Carbon Dioxide Spells Indigestion for Food Chains
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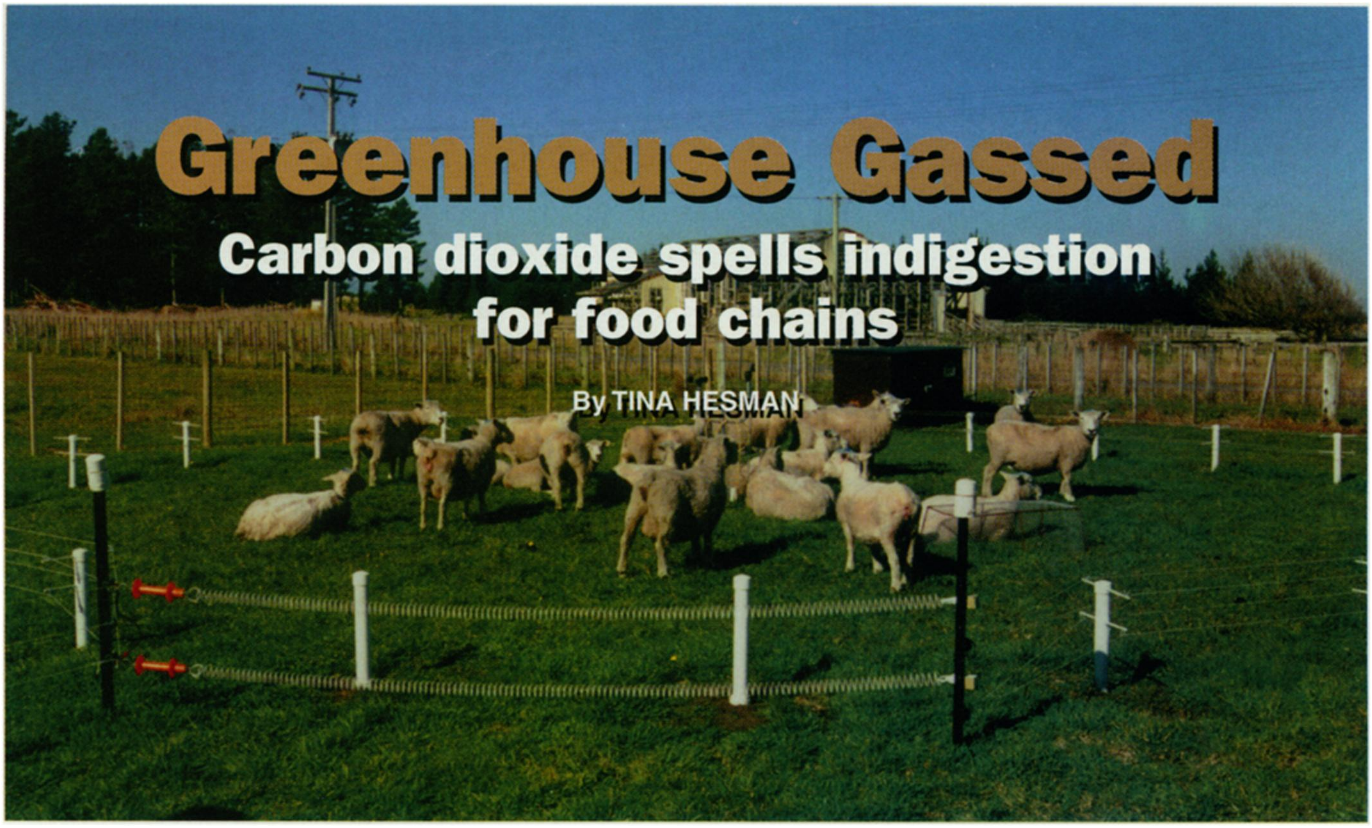
Greenhouse Gassed

Carbon dioxide spells indigestion for food chains

By TINA HESMAN



Newton

These sheep in New Zealand may teach scientists how livestock will fare as the carbon dioxide content of the atmosphere goes up. White poles ringing the pasture continuously pump CO_2 into the air.

"The last thing I'd want to get reincarnated as is a caterpillar," says David N. Karowe. He doesn't have anything personal against caterpillars; it's just that the future doesn't look very rosy for the fuzzy leaf chewers.

Increased malnutrition, attacks by parasitic wasps, and death rates await caterpillars in the coming decades, predicts the entomologist, who's at Western Michigan University in Kalamazoo. The ultimate perpetrator of the anticipated tribulations of these and other insect herbivores is a change in Earth's atmosphere.

The concentration of carbon dioxide (CO_2) in the atmosphere has risen steadily since the beginning of the industrial revolution and is expected to double from today's global averages in the next 50 years. While scientists continue to debate whether elevated concentrations of CO_2 and other greenhouse gasses, such as methane, will lead to significant changes in Earth's temperature, they agree on one thing. Boosting atmospheric CO_2 makes plants grow faster.

Paradoxically, that effect could spell disaster for plant eaters, from caterpillars to antelope, as well as the animals that dine on these herbivores, new research suggests. Fast growth often leads to poor nutritional value.

Until recently, scientists focused on figuring out how CO_2 will affect global weather. Now, a handful of researchers around the world is investigating how some of the multitude of animal species may react. The early results indicate that both wildlife and farmers may suffer as plants soak up the extra CO_2.

Carbon dioxide in the air acts like fertilizer, says David E. Lincoln, a biologist from the University of South Carolina in Columbia. Bathed in extra CO_2, plants rev up their photosynthesis, take in the gas, and use the carbon to build new fiber and starch. Even as the plants beef up on carbs, the amount of nitrogen—an indicator of protein—in their leaves goes down.

All that extra roughage might be a dieter's dream, but for caterpillars looking to bulk up before they pupate, it's a digestive nightmare. New leaves on plants grown in CO_2-rich air are starchy but protein poor. With less protein in caterpillars' leafy greens, they need to eat more to get the same amount of nutrition. Sometimes a lot more, says Karowe.

Karowe fed cabbage white butterfly caterpillars with leaves from plants grown in two different CO_2 chambers—one in which the air matches today's CO_2 concentration and one with air containing twice as much of the gas. The caterpillars that ate carbon-enriched leaves consumed up to 40 percent more plant material than their brethren did.

Unlike people who go on pasta binges, the caterpillars that ate extra carbohydrates didn't gain extra weight. In fact, their growth slowed by about 10 percent, says Karowe. It took these young insects much longer than normal to develop into adult butterflies, he says. When the adults finally emerged, they were smaller than adults that hatched from caterpillars fed on regular leaves. Karowe discussed his work last November at a meeting of the Council for the Advancement of Science Writing in Hershey, Pa.

The phenomenon of lightweights that overeat is not limited to cabbage butterflies, notes Richard Lindroth of the University of Wisconsin-Madison. He has found that caterpillars and gypsy moths also cram their bellies with significantly more food when researchers feed them leaves from aspen, birch, and oak trees exposed to elevated concentrations of CO_2.

Only caterpillars that graze on carbon-enhanced sugar maple leaves are able to fill up on the same amount of leaves as caterpillars that eat normal sugar maple leaves, he reports. Lindroth doesn't know why the sugar maple eaters fare better than other caterpillars.

Several other studies have demonstrated that, in general, moth and butterfly larvae tend to eat more and weigh less when they eat plants grown with more CO_2 in the air, says Lindroth.

To learn how much moths and butterflies eat, researchers usually study the insects in a laboratory. Working with caterpillars in the wild is much more difficult, says Peter D. Stiling, an ecologist from the University of South Florida in Tampa. Caterpillars range around on plants, and individuals and their eating habits are hard to track. Stiling and his colleagues have turned to a real home-body in the insect world—leaf miners—to investigate what happens to insect populations when CO_2 concentrations rise.

Leaf miners are ideal experimental subjects, says Stiling, because the larvae spend their entire lives inside blisters, or mines, that they carve inside leaves. Researchers can easily gauge the leaf miners' appetites by measuring the size of their mines.

The mines also provide hard evidence of the insects' fates. If the larva starves to death, its shriveled body will be in the mine. Wasp ambushes and predators' attacks leave telltale signs, too. After predatory wasps devour the leaf miner, they burst from the mine, creating shotgun-like holes. Ants, spiders, and lizards instead rip open the blisters to get at the larvae inside. Leaf miners that manage to make it through the larval stage slice a distinctive round or crescent-shape escape hole in the mine, then drop to the forest floor and begin the transformation to adulthood.

At NASA's Kennedy Space Center near Cape Canaveral, Fla., Stiling and his colleagues are determining how entire ecosystems will respond to rising CO_2. Here, in sight of Space Shuttle launches, the scientists built clear-plastic cylinders around 16 clusters of scrubby oak trees, the species that dominates the south Florida landscape. The researchers left the 3.5-meter-diameter chambers open at the top so that both moisture and insects can get in and out. Carbon dioxide was continuously pumped into eight experimental chambers, and normal air was pumped into the other eight. The experimental chambers had twice as much CO_2 as the control chambers.

Over the course of the growing season, the scientists surveyed thousands of leaves in every cylinder and recorded the fates of the leaf miners. Those in the chambers with elevated CO_2 dug out mines that were 20 percent larger—indicating they ate that much more leaf fiber—than did leaf miners in the chambers filled with standard air.

Yet autopsies revealed that miners raised in elevated CO_2 chambers were twice as likely to starve to death as the miners living in the air-filled cylinders were. "Although they may eat more per individual, a lot of them die before they've eaten their fill," says Stiling. The protein-poor leaves are "not rich enough to support them," he says. "They're all striving to succeed, but there are fewer of them making it."

Moreover, compared with miners in chambers with normal air, four times as many leaf miners were killed by parasite attacks in the chambers containing high concentrations of CO_2. Stiling speculates in the February 1999 ECOLOGICAL APPLICATIONS that bigger blisters might make the miners easier for the wasps to find. Also, if a miner spends more time growing before it leaves its mine, its enemies have more time to attack it.


Karowe

Using open-topped chambers like these at the University of Michigan Biological Station, scientists manipulate concentrations of carbon dioxide in the air.

Increased concentrations of CO_2 in the air around them may prompt insect herbivores to inadvertently signal their enemies, says Karowe. Plants release chemicals into the air when wounded by an insect bite, and parasitic wasps home in on these signals.

In addition to the plants' calling in waspish air attacks, the caterpillars themselves produce beacons for wasps. There's nothing a parasitic wasp finds more attractive than caterpillar droppings, Karowe says. Caterpillars raised on plants grown in high-CO_2 atmospheres produce up to twice the normal amount of waste—both because they are eating more and because the leaves are harder to digest, he says.

Even though the caterpillars raised on extra CO_2 are easy pickings, they're no picnic for the wasps, says Karowe. Because parasitic wasp larvae rely on the hospitality of host caterpillars for survival, when the caterpillars get indigestion, the parasites feel it too.

Malnourished caterpillars can't support as many parasites as normal-size caterpillars can. Female wasps that lay their eggs on caterpillars exposed to high concentrations of CO_2 aren't doing their offspring any favors, Karowe found. The wasps that emerge from malnourished caterpillars tend to be smaller, lay fewer eggs, and live shorter lives.


Lindroth

A gypsy moth caterpillar feasts on a leaf. Caterpillars tend to eat more but weigh less when plants are grown in unusually high concentrations of carbon dioxide.

Not all insects appear to be doomed in the CO_2-enhanced atmosphere of the future. Sap-sucking aphids, which are major agricultural pests, may in fact experience a population explosion, says Caroline S. Awmack, an ecologist from the IACR-Rothamsted agricultural research center in Harpenden, England. Aphids reproduce 10 to 15 percent faster under conditions of elevated CO_2, Awmack has found.

Unlike leaves, plant sap doesn't seem to vary much when there is more carbon dioxide around. Awmack doesn't know exactly what in the aphids' diet gives them a population boost in abundant CO_2.

Aphids seem to know what's good for them, though. Awmack, now at the University of Wisconsin-Madison, put the tiny insects, one at a time, into a Y-shaped tube. The arrangement gave the aphid a choice of dining on wheat grown in air with a normal concentration of CO_2 or in a carbon-rich atmosphere. The aphid took a whiff of vapors coming off the wheat samples and made a beeline for the plant grown under carbon-rich conditions.

"They're making a sensible decision," Awmack says.

Sensible decisions for aphids, however, can translate into big trouble for plants. When CO_2 concentrations are high, bean plants infected with aphids can't make flowers or new shoots, Awmack found. Aphids may literally suck the life out of nascent buds.

If global atmospheric change increases populations of the little sap suckers, certain crops such as beans could be badly damaged, she says in a study that

Karowe/Wageningen Ag. Univ., The Netherlands

Attacks by parasitic wasps on caterpillars, like this large cabbage white butterfly larva, may increase as carbon dioxide concentrations rise.

will be published in AGRICULTURAL AND FOREST ENTOMOLOGY.

Awmack may have found the aphids' Achilles heel, however. Normally when an aphid is disturbed, it gives off a pheromone as a chemical alarm, which warns other aphids of danger. In experiments with elevated CO_2 concentrations, aphids stop making the pheromone in response to stress and also don't respond to the pheromone if the researchers provide it. Such complacent aphids would be easy targets for a parasitic wasp and a no-hassle meal for a roving ladybug.

Awmack is beginning work to see if a compromised alarm system in wild aphid populations under high-CO_2 conditions puts them in greater-than-average danger from predators.

What's good for an aphid might not be so great for the spittlebug, says ecologist John B. Whittaker of Lancaster University in England. Instead of feeding on phloem sap, the sugary sap that nourishes growing parts of the plant and also aphids, spittlebugs suck the xylem sap, which carries water and dissolved minerals.

Whittaker and his colleagues have followed several generations of spittlebugs living in CO_2-enriched chambers. Like leaf miners and caterpillars, spittlebugs failed to thrive in high concentrations of CO_2. Instead of adapting to the bad food over time, spittlebugs do worse and worse. Survival rates dropped 27 percent over three generations.

The differences between classes of plant eaters could lead to shifts in the ecological balance among insects and the plants on which they feed, says Whittaker. It probably will be harder for some plants than others to adapt to rapid increases in certain pest populations, he says.

The threat of crop devastation by ravenous insects is not the only issue concerning ecologists. Rises in CO_2 may affect every plant-eating animal and disrupt many different food chains, experts say. "No one may be interested in little insects on oak trees in Florida," says Stiling. However, if rising CO_2 affects zebra and antelope on the African savanna, "that would be quite dramatic."

Until now, scientists simply extrapolated from insect data to predict what might happen to bigger animals. Experiments to determine the effects of atmospheric changes on large herbivores are difficult.

"All you can do is lead a tethered antelope into a chamber [holding CO_2-enriched air] and see if it eats more," Stiling says.

Researchers in ranching areas are now doing exactly that kind of experiment to predict how the changing atmosphere will affect valuable livestock. Scientists in Kansas and New Zealand are leading sheep to carbon-enriched pastures to explore what will happen to grazing animals and their grasslands when CO_2 concentrations rise.

Just as for many insects, the quality of diet for large herbivores goes down as CO_2 concentrations go up, says Clenton Owensby, a grasslands-management researcher at Kansas State University in Manhattan.

Owensby and his colleagues erected greenhouses over patches of the Kansas prairie and pumped CO_2-laden air into some and ambient air into others. The researchers turned sheep loose in the greenhouses and then collected food from the animals' throats before they digested it. Sure enough, the chosen prairie grasses grown in high CO_2 had much less protein than those from the control houses.

Stiling

The fate of leaf miners is recorded in their mines. An insect predator ripped open this brown blister to get at the leaf miner inside.

Unlike insects that compensate for protein-poor diets by eating more, cud-chewing animals like sheep tend to eat less, Owensby says. That's because bacteria in the guts of such ruminants control how much food the animals take in. The bacteria digest plant matter, extracting maximum nutrients for their host, but the microbes need protein to do their job. As the protein content of the diet falls, so does the bacteria's digestive activity. The grazing animal soon fills its rumen to capacity and must wait for the bacteria to finish digestion before it can graze again.

All that waiting around between meals could mean a longer stay on the farm while the animal gains the weight it needs to be marketable. Farmers and ranchers can feed their livestock protein supplements to make up for what's lacking in the animals' diet. Of course, that may greatly increase the cost of meat, Owensby says.

Researchers in New Zealand are also studying sheep, but in a slightly different way, says Paul Newton of AgResearch in Palmerston North. The scientists have encircled several pastures with poles that pump CO_2 into the open. Air inside each ring of poles contains twice the concentration of CO_2 as the surrounding atmosphere does.

Newton and his colleagues have turned loose a herd of about 300 sheep outfitted with backpacks to roam through the rings and surrounding pastures. The scientists want to know if the sheep prefer the carbon-enhanced plants or their regular diet. Sensors that send signals into the backpack monitor how much food and what types of plants the sheep eat and measure how much methane the animals produce.

The researchers have already learned that the mix of plants in a pasture changes when they add sheep. More protein-rich legumes grow in the CO_2-enriched areas where sheep graze than in those where they don't, Newton says. Strangely, the sheep tend to eat more of the legumes than other grasses, but the legumes still increase in number.

Because wild animals aren't as accommodating as sheep and caterpillars, scientists can only speculate what rising CO_2 concentrations will do to wildlife populations. Right now, Owensby says, "these are things only a mystic can come up with."

While rising CO_2 in the world's atmosphere could hit meat producers in the wallet, wildlife may face even higher costs. "Wild ruminants won't be so lucky to have someone chasing after them giving them protein supplements," says Owensby.