Study finds that maize roots have evolved to be more nitrogen efficient

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Selective breeding of maize over the last century to create hybrids with desirable shoot characteristics and increased yield may have contributed indirectly to the evolution of root systems that are more efficient in acquiring nutrients, such as nitrogen, from the soil, according to researchers.

Their results suggest that future breeding efforts that directly select for positive root traits could lead to yield gains needed to help feed a growing world population, while reducing pollution from excess nitrogen and reducing farmers' fertilizer costs.

About half of the yield gains in commercial corn hybrids in the last 100 years have come from improved plant genetics, explained Larry York, recent Ph.D. graduate in ecology, now a postdoctoral research fellow at the University of Nottingham, U.K. The other half came largely from agronomic practices, such as fertilizer use and higher planting densities.

"A lot of research has focused on the shoots of maize plants, such as the direction of the leaves and how they capture light, or how the plants divide matter into ears and kernels," York said. "We all know roots are responsible for the uptake of water and nutrients. However, relatively little is known about how roots do that.

"If we understand how roots have evolved and which specific root traits increase the plant's efficiency, then we can take the next step in breeding that can help decrease pollution, save farmers money and make more yield."

Finding new ways to improve plant nutrient uptake has global implications, according to co-author Jonathan Lynch, professor of plant nutrition, Penn State's College of Agricultural Sciences.

"Maize is the largest crop in the United States and around the world," Lynch said. "By the same token, nitrogen is the biggest environmental, economic and energy cost of maize production. Not only can crop varieties with improved root systems increase yields and reduce hunger in impoverished regions of the world with nutrient-poor soils, they also can decrease excess nitrogen where water quality is a critical issue, such as in the Chesapeake Bay watershed."

The researchers hypothesized that during a century of corn breeding aimed at increasing yields, root systems were indirectly selected for architecture and anatomy that are more efficient for nitrogen acquisition. To test this, they collaborated with DuPont Pioneer, which supplied 16 varieties from the company's collection representing maize grown commercially in the United States from the early 1900s to the present.

"During this time period, agronomic practices changed immensely, from using horses to plant corn at low population densities with barely any added fertilizer, to using tractors to plant high-population-density fields with significant amounts of applied fertilizers," York said. "Planting density increased about fourfold during this time, and nitrogen fertilizer use has tripled since World War II."

The researchers grew all 16 varieties in both high- and low-nitrogen plots at three different densities, representing both historical and modern growing environments. They conducted the field experiments at Penn State's Russell E. Larson Agricultural Research Center at Rock Springs.

They measured shoot mass and yield and used a technique known as "shovelomics" to dig up the top portion of the roots so they could measure root quantity, angles, diameters, degree of lateral branching and length. Using a technology called laser ablation tomography, study co-author Tania Galindo, doctoral candidate in horticulture, measured root anatomical traits, such as the size and number of cells, the size and number of xylem vessels that transport water and nutrients, and the percentage of roots that were aerenchyma, which are air-filled spaces that allow for the exchange of gases between the roots and shoots.

"The laser ablation tomography combines the power of the laser for sectioning with a simultaneous image acquisition system to capture the internal organization of tissues, or anatomy, of entire root segments," Galindo explained. "Our laboratory's application of this technology in root biology allows us to study the root anatomical characteristics of thousands of samples of maize at high throughput."

The researchers found that the newest commercial varieties performed better in every agronomic environment. These varieties also had root characteristics known from previous Penn State research to make plants more efficient at acquiring nitrogen from the soil, including fewer nodal roots, longer lateral roots and larger cortical cells. They published their results online in the journal of *Experimental Botany*.

"That the newer material performed better in low-nitrogen environments is a novel result, since researchers tend to focus on high-input cropping systems." York said. "Although newer varieties were developed for use in high-nitrogen conditions, today's higher population densities mean plants have greater competition for available nutrients."

York said the results suggest that the maize root system has evolved to be more nitrogen efficient over the past century. He noted that the research did not look directly at plant water uptake, but the results may indicate greater water-use efficiency as well. "Water use will become more important because climate change is causing greater variability in rainfall events."

The researchers said more in-depth research is needed on how specific root properties affect nitrogen uptake and on how these traits influence acquisition of other nutrients, such as phosphorous. "In addition, we need to know how the optimal root phenotype will depend on different environments—do we need the same roots in Pennsylvania as in Africa?" York said.

"Creating more nitrogen- and water-efficient crops is a major goal in a world that will see population reach 10 billion people within 50 years, requiring a 50 percent increase in food production without using more land," he said. "We believe roots will be central to meeting this challenge."

More information: Evolution of US maize (Zea mays L.) root architectural and anatomical phenes over the past 100 years corresponds to increased tolerance of nitrogen stress, *J. Exp. Bot*. (2015) 66 (8): 2347-2358. doi: 10.1093/jxb/erv074 . jxb.oxfordjournals.org/content/66/8/2347.abstract

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