scientists mentioned in these stories begins on page 16.

Agriculture's Contribution to Global Change

Scientists use the term "climate forcing" to compare the contribution of different activities to climate change. Climate forcing is a measure combining estimates of greenhouse gas emissions with the absorption of long-wave radiation from the Earth and the estimated lifetime of each gas in the atmosphere.

U.S. agriculture is responsible for less than 1 percent of this forcing, according to the Council for Agricultural Science and Technology, a nonprofit agricultural sciences organization based in Ames, Iowa. Agriculture and industry contribute in various ways to atmospheric concentrations of three greenhouse gases.

- Carbon dioxide—Microbes

The Greenhouse Effect

Solar radiation passes though the atmosphere and warms the Earth's surface. Some is reflected back into the atmosphere and dissipates into space. The greenhouse effect refers to an accumulation of specific gases that absorb the reflected radiation, effectively trapping heat in the lower atmosphere. The most important of these gases are water vapor and CO_2. Smaller amounts of methane, nitrous oxide, chlorofluorocarbons, and ozone also contribute, intensifying the greenhouse effect. But global warming doesn't mean every place on Earth will be warmer. Rather, it indicates a general rise in the planet's average surface temperature. More important than either the rise in gases or temperature would be the potential impacts of these increases—changes in the amount and pattern of rain and snowfall, length of growing seasons, sea level, and storm patterns.

The chart below shows how concentrations of three greenhouse gases changed between 1800 and 1990.

GREENHOUSE GAS EMISSION RATES

Gas	Atmospheric concentration		Current rate of change per year
	circa 1800	1990	
Carbon dioxide	280 ppmv*	353 ppmv	1.8 ppmv (0.5%)
Methane	0.8 ppmv	1.72 ppmv	0.01 ppmv (0.6%)
Nitrous oxide	288 ppbv**	310 ppbv	0.8 ppbv (0.25%)

* ppmv - parts per million, by volume
** ppbv - parts per billion, by volume
Source: United Nations International Panel on Climate Change 1992

produce CO_2 in soil as they free up carbon molecules while feeding on organic matter. Tillage not only frees CO_2 in bursts of gas, but also lets in oxygen that speeds up microbial action. Crops and other plants reduce atmospheric CO_2 levels as they take it from the air during photosynthesis. Burning forests and grasslands are other sources. But burning fossil fuels like oil, coal, and gas accounts for most of the world's CO_2 emissions.

• Methane—This gas is released from many sources, including gas drilling areas, coal mines, landfills, natural water bodies like oceans and lakes, holding ponds for animal waste, and rice paddies. Methane is also produced by the digestive processes of ruminant animals and termites. Some bacteria in soils produce methane, while others transform it to other compounds, effectively removing it from the atmosphere.

• Nitrous oxide—The synthetic form of N_2O is the "laughing gas" used by dentists as an anesthetic. Agricultural and natural processes within soils, burning of vegetation and fossil fuels, and the oceans all appear to release N_2O. On farmland, microbes emit it as they feed on nitrogen fertilizers and manure. Fertilization with nitrogen increases emissions of N_2O from cropland and pasture soils.

Climate Change and Basic Processes

Understanding climate change on a global scale means getting up close and personal with a single plant—or even with a single cell in a plant.

"Nature has a way of rewarding those who take the time to look closely at basic processes," says Steven J. Britz, an ARS plant physiologist at Beltsville.

Agency scientists around the country are examining how elevated atmospheric CO_2 and other greenhouse gases affect three essential biological processes: respiration, or the exchange of oxygen for CO_2; the use of light in photosynthesis to remove CO_2 from the air for plant growth and reproduction; and water use.

JACK DYKINGA (K5650-14)

Photosynthesis taking place in wheat plants can be measured in field chambers like this one being adjusted by plant physiologist Richard Garcia.

Research to date both confirms some long-held beliefs about plant response to elevated CO_2 and adds to what we already know.

For example, elevated levels affect a plant's respiration. James A. Bunce, an ARS plant physiologist at Beltsville, grew soybean plants in CO_2 chambers at nearly double the current atmospheric level. Surprisingly, while higher levels of CO_2 increased plant growth, they lowered plant respiration. "We expected the plants to have a higher rate of respiration," says Bunce. "It's still a mystery how the rate of respiration can be reduced without a negative impact on the plant."

Other studies show that changes in the atmosphere affect how plants use water. Like scientists at other ARS laboratories, Bunce and colleagues found that plant water use changes dramatically when the plants grow in higher atmospheric CO_2.

By studying the plant stomata—the pores on the leaf surface that regulate water loss from the leaf—

To determine how elevated CO_2 may reduce water use by crops, plant physiologist James Bunce measures water vapor conductance of barley leaves grown at twice the current atmospheric CO_2 concentration.

SCOTT BAUER (K7662-1)

they found that at higher CO_2 levels, plants use less water to produce the same amount of growth. This response is commonly seen in the growth chamber and greenhouse, but the overall reduction in water use for crops grown in the field seems to be less than 5 percent, for reasons that are not yet understood.

ARS soil scientist Bruce A. Kimball and colleagues at Phoenix, Arizona, confirmed that plant photosynthesis is immediately stimulated when you double the atmospheric CO_2. He also showed it doesn't necessarily slow down over time in crops such as wheat and cotton or fruit trees like oranges. In experiments with sour orange trees, *Citrus aurantium*, physicist Sherwood B. Idso observed sustained explosive growth over a 9-year period when the trees grew outdoors under experimentally elevated CO_2.

Scientists speculate that this level of response to increased CO_2 concentrations will lead to an overall net increase in productivity in many ecosystems.

Other greenhouse gases can add to this effect. For example, ARS plant physiologist Joseph E. Miller and coworkers at Raleigh, North Carolina, found that the atmospheric concentration of ozone near ground level affected the degree to which elevated atmospheric CO_2 stimulated photosynthesis in soybean leaves. Under today's CO_2 concentrations, ozone can suppress photosynthesis, but Miller's experiments showed that photosynthesis and yield were increased more by elevated CO_2 if plants were stressed by ozone.

"This is one example of the complexities involved in understanding how plants will respond to global environmental change," Miller says. "Clearly, we have a lot to learn about how the different contributors to climate change interact—and how those interactions will affect plant function."

JACK DYKINGA (K3750-12)

Technician Stephanie Johnson measures the rate of photosynthesis in leaves of an orange tree growing in a CO_2-enriched atmosphere.

The FACE Project

The Free Air CO_2 Enrichment project (FACE) in Arizona is helping scientists from around the world to understand how plants respond to actual field conditions representing those anticipated in the next 50 to 75 years. Large amounts of CO_2 are vented through upright pipes that maintain a constant CO_2 concentration of 550 parts per million in the atmosphere around the plants.

"Our FACE project, begun in 1989, is the longest running of five now providing researchers with information needed to assess impacts of global change," says Kimball. "We have studied cotton and wheat, while the other experiments concentrate on forage grasses, loblolly pine, chaparral, and desert plants." In general, Kimball's work has shown that crop yields increase as CO_2 rises.

[For more details on FACE, see "FACE-ing the Future," *Agricultural Research*, April 1995, pp. 4-7.]

Tillage Releases Carbon Dioxide

Decades of tillage have caused soils on American cropland to lose up to half their virgin organic matter. Much of it may literally be going up in a puff of gas—as CO_2.

"Carbon is the backbone of the organic matter that made our native prairie soils so black and fertile," says Donald C. Reicosky, an ARS soil scientist in Morris, Minnesota. "Soil carbon levels have been declining ever since the first plows tore up prairie land."

The worst of the short-term losses occurs within minutes after the moldboard plow fractures the soil, forcefully releasing CO_2 stored in soil pores and water. "It's just like opening a bottle of champagne. The gas in the air space above the liquid is released, and CO_2 bubbles out of solution to establish a new equilibrium in the air," he says.

"The CO_2 is a byproduct of microbial feeding on, and the biological oxidation of, soil organic matter," says Reicosky, who has measured CO_2 losses from soils in Alabama, Texas, and Minnesota. He gauges the amounts with a clear, plastic chamber equipped with an infrared CO_2 analyzer and carried by a tractor.

Studies by Reicosky and colleagues show that the soil releases as much as 260 pounds of CO_2 per acre per hour immediately after tillage. Over time, even more is lost because of the extra oxygen let in by tillage and the extra organic matter from crop residues plowed under. "That speeds up decomposition," notes Reicosky. "You're able to feed more soil microorganisms faster, and there goes your organic matter."

KEN HAMMOND (K5887-9)

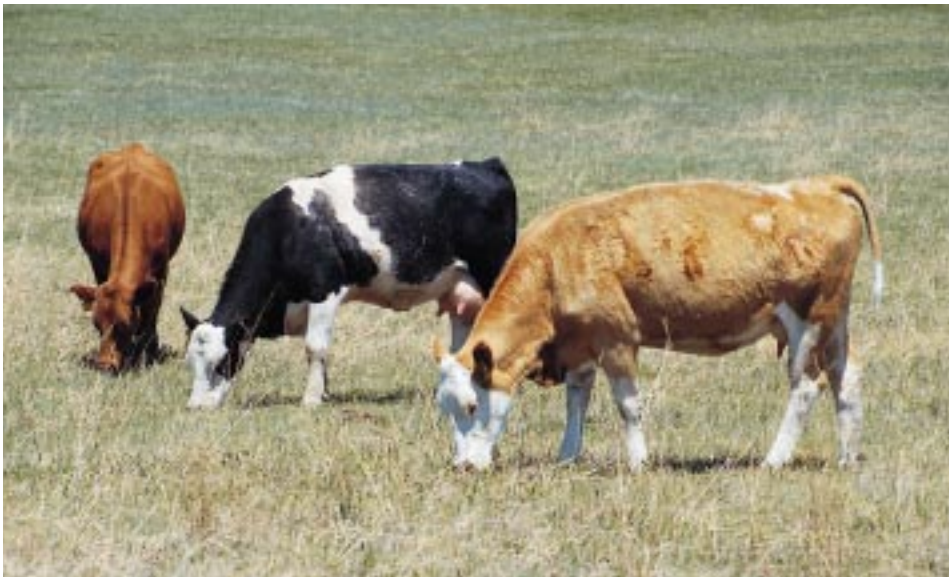
Inside the "sniffing corral" at Watkinsville, Georgia, soil chemist Ronald Sharpe (left) and soil scientist Lowry Harper check out equipment designed to measure methane concentration in air. Below: Each cow on pasture can emit about 350 liters (230 grams) of methane per day.

Not coincidentally, as the amount of soil carbon has declined, atmospheric CO_2 has gone up. The intensive tillage seen in America's post-World War II farming boom increased the rate at which soil carbon was converted into CO_2, just as the Industrial Age's coal-burning smokestacks were turning coal carbon into CO_2 at a furious pace.

But if tillage is the cause, it's also the cure, Reicosky says. Crop residue management and conservation tillage reduced carbon losses by up to four-fifths in Reicosky's studies. These practices disturb the soil less and conserve organic matter by leaving dead roots undisturbed and crop residue on the surface after harvest.

"The trick is to use crop residue

SCOTT BAUER (K7686-7)



management and other soil management techniques to keep carbon where it belongs," he says. "Let the soil serve as a storage reservoir, or sink, for excess carbon created from human activity, ameliorating the potential environmental harm of rising levels of atmospheric carbon dioxide."

There are estimates that widespread adoption of improved crop residue management could return soil carbon levels to near those of our native prairies, storing or sequestering a portion of the carbon released through worldwide fossil fuel emissions, Reicosky says.

Of course, returning highly erodible cropland to perennial grasses would be even better, says program leader Mayeux.

"To date, that has been done on 36 million acres (15 million hectares) of land taken out of production and covered with grass or trees under the federal Conservation Reserve Program," he says.

"Each year, these CRP soils may be storing almost a third of the 38 million metric tons of carbon released annually into the atmosphere by all sources related to U.S. agriculture. Most of these lands are dryland farms in the Great Plains."

Animal Waste Gives Off Gases

Like Reicosky, Lowry A. Harper, an ARS agricultural microclimatologist in Watkinsville, Georgia, also measures CO_2—not from soil but from animal waste treatment ponds called lagoons.

He has devised a system for measuring CO_2 and other greenhouse gases with an array of outdoor "sniff," or sampling, tubes connected to a laser spectrometer or an infrared gas analyzer.

For the lagoons, Harper mounts the sniff tubes on a floating barge to detect CO_2, methane, nitrous oxide, and ammonia emissions. Harper's research will not only help computer modelers better evaluate the greenhouse gases emitted from animal waste lagoons, but also establish whether there's enough methane emitted to make it worthwhile for a farmer to use it as fuel for an electrical generator.

Harper uses a land-based version of the sniff tubes for measuring methane emissions from cattle breath. He uses similar techniques to detect nitrous oxide on land and has measured significant emissions where animal wastes have been spread.

Eventually, he and others plan to adapt the equipment to measure gas emissions from soil, landfills, rice paddies, animal manure, and termite mounds.

From his tests so far with cattle in Australia, Georgia, and Texas—the first such outdoor tests in the world—Harper has found that a cow grazing on pasture can emit more than 8 ounces (230 grams) of methane per day. "That is somewhat more than estimates from indoor tests of confined animals," he says. The studies also pointed to a solution: Higher quality diets reduced methane emissions. Cows fed grain rather than pasture grass emitted only 2.4 ounces (70 grams) per day, about half as much as previous tests indicated.

Modeling the Future

Many people use a computer in day-to-day activities, be it to get cash from an automated teller machine or to compose a letter. But scientists and engineers first used—and continue to use—the power of computers to analyze complex problems like potential climate change.

Computer models help researchers get a handle on how environmental changes might affect plants, animals, water supplies, and even human comfort. In the agricultural arena, these models often go by a strange-appearing combinations of letters. Some of these are EPIC, RZWQM, CREAMS, SRM, WEPP, SHAW, NLEAP, and SPUR2. [More on RZWQM on page 18.]

"Historically, ARS has solved agricultural problems on field, regional, and sometimes even a national scale—but not on a global level, " says ARS soil scientist Ronald F. Follett. "But because we have decades of research on soil, water, crops, natural resources, and other issues that are important to global change, scientists who run global models are looking to ARS for information."

Based in Fort Collins, Colorado, Follett heads up research that focuses on the cycling of carbon and key greenhouse gases between the atmosphere and land.

From the beginning of ARS' involvement in the U.S. Global Change Research Program (see Forum, p. 2), scientists recognized the need to develop models of plant and soil processes and to scale them up to make regional predictions. The agency's scientists were well qualified to do this, having developed models that worked at the field level for many years.

"ARS researchers nationwide continue to develop the needed models," says Basil Acock, an ARS plant physiologist at Beltsville. "Many are modular so that each component can be plugged in or taken out without affecting the overall function of the larger model. This standardization allows researchers to borrow various components developed by others, and it avoids duplication of effort," he says.

The models will improve estimates of plant growth and yield, greenhouse gas emissions and sinks, and water and energy flows on cropped lands, forests, and rangelands. Others will simulate changes expected because of pests, diseases, and salinity.

The scientists run "what would happen if..." scenarios over 10- to 100-year periods. That should provide clues on how to mitigate global climate change.

"Whatever model we use to predict change, it must be responsive to all environmental factors—temperature, nutrients, water, and more importantly, land management," says Jon D. Hanson, an ARS rangeland scientist at Fort Collins, Colorado. He developed SPUR2 (Simulation of Production and Utilization of Rangelands), one of the agency's most complete models for predicting how climate change would affect U.S. cattle-grazing areas. His research suggests that the country's best grazing lands could gradually shift more to the east and north.

ARS is uniquely equipped to conduct studies in global change because it has acquired long-term hydrology and climate databases, some covering more than 40 years. The hydrology data come from measurements made on large watersheds located near Tucson, Arizona; Tifton, Georgia; Boise, Idaho; Oxford, Mississippi; Coshocton, Ohio; El Reno, Oklahoma; University Park, Pennsylvania; and Temple, Texas. Much of the data is archived at the ARS Water Data Center, part of the Hydrology Laboratory at Beltsville. ARS laboratories in Fort Collins, Coshocton, El Reno, and Temple provide the climate data.

Climate's Impact on Snowpacks

Some of the best water on Earth comes from the melting snowpacks of high-mountain watersheds in the western United States. These rugged basins provide 50 to 80 percent of the West's water for cities, farms, ranches, hydroelectric power plants, and other downstream destinations.

"But even a modest warming or cooling of our climate," says Keith R. Cooley, "could change the timing and amount of snowmelt." He's an ARS hydrologist at Boise, Idaho.

That's why Cooley and colleagues are expanding and fine-tuning computer-based mathematical models that predict how changes in the Earth's climate may quicken—or delay—snowmelt from tomorrow's snowpacks. Equally as important, they are working to improve their estimates of changes in the amount of runoff that snowpacks of the future will provide.

Three such models predicted remarkably similar trends when used to project changes in timing and yield from western snowpacks. The study was the first of its kind to encompass such a diverse assortment of western watersheds, says Albert Rango, an ARS hydrologist at Beltsville.

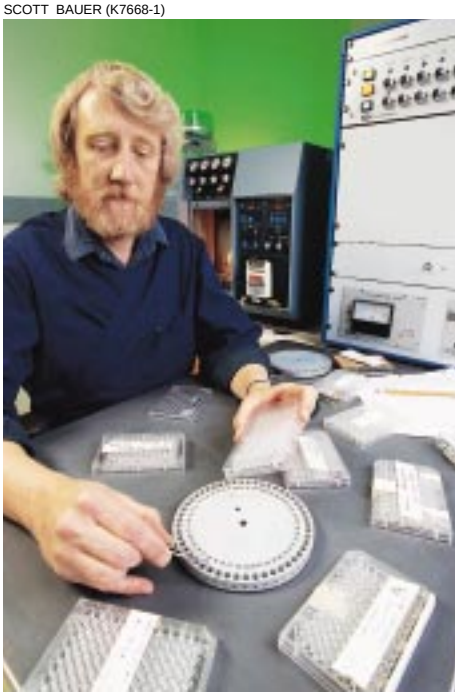
For the experiment, Rango and Cooley selected seven watersheds scattered throughout four western states and Canada. These basins ranged from sagebrush-clad slopes that receive an annual average of about 20 inches of rain or snow to thick forests of spruce and fir that receive about 50 inches. The researchers programmed the models to predict what might happen to snowfields if the Earth's atmosphere were 5°F to 9°F warmer.

Global warming, the researchers report, would cause snowmelt and runoff to start—and to peak—earlier in the year. "The greatest volume of runoff could occur not in May or June, our typical snowmelt months," says Cooley, "but instead in March or April. That means western farmers

SCOTT BAUER (K7668-11)

At Fort Collins, Colorado, technicians Julie Roth and Edward Buenger (photo below) prepare soil samples and conduct several types of analyses that will tell scientists how much carbon plants have pulled from atmospheric CO_2 and stored in soil organic matter.

SCOTT BAUER (K7668-1)



SCOTT BAUER (K5060-12)

Global warming predictions indicate the amount and timing of snowmelt and runoff may change in western basins like ARS' Reynolds Creek Experimental Watershed near Boise, Idaho.

of the next century may have to make new choices when deciding what kinds of crops to plant."

What's more, the snowpack might yield less water. "A warmer climate," explains Cooley, "not only causes the runoff to occur sooner, but may also cause less snow to accumulate at certain elevations.

At the time it was selected for the seven-basin study, the Snowmelt Runoff Model, or SRM, that Rango developed relied primarily on temperature estimates. Today's SRM takes into account two other key factors—radiation and cloud cover. Rango says a cooperative research and development agreement between ARS, the industry-sponsored Electric Power Research Institute, and the U.S. Geological Survey funded part of the work that led to the newer, more savvy model.

The Carbon Disappearance Mystery

More than 7 billion metric tons of carbon enter the atmosphere in the form of CO_2 each year. But when scientists measure the increase in CO_2 concentrations in the air, they can only account for about half of the carbon. Where are the "missing" 3 billion metric tons?

That's about the amount of coal burned for electricity during a 3- to 4-year period in the United States.

"The answer matters because if the CO_2 concentration affects climate, we can't predict what will happen in the future until we understand the global carbon cycle," says Mayeux. "If the Earth's vegetation and soils are absorbing the CO_2 we're releasing, that could forestall the rate of CO_2 buildup in the atmosphere."

Some of the missing carbon might be stored in Nevada's high deserts, Oklahoma's prairies, or in grasslands near you.

"Plants take in CO_2 and convert the carbon to leaves, stems, roots, and fruit," says Mayeux. "Since rangelands cover half the Earth's land area and contain one-third of the plant life, they're a logical place to look for the missing carbon."

ARS scientists at 11 locations across western rangelands are doing just that. They're using sophisticated meteorological instruments called Bowen ratio/energy balance units to understand how CO_2 moves between the air and vegetation on U.S. rangelands. The units run continuously on plots of at least 15 acres each.

Participating ARS locations include Tucson, Arizona; Fort Collins, Colorado; Dubois, Idaho; Miles City, Montana; Las Cruces, New Mexico; Mandan, North Dakota; Woodward, Oklahoma; Burns, Oregon; Temple, Texas; Logan, Utah; and Cheyenne, Wyoming.

Bill Dugas, agricultural meteorologist at the Texas Agricultural Experiment Station in Temple, is compiling the data under a cooperative agreement with ARS. Tagir Gilmonov, a visiting Russian ecologist, is currently working at Logan to help some of the network participants develop predictive models based on the CO_2 fluxes and weather data.

"If rangelands store excess carbon, we will find that the amount of carbon in the plants and soil organic matter increases over time," says Phillip L. Sims, a rangeland scientist at Woodward. So far, ARS researchers have learned that the amount of CO_2 absorbed by the vegetation fluctuates significantly from location to location and even over short periods at each site.

"Within 3 years, we'll know what the fluxes are on undisturbed grasslands," says Sims. Many of the locations are also conducting smaller scale experiments that compare how various management strategies affect the land's ability to store carbon.

ARS researchers in Burns, for example, designed portable, 1-meter-square plastic chambers that allow

them to measure CO_2 exchange around single plants, rather than over large areas of rangeland." This tool lets us conduct small-scale, replicated experiments," says ARS rangeland scientist Raymond F. Angell. He's evaluating the impact of fire on CO_2 absorption by rangelands.

"Prescribed burning is an effective way to increase the grass component of rangelands that have become dominated by shrubs and trees because of long-term fire suppression," Angell says. The controversy arises because burning releases CO_2 into the atmosphere. "But we believe that the increased growth right after the burn may take up more CO_2 than is released," he says.

Angell and colleagues are now measuring baseline conditions on the study sites. Then they'll burn some of the plots and use the chambers to measure changes in CO_2 uptake as the plants grow back.

Other locations are using the same techniques to study the effects of grazing and other land uses.

Change on the Range

Not only may global climate change affect tomorrow's world—it may already be shaping our natural environment.

ARS scientists have discovered that rangeland plants, like crop plants, can grow more and use less water when atmospheric CO_2 concentrations rise.

"Shrubs have invaded and are in some cases replacing native grasslands worldwide," says ARS plant ecologist H. Wayne Polley of Temple, Texas. "Rising CO_2 levels over the past 200 years may be partially responsible," he says.

That's because some plants seem to benefit more than others from the extra CO_2. The shrub mesquite, *Prosopis* sp., is one of the winners.

"Woody plant populations tend to increase as precipitation increases. Improving plants' water use efficiency could be having the same effect as having more rain," Polley says.

In much of Texas, mesquite has replaced the native prairie grasses. Such a shift in the vegetation can have widespread impacts: less forage available for livestock grazing, a shift in wildlife species that inhabit the area, changes in soil nutrient cycling, and increased erosion because shallow-rooted grasses no longer hold soil in place.

Polley and colleagues are now looking at mesquite genetics, to see if some of the plants are better able than others to use the increased CO_2.

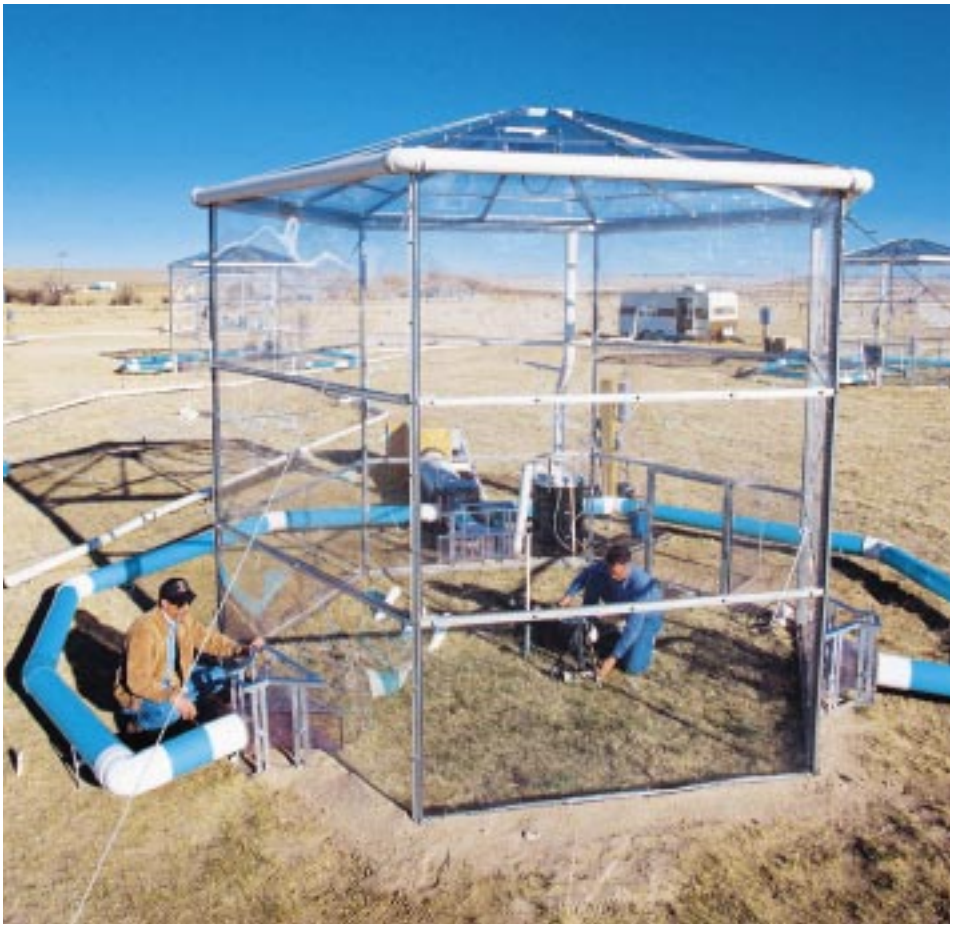
"If we find such genetic variability, then natural selection may be helping mesquite become more abundant," he says.

The grass species may also be changing.

Right now, warm-season grasses like blue grama, *Bouteloua gracilis*, dominate the shortgrass prairie in Colorado. Warm-season grasses are most productive during the summer months, while cool-season grasses like western wheatgrass, *Pascopyrum smithii*, grow in spring and fall.

In growth chamber studies, ARS plant physiologist Jack A. Morgan found that photosynthesis in cool-season grasses increases as atmo-

SCOTT BAUER (K7665-1)



Plant physiologists Jack Morgan (left) and Dan LeCain have designed and installed six open-top chambers at the ARS Central Plains Experimental Range in eastern Colorado. Three of these greenhouse-like chambers are receiving injections of CO_2 to simulate anticipated global concentrations, and three operate under current atmospheric levels.

spheric CO_2 rises.

"From research on other plants, we expected the cool-season grasses to respond more than the warm-season grasses," Morgan says. "Eventually that could give cool-season plants a competitive advantage and shift the ecosystem's species composition."

But he also found that the warm-season grasses respond more than previously believed to additional CO_2. Like mesquite, both types of grasses use less water and grow more.

Two complications in the future scenario are potential temperature increases and reduced forage quality.

"If temperatures go up without a corresponding increase in precipitation," says Morgan, "the soil may dry out enough each growing season that the plants can't take full advantage of the increased CO_2."

Morgan's and Polley's teams also found that while the plants grow larger, the concentration of nitrogen in the plant tissues goes down. That's important because protein, a key nutritional component of forage grasses, depends on the nitrogen. "The end result is more forage, but of reduced quality," says Morgan.

SALSA—the SemiArid Land Surface Atmosphere Program

Arid regions, which get less than 10 inches of precipitation annually, and semiarid regions, which get from 10 to 20 inches, constitute about one-third of the Earth's land area. Any changes the planet experiences in the future could have a profound effect on these regions because there is a close relationship between these ecosystems' health and the weather and water cycle. To help measure and predict such long-term changes, scientists from nine federal agencies, eight universities, six foreign agencies, and one private organization are working together on the SALSA program.

SCOTT BAUER (K7664-1)

Inside an open-top chamber, plant physiologists Jack Morgan (left) and Dan LeCain measure photosynthesis taking place in prairie grasses grown under elevated CO_2.

Their outdoor laboratory is the 2,500-square-mile Upper San Pedro River Basin that spans the border between northern Sonora in Mexico and southeastern Arizona. Scientists hope SALSA will establish this basin as the North American site where remotely sensed data from satellites and aircraft, coupled with computer models that predict changes, will be calibrated and validated.

"The basin is ideal for our research; it contains climatic diversity and five distinct vegetation types over distances as short as 12 miles. The Nature Conservancy has declared the San Pedro riparian corridor one of the 'Twelve Great Places of the Western Hemisphere'," says David C. Goodrich. An ARS hydraulic engineer at Tucson, he heads the overall SALSA program, with ARS as the lead agency.

Intensive hydrologic data have been collected over the past 30 years from part of this basin, ARS' Walnut Gulch Experimental Watershed. This information will be added to that collected as part of SALSA, which began in 1995.

This year, the program will concentrate on understanding the San Pedro riparian system on the U.S. side of the border. Scientists will establish baseline data by measuring surface water, groundwater, and transpiration. They'll compare their measurements to readings collected from satellites and aircraft during five overflights through October 1997.

Over the entire basin, SALSA team members from ARS, the U.S. Environmental Protection Agency, Tennessee Valley Authority, University of Arizona, and Mexico and France will concentrate on energy balance measurements from several areas, vegetative characterization from satellites, and large-scale land cover change using ground and historical satellite data.

Scientists expect to monitor how humans change the area. "We can already see some evidence from satellite images. The U.S.-Mexico border is clearly visible because of different livestock grazing practices in the two countries. The presence and possible expansion of an enormous copper mining operation at the headwaters of the San Pedro may also have significant impact on the basin's water quality and quantity," adds Goodrich.

Future plans call for collecting and archiving information like precipitation and solar radiation from the different areas over a 5- to 10-year period. Then a basin-scale hydrological model will integrate these and other variables.

Scientists hope the effort will improve how computer models predict the impact of environmental changes on the hydrology and ecology of this and other large basins.

Farming in the Future

Inside growth chambers in L. Hartwell Allen's Florida test field, rice, soybeans, and forage plants such as bahia grass are growing in air with twice the CO_2 found in today's atmosphere. Allen's an ARS soil scientist in Gainesville.

CO_2 gas—pumped into the sunlit chambers, temporary plastic-covered greenhouses, and other structures—creates a mixture of air similar to what scientists predict could be present in the Earth's atmosphere within the next century. The experiments, begun as collaborative studies with the U.S. Department of Energy, are in their 15th year.

Allen and others have found that elevated CO_2 concentrations increase plant photosynthesis. But vegetative growth—roots, leaves, and stems—increases more than seed production.

"That means that in the future, scientists may have to breed plant varieties that are capable of producing more seed in the higher CO_2 atmosphere," Allen says.

Results by ARS researchers nationwide give farmers a glimpse into how their jobs might change as CO_2 concentrations—and possibly temperatures—rise.

- Rice growers in temperate areas are likely to see a yield increase as the CO_2 concentration rises, Allen and University of Florida colleagues found. But if temperatures increase too much, yields are expected to decline. In experiments with both current and doubled CO_2 concentrations, today's rice cultivars produced the greatest yield at an average daily temperature of about 80°F and the least when daily average temperatures rose to 97°F. Since most rice is grown at temperatures close to the optimum of 80°F, temperatures would have to rise far more than modeled predictions before yields would be seriously reduced.
- Soybeans seem to be able to tolerate slightly higher temperatures than rice, Allen says. With increased CO_2, farmers should see up to 30 percent higher soybean yields—even if temperatures rise as much as 5°F—as long as rainfall remains adequate.
- Southern beef producers may have to provide more shade, more water, and high-protein supplements to keep cow-calf operations profitable. That's both because the animals would have to tolerate more heat and because the forage quality may decline in southern areas if temperatures rise significantly, according to the SPUR2 model developed by Jon Hanson. Northern producers would fare better, with increased forage quality.
- Nitrate leaching into groundwater could decrease as CO_2 increases, according to experiments in Auburn, Alabama, by ARS soil scientist

SCOTT BAUER (K4267-2)

Range scientist Jon Hanson notes the effects of four global change scenarios on calf weaning weights and compares them with the Range Dependency Index (on the monitor) showing the percentage of a region's income that is linked to range beef production.

The Ozone Hole—A Different Issue

Though sometimes confused with one another, the greenhouse effect and the ozone "hole" are separate phenomena. A form of oxygen, ozone plays two roles in the atmosphere.

Near the ground, ozone is an air pollutant and a minor greenhouse gas. In the upper atmosphere, it forms a layer that helps protect us from sunburn and skin cancer by absorbing some of the ultraviolet radiation from the sun. The "hole" refers to a thinning of this layer because of chemical reactions in the upper atmosphere, especially at the Earth's poles. To combat ozone depletion, several chemicals are targeted for reduction or elimination—including the important agricultural fumigant methy bromide. To learn about ARS research on methyl bromide alternatives, see "Beyond Methyl Bromide," *Agricultural Research*, January 1995, pp. 14-18, and visit our web site at http://www.ars.usda.gov/is/mb/mebrweb.htm

JACK DYKINGA (K3749-2)

Physicist Sherwood Idso (left) and soil scientist Bruce Kimball assess fruit production on an orange tree growing in an open-top chamber with enriched CO_2.

H. Allen Torbert and plant physiologists Hugo H. Rogers and Steven A. Prior. They found that soybean and grain sorghum plants grew larger and tied up more soil nitrogen—including nitrogen from fertilizer—under elevated CO_2 concentrations.

Even after the plants died, less nitrogen moved through the soil towards groundwater. "Because the plants are bigger, the residue contains more carbon and a higher carbon-to-nitrogen ratio," says Torbert, who's based in Temple, Texas. "The microbes that decompose the plants tie up more of the nitrogen in order to use the larger amount of carbon." The bottom line: most of the nitrogen stays in the soil.

• Increased plant growth under elevated CO_2 and higher temperatures could help reduce water runoff and related soil erosion in the Midwest, based on computer modeling done in West Lafayette, Indiana, by ARS hydrologist M. Reza Savabi. That's because the additional growth provides a larger plant canopy, which reduces the formation of a hard crust on the soil surface. That allows more rainfall to infiltrate the soil.

• Environmental stresses that normally decrease crop yields, such as air pollution or moisture stress, could be partially ameliorated with higher CO_2 concentrations, according to work led by ARS plant pathologist Allen S. Heagle in Raleigh, North Carolina. "That means increased CO_2 would have a greater benefit for crop yields during dry seasons and where concentrations of ozone are high," says Heagle.

• Alaskan farmers could get greater yields of barley and potatoes, says ARS soil scientist Verlan L. Cochran, who was at Fairbanks until 1995. Today, even under the 24-hour daylight of Alaskan summers, plants stop photosynthesis as the light intensity weakens in the early morning hours. But in experiments with elevated CO_2, photosynthesis didn't stop. That meant higher yields and an earlier harvest.

• Increased CO_2 would lead to higher wheat yields—about 10 percent more under well-watered conditions and up to 20 percent more than would be typical during drought, according to research by Kimball in Phoenix. If there's not too much global warming, some farmers may even save irrigation water because wheat plants use less water in CO_2-rich air. Kimball performed these and other experiments as part of the FACE project.

Despite the extensive research to date, scientists are still working to better predict the effects of global environmental changes on agriculture. The good news is that we have time to mitigate change and adapt to it, and ARS research will continue to work towards both goals. "In the long run," says Heagle, "we can minimize the effects of global change on agriculture by improving our crop cultivars and modifying our cultural practices."—By **Kathryn Barry Stelljes.**. **Sean Adams, Don Comis, Dawn Lyons-Johnson, Dennis Senft,** and **Marcia Wood** contributed to this article.

Need Information About Global Change? Just ASK.

Searching for information on the Internet can be frustrating. You search for table china, but you get hundreds of links about the People's Republic of China. ARS' National Agricultural Library is heading up a pilot project to make it easier to search for information on global change. The Global Change-Assisted Search for Knowledge (GC-ASK) program provides bibliographic information on global change-related research papers from nine government agencies.

"The goal is to develop a smarter search engine that uses reliable terminology to find just what you're looking for," says Roberta Y. Rand. She is the USDA global change data and information coordinator. To visit GC-ASK, go to http://ask.gcdis.usgcrp.gov:8080/

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