Critical environmental safety issues associated with GM crops

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There are several environmental concerns associated with GE crops:

I. Will toxins be produced that have non-target effects?
II. Will resistance develop in pest populations?
III. Will transgenes significantly increase the invasiveness of crops and/or wild relatives.
IV. Will land races be negatively impacted by the planting of GE crops.

1. What should be done to determine if there will be significant non-target effects of transgenes?

I. Test toxicity on indicator organisms in the laboratory

II. Monitor for toxic effects in the greenhouse and field

A four tier system is used in the USA

Tier 1

Laboratory

Analyze toxicity of microbially derived protein mixed with diet

Tier 2

Laboratory

Analyze other routes of exposure, such as transgenic leaf material and exposed prey

Indicator species

- Honey Bees
- Beneficial insects
- Non-target herbivores
- Soil organisms
- Aquatic organisms
- Birds
- Mammals
- Endangered species






Tiers 1 and 2 testing endpoints

- LD_{50} - lethal dose at which 50% of organisms are estimated to die
- LC_{50} - lethal concentration at which 50% of organisms are estimated to die
- EC_{50} – concentration where 50 % impact on development or mass is estimated to occur
- NOAEC - greatest concentration of a substance, found by experiment or observation, which causes no significant adverse effect when compared with the control

Tier 3

Long term laboratory or semi-field
(Greenhouse or cages)

Tier 4

Open field

Large enough scale to determine population level effects

Field monitoring

Above-ground

Aerial/flying invertebrates

Ground Level

Surface dwelling organisms

Pitfall traps / emergence traps / litter bags

Below ground

Soil dwelling invertebrates and microrganisms

The potential non-target effects of two genes of interest have been evaluated extensively

- Bt in cotton and maize
- Glyphosate resistance in maize and rice

Environmental safety of Bt

- Targets only lepidoterans (butterflies and moths), dipterins (flies and mosquitos) and/or coleopterins (beetles)
- Used in sprays of conventional and organic agriculture for decades
- Cause little or no harm to non-target organisms including people and wildlife

Non-target wildlife showing no adverse effect from Bt maize

- Bt protein
  - Honeybee
  - Ladybird beetle
  - Parasitic wasps
  - Green lacewing
- Bt in soil
  - *Collembola* (spring tails)
  - Earthworms
- Corn meal
  - Quail
- Corn pollen
  - *Daphnia* (water flea)
  - Honey bee

Romeis et al. 2006. Transgenic crops expressing *Bacillus thuringensis* toxins and biological control. Nature Biotechnology 24, 63-71

Environmental safety of glyphosate

- Targets an enzyme involved in amino acid synthesis in plants
- Little persistence in soil; broken down by microorganisms in days to months
- Little toxicity to insects, birds, fish or mammals

Extoxet (1996) Glyphosate.
http://extonet.orst.edu/pips/glyphosa.htm

Pesticide news (2003) http://www.pan-uk.org/pestnews/actives/glyphosa.htm

2. What has been done to delay the evolution of resistance?

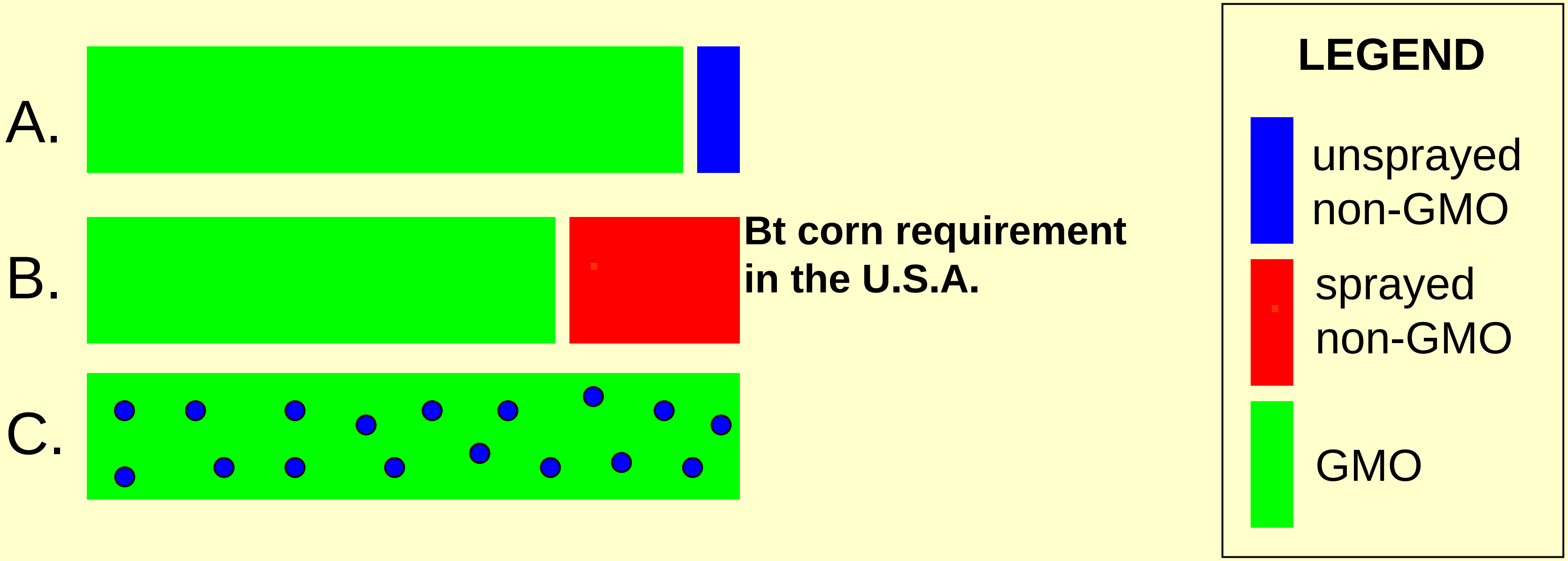
I. Using very high toxin levels
II. Stacking genes
III. Developing refugia

The hypothesis: If resistance arises in a pest population, resistant individuals will mate with non-resistant individuals and thereby dilute levels of resistance and thin out resistant individuals.

THE REFUGE MODELS

There are currently three main models accepted

A. 95:5 external unsprayed refuge
B. 80:20 external sprayed refuge
C. 95:5 embedded refuge



What has happened so far?

No resistance has been observed in the field after about 10 years of GE crops

Only one pest (Diamondback moth) has evolved resistance to Bt sprays in 50 years

Tabashnik et al. 2003. Insect resistance to transgenic Bt crops, lessons from the laboratory and field. J. Economic Entomology 96: 1031-1038

3. What should be done to determine whether a transgene will increase the invasiveness of a crop or native species?

I. Identify any compatible native relatives.
II. Determine if there is gene flow between the transgenic crop and its native relative.
III. Determine the invasiveness of the conventionally bred crop and wild progenitor.
IV. Classify the fitness impact of the transgene.

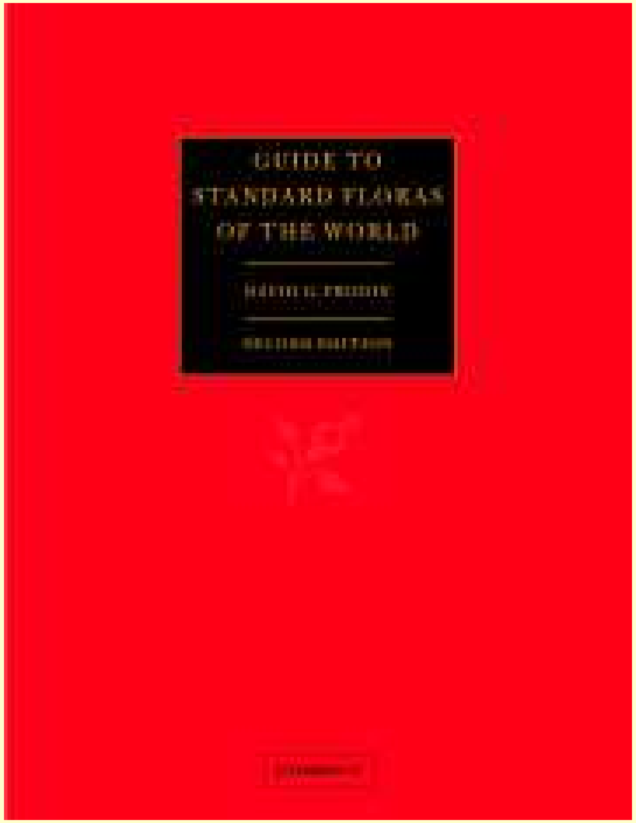
In most cases, information on the location and inter-fertility of compatible relatives has already been published:

- Published floras (botanical keys)
- Scientific literature
- Evolutionary and breeding histories

A new census is generally not necessary.

Guide to Standard Floras of the World
2nd Edition
David G. Frodin
Royal Botanic Gardens, Kew
Published June 2001

Hardback
(ISBN-10: 0521790778 | ISBN-13: 9780521790772)
Also available as eBook 124 pages



Examples of breeding/evolutionary histories:

- Sauer, J. D. 1993. Historical Geography of Crop Plants.
- Smartt, J. and N. W. Simmonds. 1995. Evolution of Crop Plants.
- Zohary, D. and M. Hopf. 2000. Domestication of Plants in the Old World.
- Hancock, J. F. 2004. Plant Evolution and the Origin of Crop Species.

African crops:

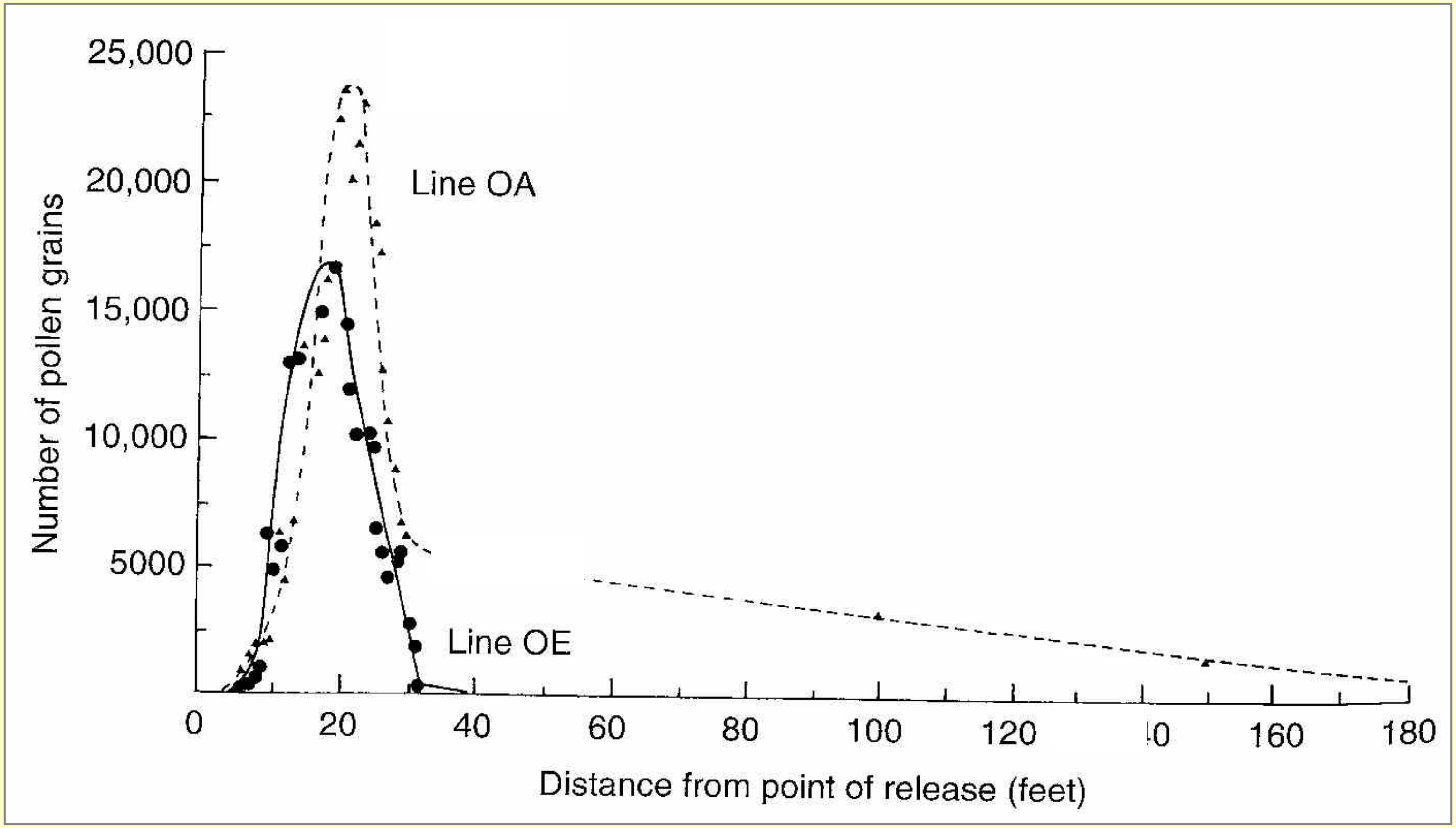
- With compatible relatives
  - Cowpea, coffee, cotton, millet, rice, sorghum & yam
- Without compatible relatives
  - Banana, cassava, coco, maize, sugarcane, sweet potato & wheat

3. What should be done to determine whether a transgene will increase the invasiveness of a crop or native species?

I. Identify any compatible native relatives.

II. Determine if there is gene flow between the transgenic crop and its native relative.

The reality is that if a compatible relative exists, transgenes will escape



3. What should be done to determine whether a transgene will increase the invasiveness of a crop or native species?

I. Identify any compatible native relatives.

II. Determine if there is gene flow between the transgenic crop and its native relative.

III. Determine the invasiveness of the crop and wild progenitor.

Information on whether the crop or native relative is invasive can be obtained from several sources:

- Personal knowledge
- Local floras
- Publications about the life history of the species

From the literature, species can generally be put into three categories of invasiveness

- Non-persistent
  - Cotton, cowpea, chickpea & maize
- Persistent but non-invasive
  - Asparagus, sweet potato, cassava & yam
- Persistent & invasive
  - Rapeseed, rice & sorghum

Invasiveness can also be measured by determining the number of “weedy” traits a species carries (Baker, 1974)

- Broad germination requirements
- Discontinuous germination
- Long lived seeds
- Rapid growth to flowering
- Continuous seed production
- Self pollinated
- Unspecialized pollinators
- High seed output
- Seeds produced in many habitats
- Short and distant seed dispersal
- Vigorous vegetative reproduction
- Brittle propagules
- Vigorous competitors
- Polyploid

This information can often be found in the literature.

Proportion of weediness traits in invasive vs. non-invasive species

- **Invasive species - 81 %**
- **Random non-weeds - 59 %**

(Keeler, 1989)

Information on persistence and “weediness” can be combined with range distributions to estimate the overall invasive impact of a crop.

Two broad categories:

1. Crops with no compatible relatives
   Need only worry about crop
2. Crops with compatible relatives
   Need to worry about crop and native relative

In general, we need to worry most about those crops that are already invasive and have compatible wild relatives

Invasive potential of crops with no compatible relatives:

1: Crop carries only a few weediness traits, and does not escape or persist (Maize)

2: Crop carries an intermediate number of weedy traits, but does not persist

3: Crop carries many weediness traits and and persists (Wheat).

Levels of invasive potential of crops with compatible relatives:

1: Crop or relative carries only a few weediness traits. Crop can escape but does not persist. Native relative does not aggressively spread (Cotton)

2: Crop or relative carries intermediate numbers of weedy traits. Crop persists. Native relative does not aggressively spread (Yam).

3: Crop or relative carries many weediness traits. Crop persists. Native relative spreads aggressively (Sorghum).

3. What should be done to determine whether a transgene will increase the invasiveness of a crop or native species?

I. Identify any compatible native relatives.
II. Determine if there is gene flow between the transgenic crop and its native relative.
III. Determine the invasiveness of the crop and wild progenitor.
IV. Classify the fitness impact of the transgene.

Relative fitness impact of transgenes

1: Neutral in the native environment (Marker genes)

2: Detrimental in the native environment (Male sterility)

3: Variable, depending on invasiveness of crop or native relative (Herbicide resistance)

4: Variable, depending on level of biological control (Pest resistance)

5: Advantageous in the native environment (Cold, drought & metal tolerance)

The three crop/transgene risk factors should be combined to determine how much experimentation needs to be conducted before a transgenic crop is released.

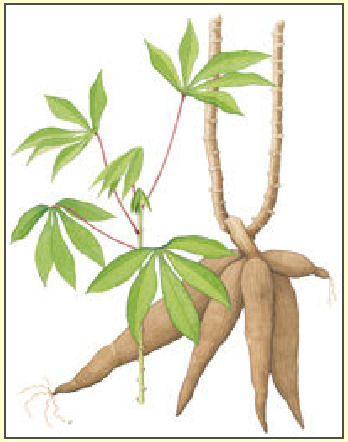
There are three overall levels of risk based on existing information:

1. Safe to deploy without any further experimentation
2. Require further experimentation
3. Probably shouldn't be done

Whether the crop has a wild relative or not is often a critical issue.

Combinations safe to deploy without any further experimentation:

- Herbicide resistance in crops with no native relatives or their relatives are not invasive.

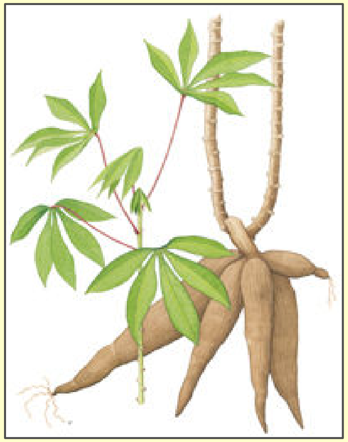


Glyphosate resistance

Combinations safe to deploy without any further experimentation:

- Pest resistance into non-invasive crops with no native relatives

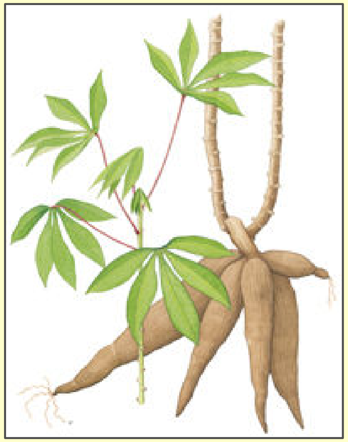
Bt, Maize streak virus resistance



Cassava mosaic virus resistance

Combinations safe to deploy without any further experimentation:

- Advantageous trait into non-invasive crops with no native relatives



Drought tolerance

Crop-transgene combinations that require further experimentation

- Pest resistance into a crop with a compatible native relative

Bt

Necessary experiments:

- Pest resistance into a crop with a compatible native relative
    - ✓ Show that a similar phenotype exists in wild populations.
    - ✓ If not, measure the level of native biological control.

If levels are significant, test fitness of transgenic crop and hybrids in representative native environments.

Crop-transgene combinations that require further experimentation

- Advantageous trait into any species with a compatible relative

Drought tolerance

Necessary Experiments:

- Advantageous trait into any species with a compatible relative
  - ✓ Need to show that a similar phenotype exists in wild populations.

If there is not, need to test fitness of transgenic crop in representative native environments

Combinations that shouldn’t be done

- Highly toxic compounds into any crop
- Herbicide resistance into a crop with a weedy relative
- Unique advantageous trait into a crop that is highly invasive or has a highly invasive relative

4. Critical issues associated with the “threat” of transgenic crops to land races

I. Land races are evolving entities.

II. Hybridization will occur where transgenic crops are planted next to land races.

4. Critical issues associated with the “threat” of transgenic crops to land races

- Land races are evolving entities.
- Hybridization will occur where transgenic crops are planted next to land races.
- Whether a transgene becomes incorporated into a land race is generally dependent on the farmer.

Potential impact of transgenic crops on land races is no different than that from conventional ones.

In summary:

- To evaluate the environmental risks associated with the release of GE crops.
  - We need to identify potential toxins and test their effects on a wide array of model, non-target species.
  - Determine the geographical range of compatible relatives.
  - Evaluate the invasiveness of the crop and its congeners.
  - Calculate the fitness effect of the transgene.

New experimentation should be based on what scientific information is already available.

In many cases, enough information already exists to proceed with release.

We can think of land races much like native species, but the two differ in that the farmer is in control.

The “threat” of transgenic crops to land races is no greater than that of conventionally bred crops

References:

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Ellstrand, N.C., Prentice, H.C. and Hancock, J.F. 1999. Gene flow and introgression from domesticated plants into their wild progenitors. Annual Review of Ecology and Systematics 30: 539-563.

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Keeler, K.H. 1989. Can genetically engineered crops become weeds. Bio/Technology 7:1134-1139.