Feature

New directions in crop protection

The spread of herbicide-resistant weeds, progress in genomics, climate change and the continuing worries about pollinator decline are forcing companies to rethink their approach to crop protection. **Michael Gross** reports.

World population is likely to cross the threshold of 7 billion in October, meaning it has doubled since the late 1960s. In relative terms, the growth has already slowed down significantly since its peak in 1963. However, in absolute numbers, there is no escaping the fact that the number of mouths that need feeding is still rising, while the agricultural surface available to produce food is remaining constant. Making matters worse, there is also an increasing demand for meat, the production of which requires more acreage than the equivalent amount of vegetarian food would.

Technology has already played a major role in making the current level of world population possible. It is estimated that more than half the biomass that mankind uses for food depends on nitrogen from the Haber Bosch synthesis. However, the efficiency improvements to be wrung out of synthetic fertilisers and chemical crop protection are already being applied around the globe, so there is not much room to expand global food production through these means.

GM crops, while rejected by many people across Europe, have been hailed as a way forward and widely used elsewhere, but are now running into serious difficulties.

Roundup over?

The green biotechnology solutions propagated by companies like Monsanto are designed for simplicity. For instance, the ‘Roundup Ready’ seeds contain a single additional gene making plants resistant to the broadband weed killer glyphosate (Roundup). Using such crops in combination with glyphosate, farmers can exterminate all forms of plant life apart from the crop they want to grow. However, as the first weeds resistant to glyphosate are now beginning to spread, this approach may be doomed to fail, as there is no backup combination of herbicide and GM crop that farmers could use to keep the glyphosate-resistant weeds in check.

As the news of this problem spreads and farmers are taking stock of their options, it is becoming clear that there aren’t any new herbicides to choose from. The runaway success of the GM approach in the US and in the developing world has made the development of new herbicides unattractive for the major chemical companies, and in any case, no fundamentally new principle of herbicide action has been discovered in the last 20 years, so the chemicals that have come to the market in this time span are all variations on known themes. This lapse in R&D has given weeds time to adapt and find ways of escaping herbicide action.

This may be a good time, then, to consider whether the ecologically dubious approach of planting hectares with clones of a single genetic variant and exterminating everything else is really such a bright idea. In the cultivation of high value crops, such as wine and cocoa, there is already an appreciation of the fact that a range of biodiversity around the crop plant may actually be helpful. Maybe other kinds of crops could also benefit from such approaches, and the natural pollinators certainly would prefer to see a bit more variety on the fields.

Cottoning on: Genetically modified cotton plants, like these in Arkansas, are widely used in the US. They carry a gene that makes them resistant to the herbicide glyphosate (Roundup). However, weeds with the resistance trait have now emerged. (Photo: Bill Barksdale/AGStock-USA/Science Photo Library.)

Natural enemy: Experts at the Centre for Agricultural Bioscience International (CABI), have selected the psyllid *Aphalara itadori* for a biocontrol program targeting the invasive weed, Japanese knotweed, in the UK. (Photo: © CABI.)

Chemical solutions

Developing insecticides should in theory be easier than herbicides. Due to the fundamental biological differences between plants and insects, there are many ways of killing pests without affecting the crops. However, specificity problems come into play as soon as one considers the useful insects that are typically found around agricultural crops, including bees and other pollinators. Thus, the harm done to 'good insects' is a major criterion in assessing the environmental impact of any insecticide.

In the 1990s, for instance, neonicotinoids were introduced as novel, 'systemic' insecticides and praised as benign towards other insects. By treating seeds with these chemicals, which would then be incorporated into all cells of the growing plants, one could ensure that their toxicity would only affect insects that nibble from the plant. There would be little environmental exposure to the toxins and even pollinators would be safe. That was the theory, at least.

However, when the unexplained disappearance of bee colonies dubbed 'colony collapse disorder' or CCD started to occur in 2006/2007, neonicotinoids were one of several factors that came under suspicion of causing the phenomenon. While there is no final explanation yet, several studies suggest that a combination of infection with *Nosema* fungi and the presence of neonicotinoids may contribute to the disappearance of honeybees. The excessive energy consumption of the fungus, as one hypothesis goes, makes the bees so hungry that they ingest unusual quantities of food burdened with neonicotinoids (see Curr. Biol *21*, R137–R139).

Green biotech has also had a blockbuster product in this field. GM plants that express the *Bacillus thuringensis* toxin, which kills caterpillars, have found widespread use, for instance in maize and cotton cultivation in the US.

Yet the remaining market for chemical insecticides, especially in Europe, where scepticism of GM crops remains strong, is large enough to motivate companies to develop new agents. Thus, the US company DuPont has recently released the new compound rynaxypyr, an anthranile diamide compound that blocks the insects' ryanodine receptor, which is a calcium channel.

The most trouble-free area for traditional chemical crop protection is the development of fungicides. There is no competition from GM crops and no hard-to-avoid side effects. In fact, there have been studies suggesting that fungicides may benefit the plants even if there aren't any fungi to kill.

Thus, agrochemical companies have enthusiastically embraced R&D in this field. Bayer CropScience, for instance, has four new fungicides coming out this year or next. Three of them (Bixafen, Fluopyram, and Penflufen) inhibit respiration in the fungal mitochondria. They can be formulated as a treatment to prepare the seeds before sowing, which minimises release of the chemicals into the environment.

Another new fungicide from Bayer CropScience, isotianil, is designed to combat rice blast, the most common disease of rice plants worldwide. It is already on the market in Japan and Korea.

Alternative approaches

There are, however, 'green' alternatives to GM and chemical insecticides. Biological control, using natural enemies of the pest species, can be applied either in the 'classical' or in the 'augmented' way.

Classical biological control is based on the observation that pests have often been transferred to new habitats without bringing their natural enemies along, which then allows them to spread unchecked and causes problems to crops. By inoculating such areas with the natural enemies of these pests, farmers can allow nature to re-establish the natural balance between the species and hold the pests in check.

Augmented biological control, by contrast, is a somewhat more drastic approach that involves breeding the natural enemy species in large quantities in biofactories and then unleashing it on the unsuspecting pest with the aim of reducing the pest population below damaging levels.

Both these approaches are well-tested for hundreds of pest species, as entomologist Joop C. van Lenteren from Wageningen University (Netherlands) documents in a recent review (BioControl (2011), DOI 10.1007/s10526-011-9395-1). The most widely used agents used in augmentative biological control are targeting aphids, whiteflies, thrips, mites and leafminers. Some control agents from the families of Phytoseiidae (mites that feed on thrips and other mites) and Braconidae (wasps) are already used in more than 20 countries. Leading markets are greenhouse crops in the Netherlands, the UK, France, and Spain.

However, the author diagnoses a "frustrating lack of uptake" of these methods, which he blames on the established culture of pesticide-dependent farming. "The pesticide industry considers biological control as cumbersome and of restricted use, most farmers have become pesticide addicted during the past 60 years, governmental institutions do not enforce or stimulate non-chemical pest control, and many regulations concerning the collection and application of biological control agents delay or even prohibit their use," Van Lenteren writes.

Still he remains optimistic, concluding that "recent developments may, however, lead to a promising future for augmentative biological control". Specifically, the author believes that the spread of pesticide resistance, combined with consumer demand for residue-free food and changes in government policies, particularly at EU level, will give an additional boost to ecological pest control.

The methods could also get a publicity boost from a major biocontrol programme launched against the invasive weed Japanese knotweed (*Fallopia japonica*) in the UK last year. This is the first time that a biological control agent has been used against a weed in the EU. Researchers at the Centre for Agricultural Bioscience International (CABI), a not-for-profit organisation based at Wallingford in Oxfordshire, have screened the many insects that keep the weed in check in its native Japan and identified one, the psyllid *Aphalara itadori*, that doesn't appear to damage any other plants. In the spring of 2010, these sap-sucking psyllids were released in a few test areas, but it will take several years to establish whether they can curb the spread of the weed in the UK.

Mellow yellow: Rapeseed is among the plants that Bayer CropScience aims to improve by accelerated mutation and selection. (Photo: © Bayer CropScience.)

Speeding up evolution

Meanwhile, the agrochemical industry is busy developing its own alternatives to GM crops and chemical agents. As quite a few important crop plants already have their genomes sequenced (e.g. rice, soy, vine, cotton, maize, and rapeseed), researchers are now hoping to go beyond the simplistic approach of introducing or changing a single gene, and improve the whole system instead.

Bayer CropScience, for instance, are aiming to optimise the entire metabolism of plants for the cultivation conditions, making them more stress resistant. As climate change is already beginning to impact on agriculture around the world, stress-resistant crops are expected to gain significant economic importance. Considering the scepticism towards GM food that is widespread across Europe, Bayer researchers are trying to achieve these goals with somewhat more 'natural' methods. Together with the seeds specialist company Nunhems in the Netherlands, they use the methods of genomics and molecular biology to speed up evolution, simply by accelerating the crucial steps of mutation and selection.

Scientists can easily boost the mutation rates using either chemicals or radiation and, given the knowledge of the genome sequence and an idea of which genes they want to change, they can select mutated seeds without having to go through the entire life cycle of the plant to identify the most promising variants. "This targeted selection saves tremendous development time, space in the greenhouse and test fields, and thus money," explains Jan van den Berg from Nunhems in Bayer's magazine, *research*.

Bart Lambert's team at Bayer CropScience wants to use the rapeseed genome, which it helped to decode in 2009, to stop the plant from shedding its seeds before the harvest. Lambert and colleagues are also tuning the spectrum of fatty acids produced by the plant. Although rapeseed oil is already one of the healthier natural oils with low content of saturated fatty acids, processing of the oil has often produced unwanted trans acids. Lambert and coworkers have now adjusted the metabolism of the plant such that these unwanted byproducts can be avoided.

Other research projects at the company aim to improve the characteristics of rice, soy, cotton, wheat, and various vegetables. Taste, durability in storage, and resistance to environmental stress like drought, frost, or shortage of nutrients are among the characteristics the researchers want to tackle. Typically, these are complex characteristics that cannot be addressed in the traditional way of introducing a single gene.

From an ecological perspective, it is to be hoped that companies learn the lessons of past problems and make good use of the genetic diversity created from the molecular breeding process, rather than narrowing down on clones of a single genotype again. As climate change and population growth continue to challenge global agriculture, diversity is likely to be a valuable asset.

Michael Gross is a science writer based at Oxford. He can be contacted via his web page at www.michaelgross.co.uk