

# *Invasiveness of Transgenic vs. Exotic Plant Species: How Useful is the Analogy?*

James F. Hancock  
Karen E. Hokanson

## ABSTRACT

Numerous ecologists and evolutionary biologists have incorrectly suggested that genetically engineered crops are analogous to exotic introductions. A growing body of evidence indicates that exotic species become invasive when they are introduced into a new area, where there are few to none of the natural constraints with which they evolved, and so they fill a new niche and their numbers explode. Most of the successful exotics are already good colonizers somewhere else and carry a whole syndrome of traits associated with weediness. This is very different from the situation facing transgenic forestry and agronomic crops. The crop antecedents are generally poor competitors outside the agroecosystem and carry few weediness traits. After the crop is engineered, it will not be removed from the complex array of natural constraints that currently faces it, and in most cases only one of those constraints will be removed by the addition of a new trait. In fact, it is much easier to predict the environmental risk of transgenic crops than an exotic introduction, as the level of risk in transgenics can be measured by evaluating the fitness impact of a single engineered trait, rather than a whole syndrome of potentially invasive traits. The risk of most transgene deployments can be effectively predicted by considering the phenotype of the transgene and the overall invasiveness of the crop itself.

It has commonly been suggested that invasive, exotic species can be used as models for evaluating the risk of release of transgenic crops (NAS 1987; Tiedje et al. 1989; Parker and Kareiva 1996; Marvier 2001). For example, Keeler (1998) states, "one set of data that can be used to understand what engineered organisms are likely to do is derived from the literature on introduced organisms. They are not genetically engineered, but they represent organisms that were introduced into communities of organisms which they had no previous experience."

We are all familiar with the 'environmental disasters' associated with the introduction of exotic species. In many instances, these species were intentionally introduced, such as *Rhododendron* in the U.K., pine in Australia, kudzu in the southeastern U.S., and purple loosestrife in eastern North America (Keeler 1988; Mooney and Drake 1986; Crowley 1997). Others arrived on their own, such as the Dutch elm disease and corn leaf blight in North America. The vast majority of introduced organisms perish or don't establish self-sustaining populations (Pimentel et al. 1989), but we keep being drawn to those that do.

## CHARACTERISTICS OF INVASIVE SPECIES

So, what does make a species invasive? To answer this question, we first need to define what we mean by invasive. Probably the most common definition given

*Jim Hancock is with the  
Department of Horticulture,  
Michigan State  
University, East Lansing,  
MI 48824.*

hancock@pilot.msu.edu

*Karen Hokanson is with  
the Department of Horti-  
cultural Science, Univer-  
sity of Minnesota, St.  
Paul, MN 55108.*

hokan018@umn.edu

is the ability to increase when rare; however, all successful species meet this criteria. Crowley (1997) suggests that invasive species should really be called “problem plants,” where the species has passed some threshold of abundance and someone is concerned. He suggests that to understand the population biology of an invading plant genotype, we need knowledge of the following: 1) abiotic environment, 2) the biotic environment, 3) interaction between biotic and abiotic environment, and 4) the year. In other words, the nature of invasiveness is a very complex situation.

Sarah Reichard recently published a series of papers presenting a framework for evaluating plant invasiveness (Reichard and Cambell 1996; Reichard and Hamilton 1997; Reichard 1999). Her decision tree is based on a predictive model derived from discriminant and regression analysis of a number of structural, life history, and biogeographical characteristics of introduced woody plants. The characteristics analyzed, most of which have routinely been implicated in association with invasiveness, included: native range, whether or not the species invades elsewhere, leaf longevity, polyploidy, reproductive system, vegetative reproduction, minimum juvenile period, length of flowering period, flowering season, length of the fruiting period, fruiting season, dispersal mechanism, seed size and seed germination requirements.

Of the woody plants that invaded the United States, Reichard found that 54% invade other parts of the world, 44% spread by vegetative means, most have shorter juvenile periods, and 51% have seeds that germinate without pretreatment, while only 3% have been

introduced from other parts of North America and 1% are interspecific hybrids. Based on these results, Reichard developed a decision tree for acceptance of exotic woody species into North America, which begins with the question “Does the species invade elsewhere, outside of North America?” Two other important questions in the decision tree are “Is the species in a family or genus with species that are already strongly invasive in North America?” And, “Is the species native to parts of North America other than the region of the proposed introduction?” Other questions in the decision tree concern whether or not the species is a sterile interspecific hybrid, rate of vegetative reproduction, the length of the juvenile period, and germination requirements.

What her analysis indicates is that a high percentage of the exotic species that become invasive are already excellent colonizers somewhere else and their population size explodes when they are introduced into a new area where there are few to none of the natural constraints with which they evolved. This is very different from the situation facing transgenic forestry and agronomic crops. They will not be removed from the complex array of natural constraints that currently face them, and only a very limited number of these constraints will be removed by the addition of a new trait through genetic engineering. The array of factors regulating natural populations must be complex, as the introduction of single biological control agents have rarely had much of an impact on invasive, exotic species (Pimentel et al. 1984).

## INVASIVENESS OF AGRONOMIC AND FORESTRY SPECIES

In fact, only a small percentage of agronomic and forestry crops are important weeds outside of agro-environments (Table 1). They rely on human disturbances to become established and rarely persist outside of specific habitats. Clearly exceptions exist, such as barley, rapeseed, and rice, but over 80% of all crop species do not persist

Table 1. Survival of North American crops in native environments

Non-persistent	Persistent/ non-invasive	Persistent/ invasive
Beet	Apple	Barley
Broccoli	Asparagus	Rapeseed
(Canola)		
Carrot	Blueberry	Rice
Cauliflower	Cranberry	Sorghum
Celery	Pear	Sunflower
Citrus	Poplar	Wheat
Cucumber	Spruce	
Cotton	Strawberry	
Eggplant		
Lettuce		
Maize		
Melon		
Onion		
Pea		
Peanut		
Pepper		
Potato		
Soybean		
Squash		
Sugarcane		
Sunflower		
Tobacco		
Watermelon		

(Source - Hancock et al., 1996)

in native environments. Crawley et al. (2001) have generated some excellent evidence of how poorly crop genotypes do in native environments whether they were genetically modified or not. When they compared the performance of transgenic and non-transgenic rape, maize, beet and potato in 12 native environments, the genetically modified plants were never found to be more invasive or persistent than their antecedents. In fact, all populations of maize, rape, and beet were extinct after 4 years, and only conventionally bred potatoes were left after 10 years (and only at one site). The transgenic rape and maize expressed tolerance to the herbicide glufosinate, the genetically modified sugar beet were resistant to glyphosate and the transgenic potatoes expressed either the insecticidal *Bt* toxin or pea lectin.

In his classic work, Baker (1965; 1974) associated a complex array of traits with colonizing ability including: broad germination requirements, short

and long seed dispersal, discontinuous germination, long lived seed, vigorous vegetative reproduction, rapid growth to flowering, brittle propagules, continuous seed production, vigorous competitors, self-compatible, unspecialized pollinators, very high seed output, plastic seed production and polyploidy. When Keeler (1989) took Baker's weediness traits and compared the worst weeds to agronomic crops she found that serious weeds possessed an average of 81% of these traits, while random non-weeds had 59% and crop plants had 42%.

To date, eleven tree crops have been genetically engineered in the United States and tested in the field: apple, papaya, citrus, persimmon, pear, plum, pine, poplar, sweetgum, spruce, and walnut. When they are rated according to Baker's characteristics, they all fall well below the random non-weeds, ranging from 21 to 50% (Table 2). Poplar has the highest average of 50%, possessing the weediness traits

unspecialized pollinators, variable seed dispersal distance, high seed production, seed production in many environments, vigorous vegetative propagation, brittle propagules, and polyploidy. However, they are outcrossing, have discontinuous seed production, short seed longevity, narrow germination requirements, discontinuous germination, are weak competitors, and grow slowly.

This suggests that in most agronomic and forestry crops, a whole syndrome of traits would need to be altered through genetic engineering to make them invasive; and Baker's list excludes most biotic controls. Because agronomic crops are often poor competitors in nature, their impact on native populations has also been generally limited due to introgression. There are numerous instances where hybridization with wild relatives has increased the weediness of the native species in agronomic fields through crop mimicry (Ellstrand et al. 2000), but there is little

Table 2. Weediness traits in transgenic trees that have been field tested in the United States.

Weediness trait	Apple	Papaya	Citrus	Persimmon	Pear	Plum	Pine	Poplar	Sweetgum	Spruce	Walnut
Broad germination requirements	no	no	no	no	no	no	no	no	no	no	no
Discontinuous germination	no	no	no	no	no	no	no	no	no	no	no
Long lived seeds (>5 years)	no	no	no	yes	no	no	yes	no	yes	yes	yes
Rapid growth	no	yes	no	no	no	no	no	no	no	no	no
Continuous seed production	no	no	no	no	no	no	no	no	no	no	no
Self pollinated	no	no	yes	no	no	no	no	no	no	no	no
Unspecialized pollinators	no	yes	no	no	no	no	yes	yes	yes	yes	no
High seed output	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Seeds produced in many habitats	yes	no	no	yes	yes	yes	yes	yes	no	yes	no
Short and distant seed dispersal	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	no
Vigorous vegetative reproduction	no	no	no	no	no	no	no	yes	yes	no	no
Brittle propogules	no	no	no	no	no	no	no	yes	no	no	no
Vigorous competitors	no	no	no	no	no	no	no	no	no	no	no
Polyploid (2n > 28)	yes	no	no	yes	yes	no	no	yes	yes	no	yes
% Weedy traits	28	28	21	36	28	21	36	50	43	28	21

evidence of crop genes effecting the overall fitness of a native species. Even though crop species have been planted among their progenitors for thousands of years, we are not aware of any report where the native fitness of the wild species was noticeably changed. When David Duvick (2000) ask a group of 20 experienced plant breeders if the introduction of conventional resistance genes has led to undesirable consequences with respect to the weediness of a crop or its relatives, the breeders knew of no example.

### ***Predicting the Environmental Risk of GMOs***

It has been suggested that genetically engineered trees pose significantly greater environmental risks than do genetically engineered food crops, because the genes inserted into trees are more likely to ‘escape’ into the wider environment (Campbell 2000). Plantation trees have been altered through breeding far less than have most agronomic crops, and as a result, are much more closely adapted to native habitats than are most crop species. However, most are not highly invasive in their native geographic range, and the transgenic derivatives and any native/engineered hybrids will be subjected to the complex array of factors that normally regulate the native populations. The bottom line in assessing the environmental risk of both transgenic trees and herbaceous crops is the nature of the transgene, i.e., how significant an impact will it have on the fitness of

native populations should it escape.

In fact, it is much easier to predict the environmental risk of transgenic trees than an exotic introduction, as the level of risk in transgenics can be measured by evaluating the fitness impact of a single engineered trait, rather than a whole syndrome of potentially invasive traits. A unique genotype is not being introduced into an environment where its native constraints are removed. The species is already in that environment and we know how invasive it is. What we need to worry about is whether the addition of a single gene will increase its existing level of invasiveness to problem levels. An increase in vegetative reproduction, a decrease in the need for pretreatment requirements, or a shortened juvenile period could certainly raise red flags concerning invasive potential. But these alterations are currently no more likely to be accomplished through genetic engineering than they are through traditional genetic improvements. If these characteristics are the subject of any research efforts toward genetic improvement, they should bear close scrutiny for their effects on invasiveness of the species.

In some cases, the risk involved in the deployment of these transgenes can be efficiently evaluated through the concept of familiarity (Hokanson et al. 2000). APHIS now assesses risk based on the biology of the crop, the nature of the introduced trait, the receiving environment and the interaction between these. Knowledge of these factors provides familiarity, which allows decision makers to compare genetically engineered plants to their non-engi-

neered counterparts. Familiarity allows regulators to efficiently assign levels of risk, without doing any additional experiments, when the phenotypic effects of transgenes closely mimic conventionally deployed or native genes. Hokanson et al. (2000), outline a number of examples where transgenic genotypes have similar non-transgenic phenotypes such as insect and virus resistance.

This approach was what was recommended by the first group of scientists who evaluated the environmental risks of transgenic crops. In the often cited paper of Tiege et al. (1989), they state “transgenic organisms should be evaluated and regulated according to their biological properties (phenotypes), rather than according to the genetic techniques used to produce them . . .” and “Long term experience derived from traditional plant breeding provides useful information for the evaluation of genetic alterations similar to those that might have been produced by traditional means, and such alterations are likely to pose few ecological problems.” One of the major conclusions of the National Academy of Sciences report on “Field testing genetically modified organisms: Framework for decisions” was that crops modified by genetic engineering will pose risks that are no different from those modified by classical genetic methods.

The problem with using the concept of familiarity is finding genes of equivalent effect and strength in natural populations. Reasonable arguments can be made for many of the transgenes that are similar to conventionally deployed resistance genes, but numerous

other engineered genes will produce phenotypes that are unique to the species or have broader effects than the native genes. Some of these transgenes are likely to be effectively neutral in the native environment, such as herbicide resistance, but others that alter reproductive potential and physiological tolerances may have much more significant impacts. Regardless, it is much easier to assign risk to transgenic crops than exotic species, as we can restrict our worry to the effect of one gene on the fitness of a species in the place it is already grown, rather than making guesses about the fitness of a whole species genome in a unique environment.

## CONCLUSIONS

The patterns of spread of invasive, exotic plant species cannot be used to predict the environmental impact of transgenic trees and agronomic crops. While it is true that some transgenes will influence individual traits associated with invasiveness, numerous other natural characteristics of these species make single changes unlikely to substantially alter their competitiveness. Invasive species have almost always been introduced somewhere where they have few to none of the natural constraints with which they evolved, and so they fill new niches and their population numbers explode. In many cases, these species were already invasive in their original habitats. This is very different than making a single change in a species already with multiple controls. Most engineered species are poor colonizers and they will be

grown in their original environment with its complex array of natural constraints. Normally, only one of these constraints will be removed by the addition of a new trait by genetic engineering. The risk of most transgenes deployment can often be effectively predicted by considering the phenotype of the transgene and the overall invasiveness of the crop itself.

## REFERENCES CITED

- Baker, HG. 1965. Characteristics and modes of origin of weeds. *In*: HG Baker and GL Stebbins, eds. *The Genetics of Colonizing Species*. Academic Press, New York.
- Baker, HG. 1974. The evolution of weeds. *Ann. Rev. Ecol. Syst.* 5:1–23.
- Campbell, FT. 2000. *Genetically Engineered Trees: Questions Without Answers*. American Lands Alliance, Washington DC.
- Crowley, MJ. 1997. Chapter 19: Biodiversity. *In*: MJ Crowley, ed. *Plant Ecology*, Blackwell Science Ltd., Oxford, UK.
- Crowley, MJ, SL Brown, RS Hails, DD Kohn, and M Rees. 2001. Transgenic crops in natural habitats. *Nature* 409: 682–683.
- Duvick, DN. 2000. Consequences of classical breeding for pest resistance. Pp. 37–42 *in*: PL Traynor and JH Westwood, eds. *Ecological Effects of Pest Resistance Genes in Managed Ecosystems*. Information Systems for Biotechnology, Blacksburg, VA.
- Ellstrand, NC, HC Prentice, and JF Hancock. 1999. Gene flow and introgression from domesticated plants into their wild relatives. *Annu. Rev. Ecol. Syst.* 30: 539–563.
- Hancock, JF, R Grumet and SC Hokanson. 1996. The opportunity for escape of engineered genes from transgenic crops. *HortScience* 31: 1080–1085.
- Hokanson, K, D Heron, S Gupta, S Koehler, C Roseland, S Shantharam, J Turner, J White, M Schechtman, S McCammon, and R Bech. 2000. The concept of familiarity and pest resistant plants. Pp.15–20 *in*: PL Traynor and JH Westwood, eds. *Ecological Effects of Pest Resistance Genes in Managed Ecosystems*. Information Systems for Biotechnology, Blacksburg, VA.
- Kareiva, P, IM Parker, and M Pascual. 1996. Can we use experiments and models in predicting the invasiveness of GMOs. *Ecology* 77:1670–1675.
- Keeler, KH. 1988. Can we guarantee the safety of genetically engineered organisms in the environment. *CRC Critical Reviews in Biotechnology* 8:85–97.
- Keeler, KH. 1989. Can genetically engineered crops become weeds. *Bio/technology* 7:1134–1139
- Marvier, M. 2001. Ecology of transgenic crops. *Amer. Scientist* 89: 160–167.
- Mooney, HA, and JA Drake. 1986. *Ecology of Biological Invasions of North America and Hawaii*. Springer-Verlag, New York.
- National Academy of Science. 1987. *Introduction of Recombinant Dna-engineered Organisms into the Environment: Key Issues*. National Academy Press, Washington D.C.
- Parker, P, and IM Kareiva. 1996. Assessing the risks of invasion for genetically engineered plants: Acceptable evidence and reasonable doubt. *Biological Conservation* 78:193–203.

- 
- Pimentel, DC, C Glenister, S Fast, and D Gallahan. 1984. Environmental risks of biological pest control. *Oikos* 42: 283–290.
- Pimentel, D, MS Hunter, JA LaGro, RA Efroymsen, JC Landers, FT Mervis, CA McCarthy, and AE Boyd. 1989. Benefits and risks of genetic engineering in agriculture. *BioScience* 39: 606–614.
- Reichard, SH. 1999. A method for evaluating plant invasiveness. *Public Garden* April, 1999.
- Reichard, S, and F Cambell. 1996. Invited but unwanted. *American Nurseryman* 184: 39–45.
- Reichard, SH, and CW Hamilton. 1997. Predicting invasions of woody plants introduced into North America. *Conservation Biology* 11:193–203.
- Strauss, S. 2000. Report of the poplar working group. Pp. 105–112 *In: PL Traynor and JH Westwood, eds. Ecological Effects of Pest Resistance Genes in Managed Ecosystems. Information Systems for Biotechnology, Blacksburg, VA.*
- Tiege, JM, RK Colwell, YL Grossman, RE Hodson, RE Lenski, RN Mack, and PJ Regal. 1989. The planned introduction of genetically engineered organisms: Ecological considerations and recommendations. *Ecology* 70: 298–315.