• **DOE:** Early indications are that most science programs will emerge relatively unscathed by the proposed 3% cut to DOE's $19.7 billion budget. But agency science officials are forecasting flat budgets for physics and other fields—meaning reduced buying power and no facility improvements. The outline also promises careful scrutiny of unnamed "major" science projects, raising fears of delays at the Spallation Neutron Source, under construction at Oak Ridge National Laboratory in Tennessee.

• **USGS:** Intensive lobbying from agency officials and outside interest groups has prompted the White House to cut in half a proposed 22% drop in USGS's $883 million budget. But even an 11% cut, says USGS director Chip Groat, means "we're going to have to [lay off] people." Groat is also worried about language calling on the agency to "better target" its contribution to managing national parks and lands. The words suggest that programs not specifically tied to federal lands—from stream-gauge networks to seismic monitoring—"would be out the door," Groat says. The one morsel of good news is that a rumored effort to shift scientists in USGS's Biological Resources Division to other Interior agencies appears to have lost steam after objections from Congress.

• **EPA:** A roughly flat overall budget (after removing pet projects added by Congress) is likely to mean level funding for its $696 million science and technology account. The outline is silent on the fate of the Clinton Administration's Climate Change Technology Initiative.

• **USDA:** Bush expressed support for agricultural research in the final presidential debate in St. Louis, and his budget calls for investing in biotech and new products. The agency's main extramural grants program, the $106 million National Research Initiative, is hoping for a small raise. **–DAVID MALAKOFF**

With reporting by Jeffrey Mervis and Jocelyn Kaiser.

BOTANY

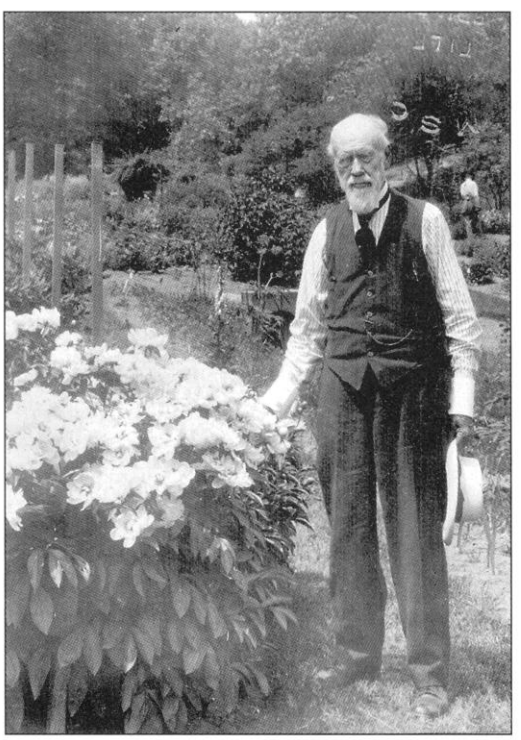
Patience Yields Secrets of Seed Longevity

After more than a century, the world's longest seed viability experiment keeps on sprouting—and inspiring scientists worldwide

On a brisk fall day almost 122 years ago, Michigan botanist William Beal stirred handfuls of ordinary plant seeds into damp sand and sorted the sand into 20 clear glass bottles. When Beal finished, each bottle was identical, containing 50 seeds from each of 20 plant species. He had a single question: How long can a seed survive in the dark, cold ground, yet still burst into life when blessed by sun or rain? To find out, Beal buried his 20 uncorked bottles mouth down, east to west, on a secret, sandy knoll at Michigan Agricultural College. Every fifth year, he decided, he would dig up one bottle, plant the contents in a greenhouse with light and water, and see which seeds sprouted.

Today, Beal's study—stretched into 10-year, then 20-year increments—has become a tradition at the school, now Michigan State University (MSU) in East Lansing. It is the world's oldest seed viability experiment. Generations of stubbornly sprouting seeds—particularly moth mullein, a European weed crowned with a showy yellow flower—have inspired far-flung researchers, from plant biologists to crop scientists to restoration ecologists. "This is nature's Rip Van Winkle story," says Frank Telewski, an MSU botanist and curator of the W. J. Beal Botanical Garden.

While Beal's seeds sleep, a growing number of scientists have moved beyond his original question to explore the mystery of seed longevity. Why do some plant seeds hang on for decades—even centuries—while others barely survive winter? And how? "Think of this tiny sliver of a seed, just a remnant of a weed," remarks Paul Cavers of the University of Western Ontario in Canada. "How on Earth can it live for so long?"



Green thumb. With cheap pint bottles and common plant seeds, William Beal launched an extraordinary experiment.

CREDIT: MICHIGAN STATE UNIVERSITY

Dark secrets

The secrets of seed longevity lie below ground, in natural seed banks. Being parsimonious, most plant species do not allow their seeds to germinate all at once. Instead, the seeds take turns—some sprout in a given spring or fall, while others sit out for one or many seasons to come. Drab and brown, the seeds attract little attention from predators and subsist on internal sugar stores. Through such tricks, plant populations boost their chance of surviving in a fickle world.

This meager underground existence can last for months—or decades, depending on the seed. Finally, if the soil is turned over at just the right time, meeting a particular seed's unique demands for temperature, light, and water, the plant will burst above ground, announcing its presence. In Holland during World War I, bloody battles and freshly dug graves at Flanders Field uprooted so much dirt that long-dormant poppies suddenly burst into red bloom. It was bitter beauty.

Every so often, a botanist reports finding viable ancient plant seeds in a canoe, say, or inside a tomb, but the estimates of plant age are often hard to confirm. So far, the oldest seed reliably recorded came from a sacred lotus in a withered lakebed in Liaoning, China. The Paozhi Basin lake, whose sediments date back to the Holocene era, had once blossomed with lotus plants cultivated by Buddhist monks. In 1994, scientists at the Beijing Institute of Botany gave Jane Shen-Miller of the University of California, Los Angeles, a handful of sacred lotus seeds. Shen-Miller and her colleagues germinated and radiocarbon-dated the seeds. They estimated one of the seeds to be roughly 1450 years old.

"The secret of the sacred lotus may be its seed coat," says Shen-Miller. "The coat is very hard, built to prevent water and air from entering and degrading the seed." The sacred lotus is also blessed with a hardy collection of repair enzymes, such as L-isoaspartyl methyltransferase and other

proteins that minimize seed damage, resist attacks by fungi, and help the seed survive harsh temperatures. "The lotus is a scientific treasure," remarks Shen-Miller, adding that the flower could reveal biochemical traits that boost quality of life by repairing the molecular damage of aging.

Although not as lovely as a lotus, Beal's subjects—midwestern weeds—have received their own share of attention. Since the earliest row crops, farmers have been hacking down and spraying pesticides at pigweed, lamb's quarters, and other unwelcome visitors in their fields—only to find the weeds return the next growing season. And the next. It was this dilemma that reportedly inspired Beal to study seed longevity.

Raised as a Quaker in rural Michigan, Beal was serious and watchful. His students were often expected to study plant specimens for hours at a time. When someone glanced up from a microscope, Beal was known to respond, "Keep on squinting." In his own work, that perseverance paid off, Shen-Miller says. "There is no experiment like Beal's in the world," she remarks. "Nobody can go back a century and start a study like this."

One Saturday morning last April, Telewski and fellow MSU botanist Jan Zeevart retraced Beal's steps once more, shoveling away decades of soil to uncover the 15th of Beal's 20 bottles. They sprinkled the bottle's contents onto a tray of sterilized soil, covered it with cellophane, and put it under the bright light of a growth chamber. As the two researchers ventured off for breakfast, Telewski couldn't help but hope that the seeds would sprout. "These seeds are like Halley's Comet," Telewski says. "You expect it to keep coming back, but you just don't know until you see it."

Days passed. Then a week. Finally, two dozen seedlings inched into the air. All but two were moth mullein (*Verbascum blattaria*), whose yellow flowers feed fly-by-night moths. The remaining plants were other *Verbascum* species. Moving the ungerminated seeds into a cold chamber, Telewski and Zeevart also persuaded one small mallow weed (probably *Malva neglecta*) to spring up. During the last dig of the Beal experiment, in 1980, *Verbascum* and *Malva* species were also the sole survivors, notes Zeevart: "The experiment has been perfectly reproduced, 20 years later." Why have these two species held on? No one knows.

Beal simply wondered how long seeds could linger underground and remain viable. But his experiments have taken on a life of their own, energizing plant biologists and restoration ecologists alike. In the 1970s, botanists Carol and Jerry Baskin, a husband-and-wife team at the University of Kentucky, Lexington, first took notice of the Beal project. Sifting through papers published at each study interval, they observed that ragweed seeds buried by Beal did not germinate until 40 years into the study. Why?

Eventually, the Baskins figured out that the ragweed might never have germinated were it not for a fluke of nature. The MSU teams always dug up the bottles in fall—but it turns out that ragweed germinates only in spring. By chance, the fall of 1919 was so cold that the ground at the MSU garden froze, preventing the unearthing of the ragweed seeds until spring—and giving them their chance to shine. "At the time, researchers didn't realize how tightly seed germination can be linked with the changing of the seasons," recalls Carol Baskin.

Aging gracefully. The star seed of the Beal experiment is moth mullein *(right)*, whose flashy yellow flowers bloom every decade. The sacred lotus *(above)* represents the oldest reliably dated plant seed: a roughly 1450-year-old seed found in China.

Indeed, at the dawn of the Beal study, scientists knew little about the life of seeds underground. In recent years, the Baskins and other researchers have shown that seeds actually slip into and out of dormancy, keeping rhythm with the changing temperatures of the seasons. Yank a fistful of summer annual seeds from the ground in fall, and no amount of light, water, or sweet murmuring will coax them to germinate. Wait until spring, however, and the right mix of warmth and wetness—sometimes even in a dark closet—will send the seedlings skyward. Some particularly ambitious plants, including moth mullein, will germinate any time a seed is unearthed and set under light.

Recreating nature

Nature has no hard-and-fast rules for which kinds of plants—weedy, cultivated, gorgeous, or gross—can survive as seeds for many seasons. In the forest, some woody plant seeds sit below ground indefinitely, emerging only after intense fire sears the soil. In the desert, a wildflower seed might wait years for the right amount of rain before sprouting. The reward of life often goes to plants whose seeds evolve ways to survive in the torrid, frozen, soaked, or parched crevices of Earth. "Nature, in her divine wisdom, devised these extraordinary keys to life that let plants survive in extreme conditions," says Robert Bandurski, a retired MSU botanist who participated in the Beal study's 1970 and 1980 intervals.

Beal's study gives hope to restoration ecologists who want to recreate landscapes that have been trampled by grazing cattle, overrun by invasive weeds, or ripped up for suburban development. "This study suggests that if plants have dormant seeds in the soil, those seeds might eventually still sprout and essentially restore the plants that were there," explains Cavers at Western Ontario. Natural seed banks, however, vary tremendously in size and viability. To restore lost ecosystems, conservationists often help nature along by scattering native plant seeds themselves.

Back in Michigan, the Beal study continues. Every dig, about half the moth mullein seeds in a given bottle reliably pop up. "We'd like to see this continued until there's just one bottle left," says Zeevart, who's preparing a paper about the most recent study results. "The way this one *Verbascum* species is going, it might survive for a very long time." When the last bottle is opened—at this rate, in the year 2100—researchers should know more about what keeps these seeds alive. No matter what they discover, Beal has already succeeded. Early in the study, he wrote about seed survival: "In the fall of 1879, five years ago, I began some experiments, hoping to add something to the information we now possess on this subject." Add something, he has.

–KATHRYN BROWN

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