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Precision and automation weed control technology

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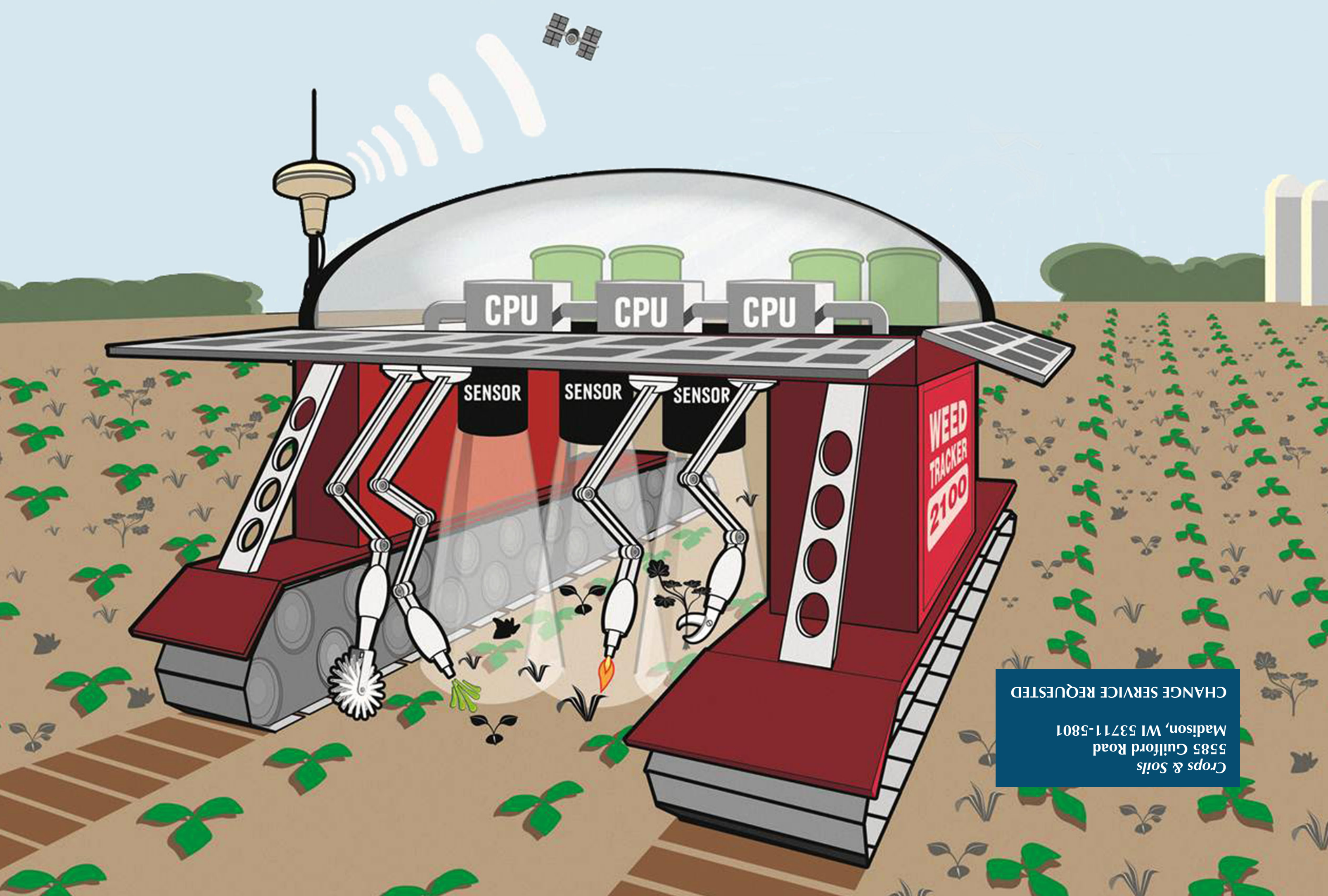

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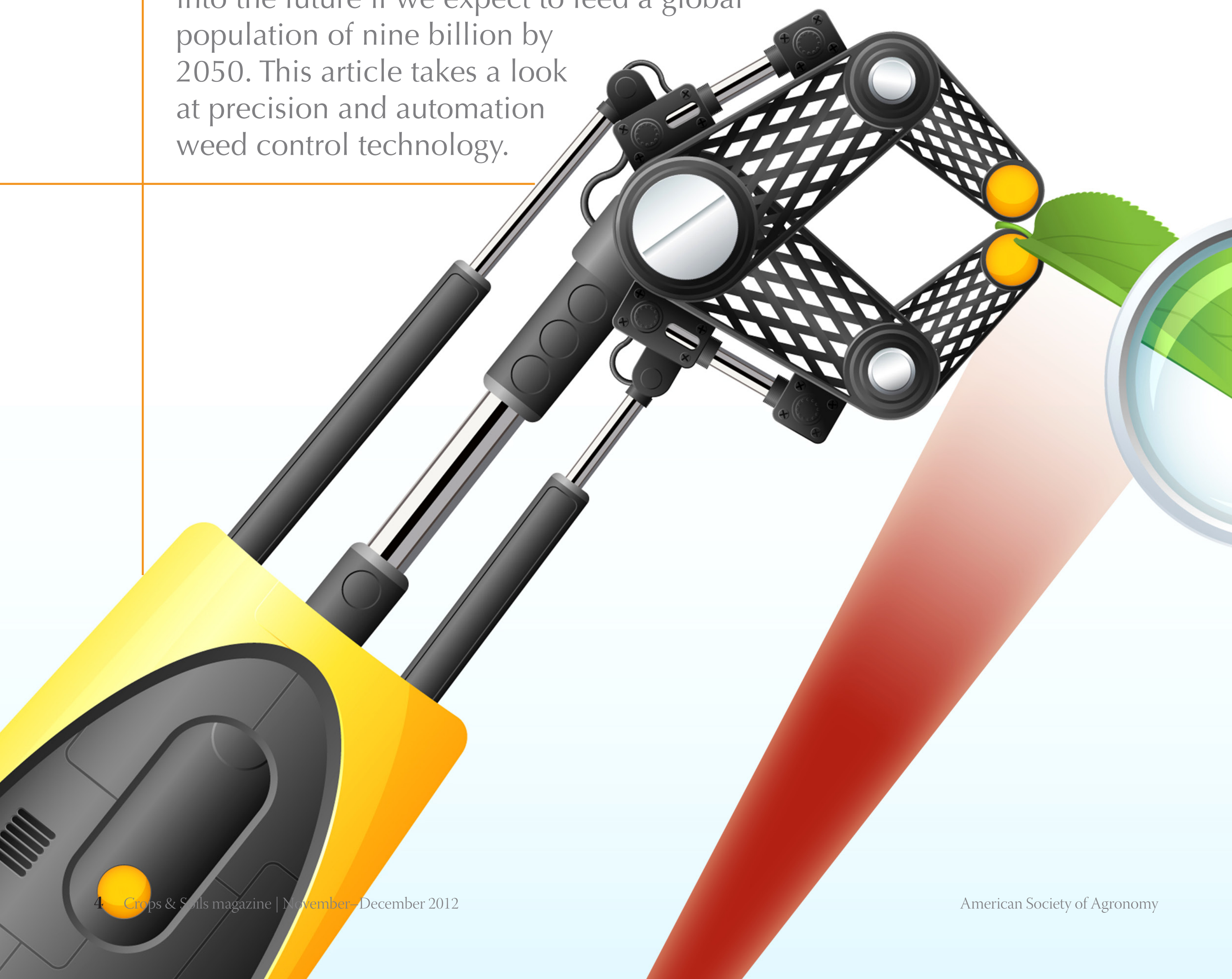
Precision and automation WEED CONTROL technology

From GPS to guidance to robots, agriculture has advanced rapidly in its adoption of new technology in the last few decades. This trend will need to continue into the future if we expect to feed a global population of nine billion by 2050. This article takes a look at precision and automation weed control technology.



By Steve Young, weed ecologist and assistant professor and **George Meyer,** professor of biological systems engineering, University of Nebraska–Lincoln

The population of the world has surpassed seven billion and is expected to reach nine billion by 2050. This presents a challenge considering the land and resources available globally. Current calculations indicate 1.2 ac are required to feed one person (Pimentel and Giampietro, 1994). The total land mass of the world is 36.8 billion ac, and 12–18% of that is arable land suitable for crops. If it takes 1.2 ac to feed one person and there are 6.6 billion ac of arable land, then we can only feed 5.5 billion people, which is dreadfully short both now and into the future. This means we either need to increase the amount of arable land or reduce the number of acres required to feed one person. The former seems to be the least likely to occur, so we are left with the latter option. But, how do we accomplish this and in such a short period of time? The answer lies in getting more precise in our management.

Not only are there challenges with just growing enough food, but increasingly we are faced with challenges from the environment and in the innovation, itself. This year, much of the U.S. experienced a drought, and this has been extremely challenging for growing crops, successfully. We are also facing challenges in the availability of cheap energy to run our tractors, not to mention fuel our societies. And, some day, the nutrients (e.g., phosphorus) available for growing crops will not be as readily accessible, and we'll be challenged with how to adequately supply our crops with fertilizers and other important nutrients.

With the increase in the preciseness of our management comes a greater challenge that must be overcome through innovation. For example, if we are going to target each individual weed in a field, what are all of the considerations that must be accounted for and can we develop the technology to precisely apply and move with the freedom necessary to account for the spatial distribution of plants? The wind, rain, and elements do not allow for friendly conditions to easily and quickly make targeted treatments to individual leaf surfaces or small plants. This challenge does not have a simple answer, especially with the challenge of limited funding of potentially high-risk projects.

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Trends

In agriculture, land use has dropped only slightly from 54 to 51% from 1982 to 2007, while labor has declined 30% and productivity has increased 50% (O'Donoghue et al., 2011). During the same period, increased adoption of new technologies has risen dramatically. Sensor technology has been one of the most rapidly developing areas of technology with widespread adoption in many fields, including agriculture. From GPS to guidance to robots, agriculture has advanced rapidly in the last few decades.

In the health and environmental sci-

Over the past decade, rapid advancements in automation have occurred for weed control in cropping systems. Bestway's AutoGlide system, shown below, is one example. The system uses ultrasonic range sensors mounted on the booms to continually monitor and maintain the height of the booms above the ground or crop canopy.
Images courtesy of Bestway.


ences, recent developments have included sensors at the micro-scale. At Georgia Tech, scientists are using nanopiezoelectronics to insert into the human body to detect signs of disease in blood, detect minute amounts of poisonous gases in air, and find trace contaminants in food. These devices are very sensitive, frugal with power that comes from minuscule generators, and tiny in size. A start-up laboratory, BioNanomatrix (now BioNano Genomics), is pursuing the key to personalized medicine, which is based on the rapid computer assessment that can sequence an entire genome in eight hours for a mere $100. With this powerful tool, medical treatment could be tailored to a patient's distinct genetic profile.

Other available or developing technologies that use sensors and powerful computing systems are pill cameras, which are remote controlled for movement in the digestive system with muscular contractions; OnStar, which can open and close car locks remotely; multi-energy X-ray imaging technology for use at airports; and sensors capable of detecting drugs in breath and monitoring hand hygiene by detecting soap fumes.

It is obvious that the trends are moving society toward more integration with technology. In cropping systems, a combination of biology and engineering have recently merged to address management tools designed to respond to the dynamics of nature in the land, air, and water.

The need for change

Crop production is most often by the acre, and in most cases, inputs are applied in pounds and gallons and averaged for an entire field using equipment that spans multiple crop rows. The needs of individual plants, including weeds, can change dramatically over very short distances. There are obvious requirements of plants, such as nutrients and water, and more subtle requirements, such as light, air, and microbial interactions. In most conditions, plants must compete for resources, which end up diminishing their overall growth and development.

Weeds in production systems often occur in patches of various sizes or as individuals growing among crop plants, yet they are managed in a way that is similar to the crop—large scale and uniform. A combination of control methods, such as chemical, mechanical, and cultural, are used at different times of the season or over several seasons in most cropping systems, but rarely are single weed plants targeted. Weeds, like crop plants, are not managed at the individual plant scale.

Precision treatment of weeds utilizes ultra-low doses of herbicides that are applied directly to the target at a very early life stage. By applying herbicides early in the life cycle

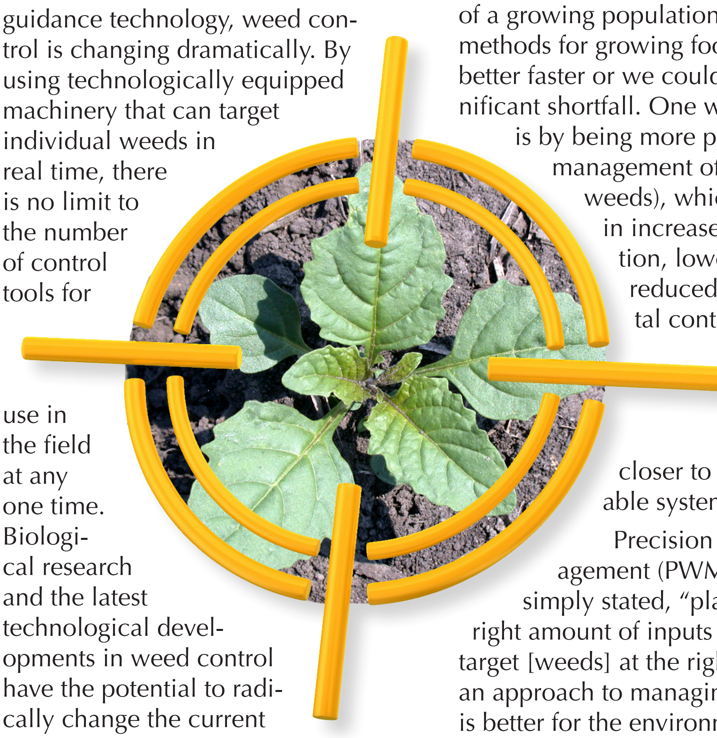
of weeds, efficacy and crop yields can be improved significantly. It has been reported that 85–100% control of pigweed species, black nightshade, and spotted spurge can be obtained in newly planted tomato using a micro-dosing jet that delivers 1.25×10^{-3} oz per spray cell (0.12 in^2) (Giles et al., 2004). Others have demonstrated a micro-dose system with a potential for controlling over 1,000 weed seedlings/ft^2 using only 0.06 oz/ac of glyphosate (Sogaard

and Lund, 2007). For 90% control of yellow foxtail and velvetleaf plants, a direct application of glyphosate, using a mechanical end effector, required 22% of the active ingredient (19.4 oz a.i./gal) in a broadcast application (Hong and Tian, 2009).

Precisely placed herbicides can be very effective in controlling weeds without resulting in lower crop yields, but the commercial availability of precision application equipment is limited by its robustness in a wide variety of field conditions, including fluctuating weather and changing plant canopy and architecture. In addition, targeted recognition and application technology for precision weed control must be easily incorporated into current systems or used as stand-alone implements.

Over the past decade, rapid advancements in automation and real-time recognition have occurred for weed control in cropping systems. The use of sensors and computers to quickly assess plants and their location within a field has led to the development of various systems. The trend for improving plant recognition technology and incorporating it with other management applications (e.g., yield, soil nutrients, and moisture) is increasing at a pace that is similar to the development of other high-end technology systems. For example, technologically advanced devises, such as electronic noses that detect volatiles released by pathogens, acoustic detectors for identifying insects, and portable PCR units for real-time identification of fungal, bacterial, and viral diseases, have been described as the future for monitoring pests in a comprehensive program for managing cropping systems (Zijlstra et al., 2011).

While several research- and a few commercial-grade systems are being developed for targeted applications, little is known about the precise rates of herbicides and other treatments that are needed to control very small weed seedlings. Studies have been conducted on reduced doses and spray volumes, but not at the micro-scale. With advances in sensors and guidance technology, weed control is changing dramatically. By using technologically equipped machinery that can target individual weeds in real time, there is no limit to the number of control tools for use in the field at any one time. Biological research and the latest technological developments in weed control have the potential to radically change the current approach to weed control and help significantly reduce environmental impacts (e.g., drift, off-target movement, and herbicide resistance) and the high cost of inputs and labor.



Black nightshade. Photo courtesy of Purdue University.

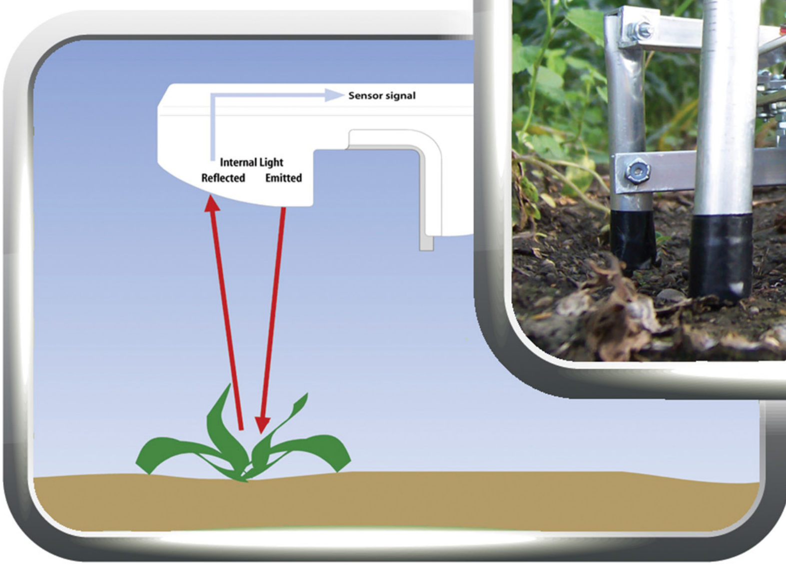
If it were possible to control weeds without disturbance, the environment would be better off and growers would have more time to focus on the things that the invention of herbicides allowed for over 50 years ago. It is safe to say that if we could manage weeds without inputting toxins, causing erosion, and changing genetics, we would. Unfortunately, as the population of the world is increasing, the amount of arable land available for producing crops is not. Therefore, we need to get more precise in managing crop production, and at the same time, take steps to protect and limit damage to the ecosystems that ultimately support every single livelihood in every single culture that occupies every single part of the globe.

What lies ahead?

In the U.S., production agriculture is contributing to meeting the needs of a growing population, but our methods for growing food must get better faster or we could face a significant shortfall. One way to do this is by being more precise in our management of pests (e.g., weeds), which will result in increased production, lower inputs, and reduced environmental contamination, which in many ways, moves us closer to more sustainable systems.

Precision weed management (PWM), which simply stated, "places the right amount of inputs on the right target [weeds] at the right time," is an approach to managing weeds that is better for the environment and

Weed control in the future will likely involve the use of robots as well as improvements in sensor and plant recognition technology. **Left:** WeedSeeker uses advanced optics and computer circuitry to sense if a weed is present. Image courtesy of Trimble. **Center:** AgAnt robot. Image courtesy of Tony Grift and the Agricultural and Biological Engineering Department at the University of Illinois. **Right:** Leafsnap is a plant identification mobile app created by The Smithsonian Institution, Columbia University, and the University of Maryland.



better for the producer as it leads to a reduction of herbicides and other costly inputs without decreasing weed control efficacy. In fact, one of the biggest contributions of PWM is the improved efficacy of controlling virtually all weeds in conventional and organic cropping systems. This paradigm shift is based on strong collaborations between biologists and engineers who are working to harness tools with powerful technology and use them in managing weeds, which are the biggest problem in cropping systems of many parts of the globe.

Most studies during the last 20 years have addressed the classification of only two crop–weed classes or general cases of broadleaf versus grasses and, in other cases, crop row versus between crop row (Tang et al., 2003). However, to precisely classify a plant species that may be imbedded within other different species of plants in an image is a botanically challenging exercise. Now is the time to put together a complete robust system that essentially mimics the human taxonomic, plant identification keying method. Future studies are needed to determine minimal digital image resolutions needed to maintain the highest species discrimination performance.

Fuzzy logic, cluster algorithms, and cluster reassembly routines mimic human perception and decision-making and tend to work well for extracting convex leaf shapes from plant canopy images (Neto et al., 2006). However, for more botanically diverse leaf shapes, such as species with complex leaves, lobed margins (indented), trifoliolates, etc., new fitness criteria must be developed to accommodate various leaf shapes. Undoubtedly, integration of specific shape and textural venation feature analyses as a fitness or classification criteria may be a key to improvement for plant species identification. Work has already begun on utilizing digital canopy architecture metrics such as three dimensions, which is important to plant taxonomy.

What do we need to do?

Success on the topic of PWM is based on the integration of expertise from two different fields of study (e.g., biologists and engineers) that can address a problem that has plagued agriculture from its very start: weeds. Since before the introduction of the first herbicides, researchers have been developing biological methods and engineering approaches to control weeds. After this time, a reliance on one management tool (herbicides) eliminated the need for real advancement in weed management and subsequently en-

gineers and biologists have worked alone.

Today, the broadcast application of herbicides is impacting our ecosystems (e.g., runoff, drift, and ground water contamination) and causing entire cropping systems to fail (e.g., herbicide-resistant weeds), signaling the need for renewed collaboration between biologists and engineers. Considering the increasing number of people on this planet

and the little amount of time to figure out how to feed them all, we cannot afford to have our current systems fail, let alone ignore what is needed for the future.

In an effort to address this need, a paradigm shift is needed by those involved in weed control in cropping systems from the grower to the consultant to the researcher. If we expect to continue to maintain current yields and also increase production in the future, we will have to think more broadly in incorporating alternative approaches in our management strategies. To facilitate thoughtful discussions, a new book, entitled *Automation: The Future of Weed Control* (Young and Pierce), is being written for biologists, engineers, and practitioners because the expertise and ideas of all three are needed to address the current challenges of protecting ecosystems and producing more food for future generations.

Interested in this topic?

A new book discussing discrete and targeted control of weeds in cropping systems using advanced technology is coming out in mid-2013. Titled *Automation: The Future of Weed Control* (Young and Pierce), it is being written for biologists, engineers, and practitioners. For more information about how to get a copy, email Steve Young at steve.young@unl.edu.

The discrete and targeted control of weeds in cropping systems using advanced technology is a first step in addressing these challenges, which is covered in this new book due out in middle part of next year.

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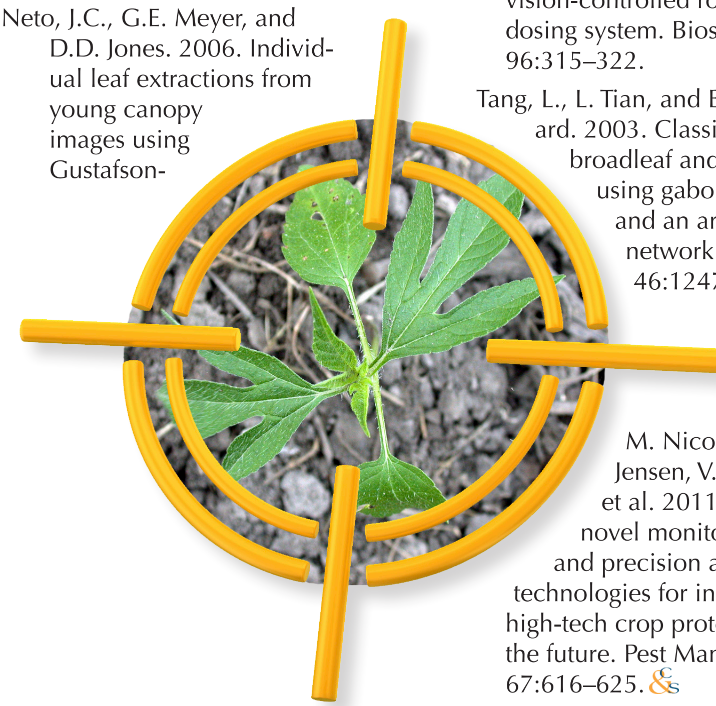

Giant ragweed. Photo courtesy of Purdue University.