Weediness in the light of new transgenic crops and their potential hybrids

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1. General Introduction

Agronomists and ecologists use the terms *weed* and *weediness* in different ways, and this is often a source of misunderstanding, especially in discussions concerning the release of transgenic plants. For agronomists, the problem of weediness is solved if the aggressive weed can be removed from the agrosystem by means of adapted measures. They are not interested in its behaviour outside of agrosystems, i.e. in (semi-)natural habitats. From the ecologist's perspective, invasions of weeds into (semi-)natural plant communities are potentially risky. Highly competitive invaders are able to disturb the species pattern. As a result, rare indigenous species of tropical islands, of regions and even continents with an old flora, only weakly influenced by migrations of the last few millenias are often weak competitors, be eliminated or markedly reduced in coverage. In worst case scenarios, the invader succeeds in occupying the entire surface of certain areas as a near monoculture, this at least for several years or decades to come until new and 'natural' enemies are fighting back. Maybe seemingly less dramatic, but for the eyes of trained field ecologists still worrysome, are dynamic situations where ecological niches are invaded, precisely wiping out rare indigenous species. This can happen (and unfortunately has happened in the past) with ecological dynamics which is triggered off by agriculture and horticulture, not to speak about all the lenient introductions of aggressive species through international traffic of all kinds (Ammann 1997).

Regarding weed problematics, gene flow from crops (transgenic or not) to closely related weeds is one of the essential factors to deal with.
It should be clear to all readers, that this problematics is not focussed on transgenic plants. It is just 'the bad luck' of this new and elegant technique that it offers more clarity to the agro-ecologists, since transgenes can be followed on a long term basis very precisely. It is now emerging through new field research, that the present day transgenes (Bt proteines to create insect resistance etc.) do not have a dramatic impact on ecosystems, although lab studies clearly show some toxic effects.
This is why we concentrate in the following example on a crop with a transformed disease resistance. If this resistance gene gets into a closely related weed population by means of hybridization and introgression, it may increase the competitiveness of resistant individuals. Such plants may evolve into a problematic weed which is difficult to be controlled in agrosystems. In case the new weed is able to grow outside agrosystems, it may cause modification in (semi)-natural plant communities as mentioned above.

The disease resistance may reveal to be a decisive factor for competitiveness enabling the species, which has so far been retained by disease attacks to spread, thus upsetting the pattern of species.

But even crops themselves may cause a weed problem as studies on *oilseed rape* have shown (Schlink 1994, Schönberger et al. 1991). Nowadays, volunteering oilseed rape (*Brassica napus*) has to be controlled by means of an adapted crop rotation system and tillage techniques, sometimes combined with herbicide applications. Furthermore, feral populations can often be observed in disturbed habitats outside agrosystems. How long such a population can survive needs to be checked. In addition, its potential for invading natural plant communities has to be analysed. (These questions have been and will be studied in the framework of the SPP project of Biotechnology 1996 - 1999 and 1999 - 2001 by K.Ammann, F. Felber, R. Guadagnolo, J. Keller Senften, P. Rufener Al Mazyad and D. Savova).

By means of an appropriate long-term monitor system observing potentially problematic weeds and their potential (natural) habitats, changes in the pattern of wild species have to be detected at an early stage. Also certain crops, such as oilseed rape will have to be included in the future monitoring system. (Ammann et al. 2000). It is an illusion that problematical weed types can „easily“ be eradicated (see Hartmann et al. 1994). Therefore, early detection of such weed types is essential.

Overall the discussion shows that aggressive weeds are not directly related to the new technologies, but in worst case scenarios it is imaginable that the transgenes may contribute. It will be of great importance to follow up pertinent cases, and make good use of the new precision the technology offers.

2. Definitions

2.1. What is a weed ?

For an extensive review of definitions, concepts and ecological characterisations of weeds and of the anthropogenic flora see Lambelet-Haueter (1990, 1991) as well as Holzner (1982) and Oka and Morishima (1982). The current literature reflects the fact that various concepts coexist and that there is no such thing as a generally accepted ‘classic approach’.

Lambelet-Haueter (1990) divides weed definitions up into popular, economical and ecological concepts whereas Holzner (1982) groups them similarly into subjective and ecological ones.
Popular as well as *subjective concepts* define weeds as plants growing in the wrong place, causing damage, being of no benefit and suppressing cultivated plant species.
Economical concepts reflect the view of agronomists who concentrate on the phenomena in agrosystems. Competition between crops and weeds, which reduce yield production is central to the definition. Thereby, the damage aspect is stressed. A weed problem is solved as soon as the plant no longer creates considerable damage in the fields, a state which is reached by means of adjusted weed control (crop rotation, tillage, herbicide application).
In contrast to the previous concept, *ecological definitions* include habitats outside agrosystems colonized by weeds. The usual preference of weeds for anthropogenically disturbed habitats is emphasized. They include cultivated fields and gardens which are artificially kept open as well as disturbed areas on road sides, recently built artificial slopes and other similar habitats. An aggressive weed can cause damage not only in agrosystems but also in (semi-)natural plant communities by outcompeting weak species.

Following Holzner (1982, p. 5), it is sometimes difficult to call a plant a weed because one and the same species may be considered in some parts of its area as a harmless component of natural vegetation, in others as a weed and again in others, even as a useful plant species.

Williamson (1988) pays attention to the fact that 17 out of 18 most feared „World's Worst Weeds“ (Holm et al. 1977) are also cultivated. The list was integrated into the German technology assessment by Sukopp and Sukopp (1994): *Cyperus rotundus, Cynodon dactylon, Echinochloa crus-galli, Echinochloa colonum, Eleusine indica, Sorghum halepense, Imperata cylindrica, Portulaca oleracea, Chenopodium album, Digitaria sanguinalis, Convolvulus arvensis, Avena fatua, Amaranthus hybridus, Amaranthus spinosus, Cyperus esculentus, Paspalum conjugatum, Rottboellia exaltata*.
Except for *Portulaca oleracea*, the above mentioned species are not cultivated in Europe.

2.2. Weed characteristics / weediness

Weeds are perfectly adapted to life conditions in anthropogenically disturbed areas. Thus, surviving strategies of weeds are so diverse that any list of weedy characteristics remains incomplete, even the well known one of Baker (1967, 1974, p. 4). He lists the following characteristics of an ideal weed:

Ideal weed characteristics (after Baker, 1974):

1. Germination requirements fulfilled in a broad range of habitats
2. Discontinuous germination (internally controlled) and great longevity of seeds
3. Rapid growth through vegetative phase to flowering
4. Continuous seed production for as long as growing conditions permit
5. Self-compatible but not completely autogamous or apomictic
6. When cross-pollinated, unspecialized visitors or wind-pollinated
7. Very high seed output under favourable environmental circumstances
8. Produces some seed in wide range of environmental conditions; tolerant and plastic
9. Adaptations for short- and long-distance dispersal
10. If a perennial, vigorous vegetative reproduction or regeneration from fragments
11. If a perennial, brittleness, so not easily drawn from ground
12. Ability to compete interspecifically by special means (rosette, choking growth, allelochemics

When applying Baker's concept of the ideal weed, we have to consider that in reality, a weed never embraces all the characteristics of the list, consequently we have to speak about a weed-*syndrome* with even additional characteristics not mentioned here
For a discussion of Baker's characters by means of statistical analysis see Williamson (1993).

Closely related species may show dissimilar behaviour. According to Williamson (1993), in Britain there are native, invasive and pest-like *Impatiens* species. In a detailed study of their biology, he shows that they have a range of ecological behaviour parallel to relatively small morphological differences. To predict and detect pest status, a well-defined monitoring system is needed. (for details see 4.6.4. in Ammann et al. 1996).

The only attribute which all weeds might have in common is a marked plasticity enabling quick adaptation to continuous environmental changes.

3. The origin of weeds

For summaries of the origin of weeds see Zoldan (1993) and Rauber (1977). Rauber (1977) lists the following pathways through which weeds evolve even today:

1. wild plants evolve into weeds
2. hybrids between crop and wild relatives evolve into weeds
3. crops evolve into weeds

Especially point two and three are important for this study.

For weed evolution, co-evolution of the crop-weed complex is essential. Pickersgill (1981, p. 378) shows the following phylogenetical relations in crop-weed complexes:

Three different evolutionary relationships between crops and their weedy relatives are possible.

- Firstly, the weed may have been domesticated to be genetically altered to a crop.
- Secondly, the weedy traits may be derived from the crop.
- Thirdly, crop and weed may have diverged simultaneously from a common ancestral wild population.

Rye is a well-known secondary cultivar having evolved from the perennial diploid weed Secale montanum Guss.

4. Crops running wild

According to Sukopp and Sukopp (1994, p. 5) who follow the definition of naturalisation by Thellung (1912), a crop, usually showing domestication characteristics, has successfully run wild if it develops a range of characteristics of a wild indigenous species, i.e., if it grows and reproduces naturally without the care of man, if it appears more or less frequently and continuously in suitable habitats and if it has succeeded in surviving for a number of years (even years with extraordinary climatic conditions). For details see chapter 4.3.
Having occupied an ecological niche, a plant may develop poorly and may be eliminated after a short time, it may be integrated inconspicuously in the existing species pattern or it may turn out to be an aggressive, competitive weed (often only after many years of adaptation).

In its range of cultivation within Central Europe, cultivated oilseed rape (*Brassica napus*) frequently invades segetal and ruderal habitats. Rich (1991) lists the habitats of feral oilseed rape for Great Britain and Ireland:

‘A common yellow crucifer of roadsides, waste and cultivated ground, docks, cities and towns, tips, arable fields, riverbanks etc. Widely cultivated for seed oil or as a forage crop and consequently casual or naturalised wherever oilseed rape is grown on the British Isles.’

5. Crops showing weed characteristics

Following Schlink (1994), almost all crops are able to appear as volunteers in the subsequent culture after remaining in the field by harvest loss. The trend towards short term crop rotation systems poor in species has stimulated the spread of volunteers. As well as weeds, volunteers of various crops compete with the cultivated crop for growing factors. Furthermore, they are a potential intermediate host of pests (and beneficial insects) in crop rotation systems.

5.1. Case study *Brassica napus*, oilseed rape

This phenomenon is presented below showing data of oilseed rape (*Brassica napus*) by Schlink (1994) who extensively studied its *weed characteristics*. Concerning germinating ecology, *Brassica napus* has all requirements to establish itself as a „wild plant“ in an agrosystem with tillage or in a ruderal habitat. Furthermore, in its growth behaviour and in its high potential of reproduction, oilseed rape resembles segetal weeds and thus represents a typically competitive weed. In crop rotation systems including oilseed rape, the „unidentified“ volunteering rape is capable to pass through all developmental stages up to seed maturity. Seed loss before and during harvesting encreases the seed stock in the soil even by seeds produced by volunteers. In this way, selection of enduring genotypes in the field is possible. Simultaneously, the seed stock in the soil is constantly enlarged by new genotypes due to rapid development of new varieties of oilseed rape.

Excerpts from a manual for experts in cultivation of oilseed rape in Top Agrar, Rapsanbau für Könner 1991:

Oilseed rape germinates like a weed. Under favourable conditions, it appears four or five days after sowing (Schönberger and de Vries 1991, p.23.).
Volunteering oilseed rape is problematic in the subsequent culture, whereby lost seeds may germinate over a long period of time and therefore may cause problems. Due to application of growth hormones, control of volunteering oilseed rape in cereals is no problem [per se]. But volunteering oilseed rape can become a leading weed, especially in dry zones. Because of its long germination period, its high competitiveness and difficulities in harvesting, herbicide application after germination will be necessary even if no weeds are present. Control of volunteering oilseed rape in culture of oilseed rape is very difficult. Therefore stands may vary greatly in their density which is negative for survival in wintertime and for quality, favours pest growth and depression of ripe plants (Blanck 1991, p. 98).

Soil seed bank:
The ability of seeds to survive in the soil for a long period of time is caused by dormancy, germination biology and ecology, even under changing environmental conditions.

Following Zohary (1992), the spread of seed germination over two or more years is a common adaptation particularly of annual species. Partitioning of seed germination yield over two or more years is an effective device to buffer the otherwise crippling effects brought in by climatic fluctuations. But such allocation does not serve just to evade disasters. It also acts as a balance which buffers the selection in any particular year, and prevents extreme annual shifts in the genetic composition of the population.

According to Schlink (1994), crop breeding generally selects well-germinating genotypes. Especially in the breeding of winter oilseed rape, which can be sown just after harvesting, high germination rates of fresh seeds might have been a secondary breeding goal. In contrast, seeds of oilseed rape are able to survive for a long time in the soil what has been proven by model experiments using four different varieties. They have shown surviving rates of over 70% for a period of 1,5 years and of almost 60% after five years of exposition in the soil. These rates usually are met only by weeds. The surviving seeds of oilseed rape were sensitive to light which is characteristic for wild species that are adapted to segetal and ruderal habitats. Furthermore, the surviving seeds in the soil showed changes in their germination readiness due to a dormancy cycle induced by seasonal shifting of soil temperature. Such a survival strategy is well-adapted to ecological conditions in temperate zones. It is a typical characteristic of wild plants (Schlink 1994, pp. 136-138).

According to Schlink (1994), the strategy of eradicating volunteering crops in agrosystems, as it was followed some decades ago, is not reasonable, due to the fact that the supply of fresh seeds to the soil seed stock is guaranteed by the cultivation of the crop itself.
Even if seed loss during harvesting could be prevented, not all sown seeds would germinate under particular conditions as certain genotypes would develop a secondary dormancy and would therefore be added to the bank of dormant seeds.

5.2. Case study *Beta sativa*, sugar beet

In contrast to biennial sugar beet, in weedy annual forms specific alleles cause early development of stems and inflorescences already in the first year (Rauber 1977). Feral, early shooting and blooming sugar beet cause certain problems in Switzerland. (Weedy hybrids between sugar beet and sea beet have not yet been found in Switzerland, they seem to be restricted to the Atlantic part of Europe). In case of development of ripe seed before the harvest period they can produce feral seed banks persisting for many years. Offspring of these seeds show again strong tendency to early shooting, therefore being a serious weed problem in sugar beet fields. According to Bartsch (1995) annual forms can be a result either of vernalisation during cold springs or evolve through introgression of dominant genes causing annual forms from wild populations. This would contradict the opinion of Rauber previously cited. Compare also chapter 8. on genes for weediness.

6. Reversion of crops to wild types

There is no reference to a case where crops would have totally been reverted to their wild type or where they would have lost all domestication characters (Sukopp and Sukopp 1994). Centuries or even millennia of domestication obviously cannot be taken back easily.
According to the NRC Report on Field Testing (1989), domesticated crops, such as wheat, maize and soybean, have been genetically modified in traditional breeding to such an extent that they can no longer compete effectively with wild species in natural ecosystems. These crops are unlikely to revert to a weedy condition upon further genetic modification. Some less domesticated crops such as forage grasses [and oilseed rape] are more likely to revert to a weedy condition.

However, the example below shows that a single gene change may be sufficient to revert a crop to a wild type. This has been shown by a photograph of Schwanitz given by Rauber (1977) with the example of Maize, which turned into „corn-grass" having a much smaller size in stem and leaf. Still, this is again not a reversion into a wild grass.

In addition, Sukopp and Sukopp (1994) as well as Bartsch et al. (1993) noted that in case of cultivars which have a low degree of domestication, one mutation can cause the weedy form which then successfully spreads. The loss of spikelet spindle toughness of cereals, for example, is sufficient for regaining the ability to spread diaspores (e.g. *Avena*).

Another example is *Avena sativa* with its fatuoid mutant: Loss of a combination of genes which suppress awn, pubescence and easy dehiscence of caryopses transform *Avena sativa* back into nearly wild plants (Roesler 1969 in Rauber 1977).

7. Weeds evolving from hybridizations between crops and related wild species

For details see chapter 3.
The NRC Report on Field Testing (1989) gives a list of case studies of crops becoming weeds after hybridization with wild relatives: Weedy beets in Western Europe; *Secale cereale* in California, where a weedy rye probably derived from a cross between *S. cereale* and *S. montanum* is leading to the abandonment of rye cultivation; Squash (*Cucurbita pepo*) - important in the Southern United States, already genetically modified; "Hybrid Grain Sorghum" and others.

7.1. Brassica napus, oilseed rape

It is a biological fact that genes will escape from transgenic oilseed rape into the gene pool of *Brassica napus* which contains not only *B. napus* but also its relatives *B. rapa* subsp. *campestris* (L.) Clapham *(= B.campestris* auct.*), Raphanus raphanistrum* and other species.

Introgression of genes of oilseed rape (*B. napus*) in natural populations of *Brassica rapa* subsp. *campestris*:
In an ongoing research program (Group of R. B. Jörgensen at Risö, Mikkelsen et al. (1995), the behaviour of transgenic *B. napus* (herbicide tolerance, insect or fungal resistance) and *Brassica rapa* subsp. *campestris* is studied in natural habitats by screening populations over several years using non-destructive methods. Other populations are harvested yearly to check biomass and seed production. Their experiments revealed transgene flow from oilseed rape to *Brassica rapa* subsp. *campestris* and introgression by backcrossing in the test field.

Jörgensen (1993) and Jörgensen and Andersen (1994) underline the importance of weedy *Brassica rapa* subsp. *campestris,* a common weed in Northwestern Europe. (In Switzerland, re-discovered in 1995 by Pia Rufener Al Mazyad as a common weed in traditional mountaneous agriculture systems*).*

Brassica rapa subsp*. campestris* possesses many agronomically important characters (e.g. yellow seed colour, pathogen resistance, cold tolerance) that are demanded in the breeding of *B. napus*. This together with the good cross-compatibility makes the species an attractive gene resource.
With efficient agricultural practice the wild form of *Brassica rapa* subsp*. campestris* is almost exclusively found as a weed in oilseed rape fields where herbicide elimination is not applicable. However, herbicide treatment in oilseed rape fields will be possible with the introduction of genetically modified oilseed rape with genes for herbicide tolerance. These genetically modified varieties are already in field testing and will be marketed within few years in Europe, in Canada herbicide tolerant canola is already on the market. When this happens the wild form of *Brassica rapa* subsp. *campestris* could be endangered in a worst case scenario. But pragmatically it could also happen that the rare subsp. campestris becoming herbicide tolerant could safe its existence.

In addition, weedy *Brassica rapa* subsp. *campestris* and its hybrids with oilseed rape could be disseminated with certified seeds. Herbicide tolerant oilseed rape might induce the evolution of a new weed (Jörgensen and Andersen 1994, p. 1635):

As the gene for herbicide resistance is likely to be transferred to *Brassica rapa* subsp*. campestris* by hybridization and backcrossing, the use of this herbicide strategy will be inapplicable after a few years. Like many other weeds, *Brassica rapa* subsp. *campestris* is characterised by seed dormancy and longevity of the seeds. Therefore, *Brassica rapa* subsp*. campestris* with transgenes from oilseed rape may be preserved for many years in spite of extermination efforts. *Brassica rapa* subsp*. campestris* with other types of genes transferred from *B. napus* might affect natural ecosystems as well as the agro-ecosystem.

For an overview of additional hybridization experiments between oilseed rape and close relatives see chapter 2. hybridization and Sukopp and Sukopp (1994).

7.2. *Beta vulgaris,* Sugar beet

Weed-beets, hybrids between sugar beet (*Beta vulgaris* ssp. *vulgaris*) and the wild type seabeet (*B. vulgaris* ssp. *maritima*) are more aggressive in culture than the wild type. This has been shown since the seventies. For an overview see Madsen (1994) and Pickersgill (1981), as well as Sukopp and Sukopp (1994).

After Bartsch a main source of weediness after gene introgression is pollen transfer from *Beta vulgaris ssp. maritima* into seed production fields of *Beta vulgaris ssp. vulgaris* in the Netherlands and Northern Italy. Long term consequences cannot be evaluated from this study, but one result seems to be clear already now: Genetic diversity is not reduced by the constant and probably decades old gene flow from the cultivated beets to the wild coastal beets.
Fredshavn and Poulsen (1993) studied differences in the competitiveness of the *Beta*-complex when using transgenic *Beta*. There was no enhanced competitiveness observed.

8. Genes of weediness

There is space for only a few examples for weediness genes here. Due to the fact that weeds have a large variety of characteristics, as is shown in paragraph 2., no definitive list can be given.

Lupi (1995, according to OECD 1993b) states in his BATS report that according to Baker (1974), weediness is a multicharacter attribute and the addition of one gene is unlikely to cause a crop to become a weed. In contrast, Fitter et al. (1990) and Williamson et al. (1990) suggest that the alteration of one gene may indeed be enough to change a crop into a weed. If a crop species has very few weedy characteristics, the addition of one or a few genes would be unlikely to cause the crop to become a weed problem. Special attention might be warranted where the crop has weedy characteristics or the added genes might be expected to improve the crops competitive ability in natural or agricultural ecosystems.

Also in the above cited case of *Beta vulgaris ssp. vulgaris* Hoffmann et al. (1970) in Rauber (1977) state, that cultivar and weedy relative are identical except for one single allele B/B+.

9. Herbicide tolerant weeds

For most of the existing studies, comparisons between transgenic and non-transgenic crops, which have been done in view of weediness, are based on herbicide tolerance. One of the reasons for this is that herbicide tolerance serves as easy marker gene in a well defined artificial system, since herbicide treatment is not done outside agricultural systems.

9.1. Natural herbicide tolerance in wild species

Gressel and Kleifeld (1994) studied a case of a spontaneous mutation causing herbicide tolerance in *Brachypodium distachyon.*

"It was a surprise when a relatively rare, innocuous grass species, *Brachypodium distachyon* (L.) P. Beauv., appeared as a monoculture along simazine-treated roadsides in Israel over ten years ago, having target-site resistance to s-triazine-type herbicides (Gressel et al., 1983). The wild type was sensitive to triazine herbicides. There is a strong possibility that Brachypodium seeds came with the road foundation material, thus bringing the large quantities of seed needed for selection. Sterilant levels of simazine were used along the roadsides selecting for the rare resistant individual(s). Seeds of such individual(s) rapidly spread due to vehicular movement, as well as run-off, resulting in hundreds of kilometres of roadsides being covered by this weed. The road authorities continued to apply simazine; nothing but *Brachypodium* could grow until seven other grass species and *Amaranthus blitoides* (covered with *Cuscuta*) evolved resistance to triazines. These other weedy species were all indigenous to the nearby agroecosystems. Simazine-resistant *Brachypodium* could not compete with the truly weedy species and was displaced, becoming rare. The road authorities then began using other herbicides (especially diuron), which easily decimated the *Brachypodium*. One must go back to the sandstone hills, its niche in the wild, to find it. It remains a weed only in some olive orchards and industrial sites where simazine is still used as a sole herbicide. These are all on poor soils, similar to some extent to its wild home, and the other simazine-resistant grasses are taking longer to displace the *Brachypodium* in such habitats.

Implications
We believe that these case histories indicate the following:

1. Wild species can acquire genes for herbicide resistance. In the documented cases the acquisition was by selection; it could occur in other species by cross-pollination with crops, transgenic or mutated.
2. Such selections can probably only occur in the rare instances when a large population of the wild species is brought into contact with a herbicide or with a related resistant crop species. Nevertheless, we do not know of instances where crops have conferred any of their natural herbicide resistance's on wild relatives. With Brachypodium, selection was possible after moving seed from the wild to a treated area. The same could also occur with other wild species when virgin land is brought into cultivation. It may thus be advisable initially to use mechanical weed control to lower the level of wild species in a new agroecosystem.
3. Genes for herbicide resistance can temporarily elevate wild species to weed status.
4. Resistant wild species will remain weedy until more typical weed species evolve resistance and displace the wild species or until the selective herbicide chemistry is replaced by a different chemistry.

Thus, there seems to be little risk of a wild species remaining a weed for long periods."

It seems logical to conclude from the example of *Brachypodium* that if a transgenic crop transfers herbicide resistance genes to a wild relative, that species will most probably be a weed for only a short period.

Comment of the authors:
Generalisation from that one case to any plant species and any type of transgene as it is proposed by Gressel and Kleifeld (1994) plays down the risks and is not acceptable for a serious risk assessment.
We do not know enough to back up such generalisations. In some additional caveats the authors themselves do weaken the above made statements: They admit that there are herbicide resistances as the mentioned simazine resistance which reduce considerably the competitiveness of the new weed, while others in contrast do not.
Still it is remarkable, that in this exceptionally well documented case with an unwillingly clear-cut experimental set-up there are mechanisms of competition described, which indicate, that in certain cases the worst case scenario of an escaping resistance gene turns out to be by far not so dramatic as stated in most papers critical to genetic engineering.

9.2. Herbicide tolerance in wild species induced by hybridization with herbicide tolerant transgenic crops

Madsen (1994) tested the competitive ability and growth behaviour of a hybrid between seabeet (*Beta maritima*) and transgenic sugarbeet (*Beta vulgaris*) with a glyphosate resistance. She tested in a field experiment whether the hybrid had a higher biomass and a higher competitive ability than the non-transgenic parental types. The hybrid did not produce more biomass than sugarbeet and the competitive ability of the hybrid did not exceed the expected level of a non-transgenic hybrid between sugarbeet and seabeet. Considerations for the release of herbicide tolerant crops have been published by Bainton (1993). The author concludes that, although there are no grounds for major concern, the Ministery of Agriculture, Fisheries and Food of the United Kingdom should remain alert to adverse developments and be ready to investigate any matters to which the Advisory Committee on Releases to the Environment draws attention.

See also the case story of *Avena* in chapter 4.4.4.2.

In a general discussion of herbicide resistance evolving herbicide resistant weeds, Madsen (1994) concludes that during herbicide applications, selection pressure from e.g. glyphosate is posed on the population privileging herbicide resistant types what should be prevented by crop- and herbicide-rotation. Recalling the case study of *Brachypodium* by Gressel and Kleifeld (1994), for certain herbicide types the developed resistance of a weed will only be problematic during herbicide application.

Regarding (semi)natural habitats, Crawley et al. (1993) and Timmons et al. (1996) acclaim that a herbicide resistance outside the arable land does not provide an advantage to a wild relative, because there is no selection pressure in favour of herbicide resistance in natural habitats. For more details see chapter 4.4.4.1.

Sukopp and Sukopp (1994) add that there are other odds against a rapid spread of crops in natural habitats: Long term observation experience of traditional weeds of agricultural systems show that these species are often nicely confined to areas strongly influenced by man. Massive application of herbicides has led to the development of numerous herbicide resistant weeds up to now.

10. Enhanced weediness in transgenic crops? The need for a monitoring system

In their often cited PROSAMO field study Crawley et al. (1993) showed that the analysed transgenic varieties of oilseed rape were slightly less competitive than traditional ones (see also chapter 5.1., 4.2., 4.4.4.1). Considering population biology, the analyses can be criticized in the way that just mean values are discussed. Weber (1995) demands in her critical discussion of Crawley et al. (1993) that risk problems accessible to empirical verification should actually be approached empirically. Also she emphasises that the spectrum of methods should be widened. She and also Sinemus 1994 are critizising, that the PROSAMO study has been narrowed down to proof or to disproof the "genetic baggage hypothesis".

Weber (1995) presents the following long-term *scenario* for transgenic oilseed rape which seems to be compatible with the results of the experiments carried out by Crawley et al. (1993) (p. 121-122):

1. Transgenic oilseed rape may change to be more invasive through recombinant characters or through position effects or through selection effects by herbicide application to herbicide tolerant crops or even through further evolution.
2. Transgenic oilseed rape may establish itself in disturbed places, from where it could invade undisturbed habitats.
3. Transgene oilseed rape individuals could develop enhanced competitiveness and invade thus undisturbed habitats.

Again we have to emphasize that the above comments of Weber are purely hypothetical and first hints of other authors show that these worst case scenarios do not apply for this case.

Sukopp and Sukopp (1994), p. 67 stated that:

After three years running time the following results can be seen (Crawley et al. personal communication and Crawley et al. 1993): Transgenic and non-transgenic crops (oilseed rape, potatoes, maize) have the same competitiveness outside agrosystems. They hardly can persist more than one generation. In no case sexual reproduction has been observed.

Since there is no long term monitoring on transgenic crops existing which concentrates on weediness in all aspects, scenarios must momentarily remain speculative, see concepts cited in Ammann et al. (2000).

According to Fredshavn et al. (1992), the environmental consequence of releasing transgenic plants to unconfined conditions depends on the changes in survival rate, growth behaviour and hybridization possibilities caused by the transformation.

Survival rate depends on the growth conditions: soil type, water and nutrient supply and plant cover. Crucial for invasion of natural habitats is the establishment period immediately after the seed has germinated („the child mortality“). Later the competitiveness of the plant determines the success as an invader. Fundamental changes in growth behaviour may allow the plant to invade new habitats not formerly occupied by the non-transformed genotype, but more likely, the growth behaviour is only slightly modified, and the transformed plant is limited to the same habitats as the nontransformed genotypes.

Such phenomena concerning sensitive developmental phases should be considered when planning a long term monitoring system.

From the literature, Madsen (1994) concludes that there is no evidence that herbicide tolerant crop plants should become weeds, unless they already possess the traits for weediness, and if only one herbicide is used consecutively in several crop rotations for a longer period of time.

Long before transgenic herbicide tolerant crops have been developed, Rauber (1977) pointed to the possibility of negative consequences: The following scenario developed by Rauber is still valid today.

New developments are made possible with the availability of modern herbicides: Their impact lacunas produce ecological niches for resistant populations. A possible future problem is that new weeds could emerge from hybrids from crops and their wild relatives (cultivated and wild oat) and also from the crops themselves (sugar beet and weedy beet). In spite of or because enhanced precision physiological and ecological selectivity of future herbicides, it will be more and more difficult to fight these new tolerant varieties. They will have the same genome as the cultivar, except for at least one allele causing weediness. Possibly there will be some future annual weeds, developing as a perfect mimicry to crops, in this way reaching back to prehistoric times where weeds and crops where still very close and connected through a full range of intermediate forms in fields and seed mixtures.

In an extensive compilation study Ewel et al. 1999 give an account of the research needs related to introduced species. The study is an excellent example that weeds, invasive species and the introduction of new species, whether transgenic or not, needs much more attention, it also is a convincing plea for a more holistic view of the problems related to weeds. Although the article is dealing with the much broader field of introduced species as a whole, much can be learned for the narrow topic of agriculture.

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