

Review Article

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Genetically Modified Crops and Soil Ecology: A Critical Review

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ABSTRACT

A GM or transgenic crop is a crop which contains a gene or genes of a different species artificially inserted in its genome, which may come from an unrelated plant or from a completed different species. GM plants have been deliberately developed for a variety of reasons: e.g., longer shelf life, disease resistance, pest resistance, herbicide tolerance, nutritional improvement, resistance to such a biological stresses as drought or nitrogen starvation. Since GM crops were first commercialized in 1996, the planting of GM crops has consistently increased by 10% or more each year worldwide. The global hectareage of biotech crops have increased more than 100-fold from 1.7 million hectares in 1996 to over 175 million hectares in 2013 – this makes biotech crops the fastest adopted crop technology in recent history. The number and type of microorganisms inhabiting the rhizosphere of wheat were markly affected by the substitution of a chromosome pair from a variety of spring wheat relatively resistant to common root rot. Number of nematodes, collembola and ants were more in Bt plants rhizosphere as compared to non Bt plants rhizospere. The composition of microbial communities in the rhizosphere is governed by quality and quantity of carbon substrates that are released as root exudates. Targeted genetic traits for improved plant nutrition include greater plant tolerance to low Fe availability in alkaline soils, enhanced acquisition of soil inorganic and organic P, and increased assimilation of soil N.

Keywords

Genes, GM crops, Rhizosphere, Nematodes, Bt plant, Exudates, Plant nutrition.

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Introduction

A transgenic crop is a crop which contains a gene or genes of a different species artificially inserted in its genome, which may come from an unrelated plant or from a completed different species. The inserted gene sequence (known as the transgene) may come from another unrelated plant, or from a completely different species: transgenic Bt corn, for example, which produces its own insecticide, contains a gene from a soil bacterium, *Bacillus thuringiensis*. Genetically modified (GM) plants possess a gene or genes that have been transferred from a different species. GM plants have been deliberately developed for a

variety of reasons: e.g., longer shelf life, disease resistance, pest resistance, herbicide tolerance, nutritional improvement, resistance to such abiological stresses as drought or nitrogen starvation (Icoz and Stotzky, 2008).

Brief history

The history really begins with Charles Darwin's notions of species variation and selection. The first genetically modified plants – antibiotic resistant tobacco and petunias – were produced by three independent research groups in 1983 (Bevan

and Chilton, 1982; Fraley, 1983). Scientists in China first commercialized genetically modified tobacco in early 1990s. The first GM crop approved for use in the USA was the FlavrSavr tomato in 1994, which was developed to have a longer shelf life. Since then, several transgenic crops have been developed including “Canola” with modified oil composition, cotton and soybeans resistant to herbicides, etc. Bangladesh approved a biotech crop (Bt eggplant) for planting for the first time in 2013, whilst the situation in Egypt put planting on-hold, pending a Government review. GM foods that are available in the market include potatoes, eggplants, strawberries, carrots, and many more are in pipeline.

Global scenerio GM crops

More than half the world’s population, 60% or ~4 billion people, live in the 27 countries planting biotech crops. The most popular crop is Soybean followed by maize, cotton and canola (James, 2013). By trait wise, herbicide tolerance is the most prefer and is mostly grown in the developed countries (James, 2013). In 2011, the area under Bt cotton in india soared to a record of 98.54 lakh hectares, equivalent to 88 % of the record 11 million hectare cotton crop planted in the country (Table 1). An increase of 94 lakh hectares in 2010 to 98.54 lakh hectares in 2011 was recorded with an adoption percentage of more than 80%. The approval by Bangladesh to Bt eggplant is important in that it serves as an exemplary model for other small poor countries. Also, very importantly, Bangladesh has broken the impasse experienced in trying to gain approval to commercialize Bt eggplant in both India and the Philippines. It is noteworthy that two other developing countries, Panama and Indonesia, also approved cultivation of biotech crops in 2013 for commercialization in 2014 (James, 2013).

Mode of action

The mode of action and the structure of the Bt insecticidal proteins are two major factors in understanding the safety and risks of Bt insecticides or Bt transgenic crops. Bt and its insecticidal proteins have a high degree of specificity, which accounts for their relative safety to most non-target organisms. Cry proteins produced by the bacterium are usually crystalline (called insecticidal crystal proteins—ICPs) and are protoxins with a molecular mass (Mr) of about 130–140 kDa that require cleavage by proteases to produce the biologically active form (toxins) with a Mr of 60–70 kDa (Schnepf *et al.*, 1998). Therefore, ICPs must be ingested to have an effect and require alkaline conditions, typically in the range of pH 8–11, in the insect midgut, to be solubilized to a form conducive to activation by midgut proteases. Activation appears to require the presence of active indigenous bacteria in the midgut (Broderick *et al.*, 2006).

After ingestion, the protein molecules pass through the peritrophic membrane and bind to specific receptors. Binding is an essential step in the intoxication process, and in susceptible insects, the toxicity of a particular Cry protein is correlated with the number of specific binding sites (i.e., receptors) for it on microvilli, as well as its affinity for these sites (Schnepf *et al.*, 1998; Pigott and Ellar, 2007). Many chewing insects that ingest ICPs do not have the appropriate receptors, even if they have alkaline midguts, and, thus, are not sensitive to the toxins. In highly sensitive insect species, the microvilli lose their characteristic structure within minutes of toxin insertion, and the cells become vacuolated and begin to swell. This swelling continues until the cells lyse, resulting in extensive damage to the midgut wall and in paralysis and eventually death of the insect (Icoz and Stotzky, 2008).

GM crops and soil microbial population

After harvest, decomposition of plant litter can release novel the surrounding rhizosphere and soil, along with other proteins into the soil environment (Donegan *et al.*, 1997). The tillage system will influence the amount of interaction that occurs between the novel proteins and the microbial community (Angle, 1994). Under zero- tillage, crop residues are left concentrated on the soil surface, limiting the soil microorganisms that come in contact with the proteins to those at the soil surface.

Under conventional tillage the plant litter will be incorporated into the soil, diluting the concentration of the gene products but increasing the number of organisms exposed (Figure 1). Transgene products have also been shown to be released directly from the plant roots from sloughed and damaged root cells as well as through root exudation. Transgenic Bt corn (*Zea mays* L.) was found to release a *Bacillus thuringiensis* insecticidal endotoxin from its roots (Saxena and Stotzky, 2000).

The effects of plant roots on soil microorganisms in the rhizosphere are well known. Earlier studies revealed that the numbers and types of microorganisms inhabiting the rhizosphere of spring wheat (*Triticum aestivum* L.) were markedly affected by the substitution of a chromosome pair from a variety of spring wheat relatively resistant to common root rot (Table 2).

Glyphosate applied to Roundup Ready soybean [*Glycine max* (L.) Merr.] cultivars enhanced colonization by *Fusarium*, a known root pathogen (Kremer *et al.*, 2000), leads to severely reduce the benefits of using these cultivars in a crop rotation. Donegan *et al.*, (1997) investigated the potential ecological impact of genetically engineered plants on soil ecosystems by burying litterbags containing leaves of transgenic tobacco that

expressed Proteinase Inhibitor I into field plots and found differences in carbon content between the decomposing parental and transgenic plant litter supporting the concern that genetic manipulation of plants may produce changes in plants that are unintended. They also found differences in nematode and *Collembola* numbers in the soil surrounding the transgenic plant litterbags (Dunfield and Germida, 2004).

Donegan *et al.*, (1995) observed that two of the three transgenic cotton lines produced a significant but transient increase in the number of CFUs of culturable bacteria and fungi, while Saxena and Stotzky (2001) found that there were no significant differences in the colonial forming units of culturable bacteria, actinomycetes or fungi between upland soil amended with biomass of Bt-corn and non-Bt corn after 45 days of incubation.

Significant differences ($P < 0.05$) were observed in the number of nematodes, collembola and ants between the Bt and non Bt cotton rhizosphere (Table 3). Number of nematodes, collembola and ants were more in Bt plants rhizosphere as compared to non Bt plants rhizosphere. Number of nematodes, collembola and ants were highest in Bt and non Bt cotton rhizosphere at flowering stage (Mina, 2011). More detailed studies on the composition and diversity of these groups of microorganisms using different molecular and biochemical techniques are necessary.

GM crops and plant nutrition

The recognition that abiotic stress, such as nutrient deficiency, is a major factor limiting crop performance under different environmental conditions and agricultural management practices has led to efforts to develop transgenic crops with improved traits to acquire nutrients from soil (Hirsch and Sussman, 1999).

Table.1 Area and production of Bt cotton in India (lakh hectares)

States	Area (lakh ha)	Area under Bt cotton (lakh ha)	Production (lakh bales)
Andhra Pradesh	17.84	17.50	53.00
Gujarat	26.33	21.33	105.00
Haryana	4.92	4.70	17.50
Karnataka	5.95	3.95	12.50
Madhya Pradesh	6.50	6.00	20.00
Maharashtra	39.32	36.21	88.00
Orissa	0.74	0.00	2.50
Punjab	5.30	5.10	21.00
Rajasthan	3.35	2.75	9.00
Tamil Nadu	1.22	1.00	5.00
Uttar Pradesh	0.30	0.00	0.50
Others	0.15	0.00	0.25
All India	111.42	98.54	334.25

Source: Clive James, 2013

Table.2 Effects of transgenic plants on rhizosphere microorganisms

Novel trait	Plant	Phenotype Gene	Changes in rhizosphere of GM plants
Herbicide tolerant	Rape seed	glyphosate tolerant (<i>EPSPS</i> , <i>GOX</i>)	composition of microbial community different
	Soybean	glyphosate tolerant (<i>EPSPS</i>)	increased colonization by <i>Fusarium</i> spp.
Insect resistance	Cotton	lepidopteran and coleopteran control (Bt var. tenebrionsisentotoxin)	Transient increase of bacteria and fungi.
	Tobacco	insect resistance (Proteinase Inhibitor I)	numbers of <i>Collembola</i> and nematodes
Pathogen resistance	Wheat	root-rot resistance (Chromosome S-615), resistance to phytopathogenic bacteria (T4-lysozyme)	composition of cultivable rhizosphere community, no changes in plant beneficial bacteria

Source: Dunfield and Germida, 2004

Table.3 Number of nematodes, collembola, ants in Bt and non Bt cotton rhizosphere

Treatment	Nematodes Numbers 250 g ⁻¹ soil	Collembola Numbers 250 g ⁻¹ soil	Ants Numbers 250 g ⁻¹ soil
Bt rhizosphere	808.2	5.4	3.9
Non Bt rhizosphere	787.1	4.6	2.9
CD(P < 0.05)	15.58	0.77	0.69

Source: Mina, 2011

Table.4 Transgenic traits for improved plant nutrient acquisition from soil

Trait	Mode of action	Crop
Tolerance to low Fe availability in alkaline soils	Root exudation of mugineic acid, phytosiderophores	Rice, Sorghum
Tolerance to low P availability in acidic and alkaline soils	Root exudation of organic acids (e.g., citric and malic acids) to solubilize soil P	Corn
Improved assimilation of soil N	Increased activity of NADH-glutamate synthase in plant	Tobacco

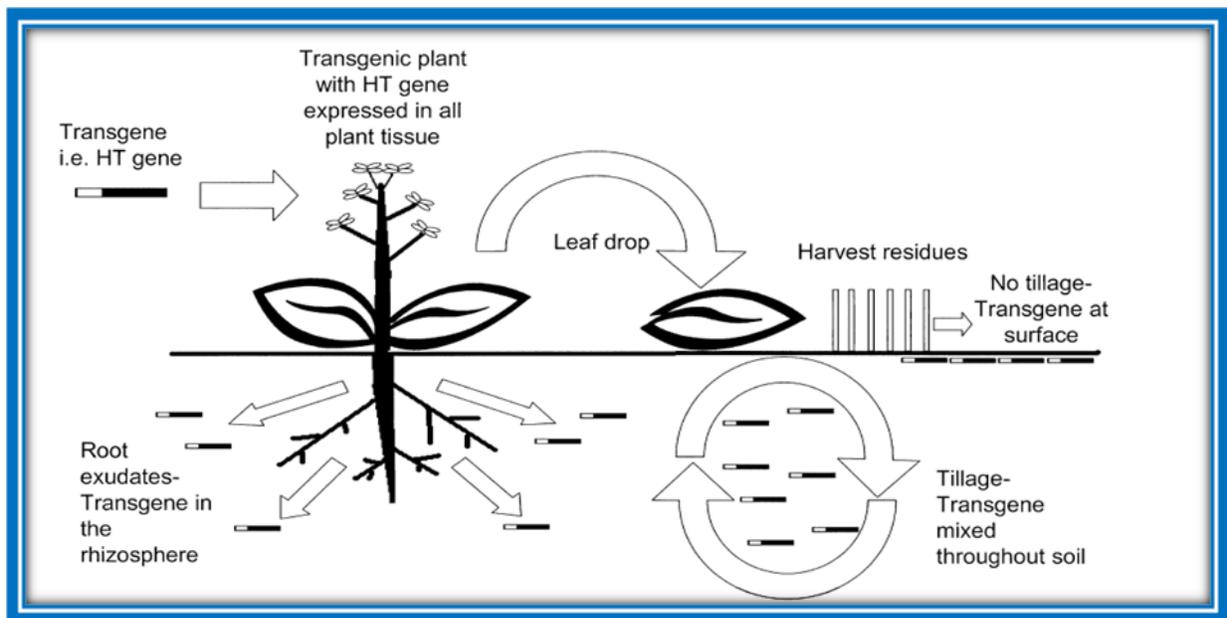
Source: Motavalli *et al.*, 2004

Table.5 Chemical properties of straw of Bt and non Bt maize varieties

Properties	Nobilis	Nobilis Bt	Prelude	Valmont Bt
Cry1Ab Bt toxin (µg/g maize residues)	0.0 c	3.9 a	0.0 c	0.7 b
Total C (mg/g)	430 a	443 a	444 a	437 a
Extractable C (mg/g)	21 b	35 a	22 b	22 b
Total N (mg/g)	13.2 a	6.7 d	9.6 c	11.1 b
Extractable N (mg/g)	2.8	1.4	1.5	2.0
Lignin %	6 a	7 a	7 a	6 a

Source: Raubuch *et al.*, 2007

Fig.1 Potential sites of interaction between transgenes and soil microbial community



Source: Dunfield and Germida (2004)

Table 4 shows examples of targeted traits that have been researched include improved plant tolerance to low Fe availability in alkaline soils, enhanced acquisition of soil inorganic and organic P, and increased assimilation of soil N (Motavalli *et al.*, 2004).

The residues of Novelis-Bt contained five times higher concentrations of the Bt toxin Cry1Ab than Valmont-Bt (Table 5). The Bt variety Novelis-Bt had the highest concentration of extractable C, but the lowest concentrations of total N, and extractable N. In contrast, the parental variety Nobilis had the highest concentrations of total N and extractable N. However, the extractable fraction was identical at 21% of total N in Novelis-Bt and Nobilis. The extractable N fraction was considerably lower at 17% in Valmont-Bt and Prelude (Raubuch *et al.*, 2007).

Available N in cotton rhizosphere soil at different growth stages at Varanasi was reduced by 12-13% under Bt cotton over non-Bt isoline and *no crop* treatment (Beura and Rakshit, 2011). There may be a possibility of higher N uptake by Bt cotton when compared with the non-Bt isoline. They also found that significant increase in available P and Zn in the soil under Bt cotton compared to non-Bt isoline and *no crop* treatment. The increasing root length value and root biomass observed in the study resulted in greater root exudates and readily metabolizable C. Among the examples of factors affecting soil P availability, root exudates, such as organic acids, H⁺ ions, sugars and phosphatases, facilitate the solubilization and desorption of mineral P (Ryan *et al.*, 2001).

Effect of root exudates

The main interaction zone between the plant and soil biota is at or near the root surface in the rhizosphere. Both plant roots and soil

microorganisms alter and are affected by soil chemical and physical properties in the rhizosphere. In the example of factors affecting soil P availability, root exudates, such as organic acids, H⁻ions, sugars and phosphatases, facilitate the solubilization and desorption of mineral P as well as affect the activity of rhizosphere microorganisms (Ryan *et al.*, 2001). Alterations in the composition and quantity of root exudates through the introduction of new genetic traits may therefore, directly affect processes, such as mineral P solubilization, or indirectly affect P availability through changes in the activity of rhizosphere microorganisms. Plant roots excrete several substances into the rhizosphere soil, including exudates, secretions, mucilages, mucigel, and lysates (Kennedy, 1998). The insecticidal toxin in root exudates (as well as pollen and crop residues) produced by Bt corn binds rapidly to montmorillonite and kaolinite clay minerals, humic acids, and organo mineral complexes, which protect the toxin from microbial degradation. The bound toxin retains its insecticidal activity and has been observed to persist in soil for up to 234 days (Saxena *et al.*, 1999). Similar results on the persistence of the insecticidal toxin of Bt cotton but for shorter periods of time (up to 140 days) have also been reported by Palm *et al.*, (1996).

Different effects, ranging from no effects to minor effects of Bt plants on microbial communities in soil have been reported but the differences in microbial community structure were transient.

Genetically modified crop residues have enhanced nutrient concentration and also improved plant efficiency under stress conditions.

Transgenic crops have immense potential to provide economic and environmental benefit, but few reports which have shown negative

impacts of transgenic plants on soil ecosystem have created a doubt on benefits of transgenic crops.

So to clarify those doubts and to say conclusively, more long term experimental studies which should monitor each and every aspect of soil ecology are urgently needed in each and every nation, which may allow commercial cultivation of transgenic crops.

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