The essential need for GM crops

The need for GM crops is growing rapidly as a consequence of the overriding priority for the sustainable generation of vastly increased food production. Although demands for energy and raw materials from the bioeconomy remain, they may become eclipsed by the quest for more food.

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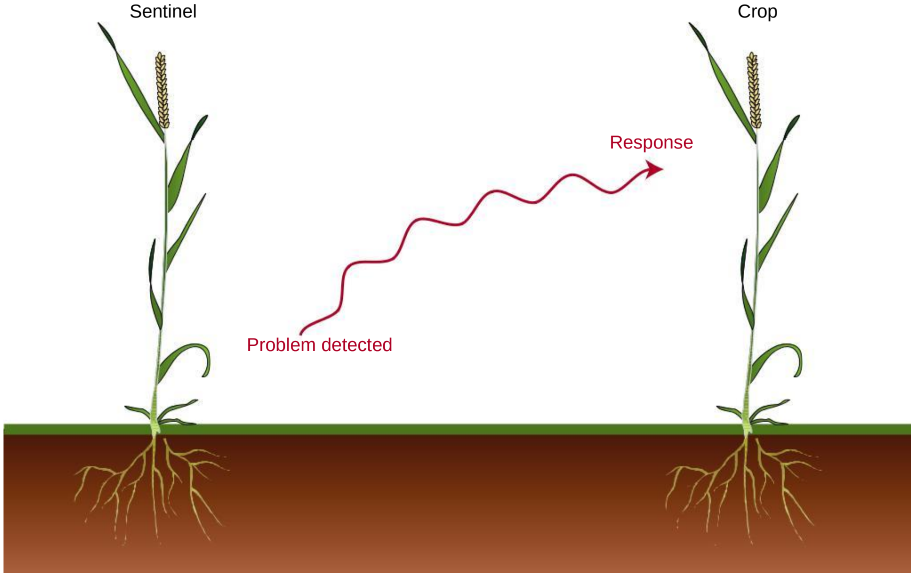

Figure 1 | Smart GM sensing to optimize farm inputs. Sensitive 'sentinel' plants would detect a problem (for example, pests, diseases, weed competition and depleted nutrients and water) or even an opportunity (such as excess nutrients and water), and signal to the main crop of 'smart' plants. Their GM-enhanced response to volatile signal compounds would be linked to gene expression of GM traits that can deal with the problem or opportunity.

Agriculture has long been a driver of technological innovation in the bioeconomy[1]. But any attempt to generate more food with current technologies, all of which require high inputs of energy for soil preparation and production as well as delivery of fertilizers and pesticides, will raise even further the already excessive carbon emissions resulting from agriculture. The highly energy-demanding Haber–Bosch process — an artificial nitrogen fixation process that is widely used as a source of fixed nitrogen — demonstrates how dramatically we are subsidizing current food production. About 80% of human bodily nitrogen has passed through the Haber–Bosch catalytic fixation of atmospheric nitrogen[2].

In addition to major inputs relating to land preparation, nitrogen fixation and phosphorus acquisition, our efforts to counter inputs in crop resistance to pest diseases and weeds also contributes to the high carbon footprint of agriculture, and reductions in harvests due to these constraints are losses for which the carbon footprint has already been made. Thus, as was comprehensively described in a Royal Society report from 2009[3], we need to deliver, as rapidly as possible, new traits by seed and other planting materials so as to minimize and even eliminate the need of seasonally applied inputs. Nonetheless, by approaching these objectives, we will raise the opportunity for such sustainable interventions as to allow active reduction in carbon footprint and the sparing of land for ecosystem services[4].

Currently, we see no clear approach to solving many of these problems other than by using genetic modification (GM)[5]. Complex traits, such as those associated with nitrogen fixation, may also require extensive molecular guided breeding programmes. Nonetheless, GM will be the tool of choice in this dramatically difficult scientific and technological quest. Interim solutions, including improved decision support systems, are essential — but entirely new technology will also be crucial.

It seems inevitable that to reduce the intensity of land preparation much arable farming will need to convert from annual to perennial cropping systems. This perennialization will undoubtedly be achieved by sophisticated breeding efforts, but augmented by GM-based traits to overcome the expected problems associated with such new crops. For example, perennialization will aggravate problems of rhizosphere pests and diseases, including nematodes and soil-inhabiting fungi, and so crop varieties will need to be made more resistant to such assaults.

Here, the generic term GM includes all the new and emerging techniques of genome editing and synthetic biology. These will be even more important when addressing nitrogen fixation, improving the efficiency of photosynthesis, and transferring other essential traits to crop plants. However, to solve these problems, we face two major challenges: public acceptability and a paucity of relevant genes.

Public acceptability

In the UK, public engagement at all levels and particularly with younger generations, through social media, has fortunately reduced the effectiveness of GM crop destruction as a political statement by those most vehemently ill-disposed towards this technology. This should by no means make scientists in the field complacent, however, and it is essential that a dialogue be maintained with all stakeholders, including the public. With some specific exceptions, such destruction of GM crops continues in Europe, and non-evidence-based criticisms of GM make the widespread development of these technologies difficult, forcing out of Europe such activities by major industrial players (as recently occurred with the chemical producer BASF). Although there is a belief among many life scientists that GM is the only way forward to deal with problems of food sustainability without damaging the environment, there must not be a return to the levels of arrogance seen in the scientific community during the early, rapid-expansion stages of GM crops.

The acceptance of field experiments with GM in the UK (and some other regions in Europe) is not a direct indication that large-scale incorporation of GM products into the food chain will be accepted in the near future. Even where this is already the case, such as in the US and Brazil, there are still substantial and vociferous detractors. In furthering public acceptability, we must offer much more to the public itself, and this requires substantially more investment in the science[3]. Of course, food security will gradually grow in importance and drive the move towards widespread acceptability of GM crop production and hence GM food consumption. However, it must be acknowledged that the rapid expansion of GM technologies has yet to solve the foreseen problems of food availability.

Hypothesis-driven (or 'blue sky') research into the use of GM must be funded, but only with public and thereby political support. The UK currently invests less than its fair share into such research relative to its gross national product. This should be rectified, not only to promote national and global food security, but also because the UK, despite a lack of national resources, maintains a world-leading position that could be the basis of the exports of economically valuable GM-related technology. Since the Royal Society report[3], which has so far been acted on with negligent insufficiency, dangerous arguments against adoption of its recommendations have emerged. Nevertheless, it is reassuring to see sustainable intensification as a cornerstone of current Research Council (for example, BBSRC) policy.

Not enough genes

In the future, it will be important to investigate whether the new GM-based traits can be employed in mono-cultured crops, or whether mixed cropping or the complimentary engineering of rhizosphere organisms will be needed. But we have not yet made sufficient progress in identifying genes that can be engineered to improve efficient nitrogen fixation and effective scavenging of bound phosphorus available within current cropping systems. The range of robust genetics for disease and herbivore resistance is limited, and large resources are still directed at relatively traditional breeding programmes rather than capturing genetics from sources taxonomically distant from the current 'elite' cultivars.

Hypotheses relating to new traits for crop protection are being tested. For example, our group at Rothamsted Research is using genes for pheromones that regulate pest behaviour, but although this approach has been successful in testing the scientific principles, it has so far been unsuccessful in terms of providing a new crop protection strategy[6]. Dramatic progress has been made concerning pathology and control of fungal pathogens, such as those causing potato late blight (*Phytophthora infestans*)[7] and Asian soybean rust (ASR; *Phakopsora pachyrhizi*)[8], which was achieved only by targeting genetics well beyond the contaminated host species. But for major potential problems (including ASR) that would, if unchecked, substantially threaten global production of animal feed for zero-grazing husbandry in Europe, we are currently dependent on the deployment of synthetic fungicides.

There are also examples of truly excellent research programmes in crop production, specifically for C_4 photosynthesis[9] and biotechnological nitrogen fixation[10]. However, an even greater effort is needed to translate these studies into practice. We must prioritize moving to tactical gene promoter systems rather than relying on constitutive expression of new GM traits. Success here would see the realization of a self-protecting crop. 'Sentinel' plants within a field would identify emerging threats or challenges, be they the arrival of pests or the approaching scarcity of nutrients, and use volatile signals to elicit defensive responses in the crop itself[11] (Fig. 1).

The arguments above demand that the Royal Society's recommendation for further UK funding in this area of £2 billion over 10 years[3] be enhanced and enacted forthwith, and that other countries make similar investments worldwide. If not, we will have fallen far short of solving the technological challenges by the time negative effects of food shortages on society make discussions of the acceptability of GM food wholly irrelevant. ❐

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