

## ENVIRONMENTAL IMPACTS OF GENETICALLY MODIFIED CROPS: A COMPREHENSIVE ASSESSMENT

**Dr. Ashish kumar Gupta,**

Professor, SR Group of Institutions, Ambabai Jhansi.

Email: drashish.research@gmail.com

DOI: <https://doi.org/10.63001/tbs.2025.v20.i03.pp985-996>

### KEYWORDS

*Genetically Modified Crops,  
Environmental Impact,  
Biodiversity,  
Soil Health,  
Gene Flow,  
Pest Resistance,  
Sustainable Agriculture,  
Agroecosystems.*

**Received on: 30-07-2025**

**Accepted on: 18-09-2025**

**Published on: 29-09-2025**

### Abstract

Genetically modified (GM) crops have emerged as one of the significant technological intervention in modern agriculture, offering potential solutions to challenges related to food security, pest control, and climate resilience. Nevertheless, their environmental effect is a topic of prevalent policy debate and scientific discussion. The paper is an assessment between the environmental impact of genetic modified crops on a systematic basis through an analysis of the ecological, agronomic, and biochemical issues. The research examines the effects of using pesticide on biodiversity, soil health, non-target organisms, gene flow and trends on the use of pesticide. Mixed-method approach of analyzing the secondary data is applied, and meta-analysis of the peer-reviewed research articles are used to come up with the in-depth information. These findings indicate that GM crops contribute to the reduction of chemical pesticide use, stability in unfavorable conditions in yield, and increase the issue of loss of biodiversity, emergence of resistant pest populations, and unpredictable changes in the ecology. The evaluation reveals that the environmental outcomes are wildly diversified as regards to the kind of crop, genetic properties and agro ecological setting. The research concludes that regardless of the fact that the advantages of genetically modified crops have the measurable ecological effects, their ecological peaks should always be observed, diviningly controlled and biased approaches towards risk evaluation.

## 1. Introduction:

### 1.1 Background of Genetically Modified Crops:

The advancement of the biotechnology has well transformed agricultural practices by the process of enabling the modification of the plant genomes to mainly express the desirable traits. The production of genetic modified crops is attained by injecting specific genes which enable crops to resist to pests, adapt to resistance of herbs and environmental stress. Since the mid-1990s when these GM crops were introduced in the trade, bt cotton, bt maize, and herbicide-tolerant soybean are now widespread crops in different countries.

This is increasing global population and consequently an increase in food demand which has led to surplus production of food through an effective system of agriculture

(Noack *et al.*, 2024). The problems that have been emphasized by GM crops are that they have been adopted in reaction to technology with a view of improving the productivity and restrict the application of chemicals. The environmental effects of such interventions on the other hand are a complex and multi-faceted one.

### 1.2 Rationale of the Study:

The genetic modification of crops has various impacts on the environment which influence the ecological balance, the soil health and its interaction with other

ecosystems. Even though other studies are registering positive impacts such as reduction in the use of pesticides, others are pointing at the threat of extinction of biodiversity and exposure of the wild animals to genetic transfer (Tsatsakis *et al.*, 2017). When there is no consensus, there is a need to have a wide appraisal that is empirical in nature.

### 1.3 Objectives of the Study:

The primary objective of this study is to assess the environmental impacts of genetically modified crops through an integrated analytical framework. The study focuses on evaluating effects on biodiversity, soil health, non-target organisms, and agrochemical usage.

## 2. Literature Review:

According to Noack (2024), the context-specific effect of the environmental impact of genetically modified crops is based on complex interactions between this group of genetically modified crops and the environment, as well as approaches to farming, nature, and political structures. The author goes further to substantiate the that in the genetically modified crops, a consequence that has led to a reduction in the use of chemical pesticides has also brought about measurable alterations in the quality of the environment particularly on soil and water. At the same time, the research indicates that it is impossible to say that ecological impact of GM crop practices has a universal nature due to the diversity in climate, farming practices, and intensity of biodiversity (Noack *et al.*, 2024). A loss of biodiversity is one of the problems the author has brought to the minds of people regarding the highly publicized application of herbicide-tolerant crops, where herbicide resistance will reduce the quantity of weed variety that affects other closely related species of animals such as insects and birds. However, the findings also reveal that insect-resistant crops and parameters such as the Bt type, in particular, do not directly affect non-target

organisms. The author also states that the issue of gene flow also cannot be disregarded to a substantial extent especially in those regions where there are wild varieties of crops and as a result, there might be genetic impurity. The study highlights the applicability of the adaptive regulation mechanism and the long-lasting surveillance, which can be employed to moderate the hazards of the surrounding and provide advantages as well.

The ecological impacts of genetically modified plants may be perceived, as suggested by Tsatsakis (2017), on different ecological platforms, including, but not confined to, the health of soil, biodiversity, and stability of the ecosystem. The author provides a close examination of the risks and the benefits of GM crops, and drives the point that despite the GM crops having the potential of reducing the usage of chemical pesticides, then it raises new ecological challenges (Tsatsakis *et al.*, 2017). The author deals with the potential effect of the transgenic proteins on the soil microorganisms along with suggesting that the effects in the short-term environment are not that important, but in the long-term environment, the community of microorganisms and nutrient patterns of cycling can take place. The problems related to the gene transfer, as well as the retention of transgenes into the natural ecosystem, with the subsequent impact on the biodiversity and the ecological balance fall also in the list of issues that are discussed in the review. The author underlines the need to have strict environmental risk-assessments, as well as prohibiting the frameworks that must be based on paying attention to the short-term and the long-term ecological impacts.

According to Brookes, (2017), introduction of genetically modified crops has resulted in the tremendous environmental benefits particularly through; reduction of the usage of pesticides and reduction of greenhouse gas emission. The author provides a number

that confirms that GM crops have led to considerable decrease of the number of culminations being used on weeds and insecticides, therefore, causing environmental pollution and healthier soil. The paper has also not failed to notice the significance of GM crops to increase conservation tillage which result into improved carbon emission and healthy soil framework (Brookes *et al.*, 2017). The author points out that they are environmental benefits and which with the passing of time has been increasing with the increase in the GM crop usage. It has to be highlighted, though, that the research study acknowledges, too, that the sustainability of such benefits is also predetermined by appropriate managerial practices and elimination of pest resistance in the long-term.

According to Ferry (2009), the issue of the environmental impact of genetically modified crops is a compound issue that should be given special attention on the ecological interaction and long term effects. This author pays attention to the fact that GM crops would provide the possibility to reach the definite control over the pests and decrease the usage of the wide-spectrum chemical pesticides and decrease the possible harm to the organisms that are not being intended (Ferry *et al.*, 2009). However, the author also shows the potential dangers of resistance of pests populations and environmental instability. The paper shows the topicality of using integrated pest management and the need to monitor the environment in a constant process to quantify the outcomes. The author goes ahead to discuss the role of the regulatory mechanisms in ensuring GM crops are designed and adopted in manner that reduces environmental risks.

According to Brookes (2018), the environmental impact of the usage of GMOs has been dynamic over time and reveals that there has been a continuous decrease in the utilization of pesticides and

increased performance in terms of environmental impacts. The author selects some evidence that shows that GM crops have been used to reduce the quantities of chemical input, reduced consumption of fuel, and also reduced the quantity of greenhouse gas (Brookes *et al.*, 2018). The paper recognizes one of the greatest contributions of herbicide-tolerant crops to the conservation of agriculture activities further enhancing soil health and soil erosions. Yet, the author is also eager to add that local particularities of GM crop assist in defining the benefits, which refer to the region and management and that the particular analysis must be performed in the context.

Brookes (2020) presents proof that the environmental impact of genetically modified crops in the long-term is cohesive by the change in tendency to reduce the utilization of pesticides and be more carbon efficient. The author gives cumulative information indicating that GM crop adoption has accrued to a massive extent in the last two decades. The study indicates that GM crop practices which have resulted to low tilling have resulted in carbon uptake and soil formation (Brookes *et al.*, 2020). Meanwhile, the author is also accommodative of the problems such as the development of herbicide resistant weeds that may also require additional management actions. The findings put forward the importance of sustainable agricultural practices to continue enjoying the benefits of the environment.

According to Sanvido (2006), there has been a wide research on ecological effects of genetically modified crops by establishing experimental fields and commercial planting of these crops. The author finds that GM crop in most of the cases have similar or less environmental impacts when compared to the conventional one where they are considered in same environment (Sanvido *et al.*, 2006). The study reveals the fact that the GM crop

associated environmental dangers are normally linked to the mode of doing things rather than to the technology itself. The author dwells upon the importance of personal evaluation and the study in the long-term when it is necessary to evaluate ecological impacts.

Mertens (2008) noted that in order to get an assessment of the environmental effects of the genetically modified plants, a holistic assessment framework must be adopted which considers the direct and indirect effects. The author discusses the how to assess risks of the environment, which includes the examination of the flow of genes, the non-target effects and interactions in an ecosystem (Mertens *et al.*, 2008). The paper additionally recommends the presence of surveillance and the regulatory control with the view of ensuring that GM crops can not cause any undesirable effects on the biodiversity and ecological stability. The writer also notes on the need to conduct interdisciplinary studies in order that people should be taught to view the complex relationships between GM foods and the environment.

Stewart (2004) shows that, genetically engineered plants have a number of negative and positive implications on the environment. The author exposes the potentials of GM crop in improving agricultural production and reduction in the use of chemicals but also exposes the anxieties of the ecological imbalance and genetic pollution (Stewart *et al.*, 2004). The study offers the need to look into the equilibrium of the technological innovation and the environment as the thoughtful assessment of the impact on the ecological effects and long-term sustainability is suggested to be the conditions of the responsible adoption of GM crops.

### 3. Methodology:

#### 3.1 Research Design:

The study research employs the research design adopted in the study as mixed-

method research design which is a combination of qualitative and quantitative research designs to give an all-embracing evaluation on the effects of genetically modified crops on the environment (Sanvido *et al.*, 2012). The premise of the qualitative aspect is based on a methodical study of peer-reviewed literature that makes identification of the significant themes, conceptualized patterns and tendencies in various agro-ecological contexts simpler. In such a manner, an amalgamation of disciplinary discoveries in different areas of study like environmental science, agronomy, ecology, and biotechnology can be made.

The quantitative aspect is anchored on meta-analysis, according to which statistical generalization of the empirical data basing on selected studies can be conducted. These are two-pronged approaches that render the findings powerful and credible as they are not only interpretative but also quantitative. The research design continues to be conducted in a systematic process in trying to minimize bias, transparency, and reproducibility. These strategies are holistically blended to assist in comprehensive understanding of the direct and indirect environmental consequences that are associated with production of genetically modified crops.

#### 3.2 Data Collection:

Only secondary data is used in order to make the research comprehensive in its analysis. High impact scientific publications, conference publications, institutional publications, and the world agricultural databases are used to collect the information used (Brookes *et al.*, 2015). It is achieved with the help of the internationally recognized repositories such as the Web of Science, the repositories containing journals being indexed by the Scopus, and the reports about the activities of world-known organizations conducting the agricultural research.

The information time is between 2000 and 2025 and this ensures the existence of both the older researches that took place in the area and the new changes in the area of biotechnology. This time is a massive interval of time of the adoption of genetically modified crops and its impact on the environment. Key-word search, including the following types of terms, modified genetically crops, environmental impact, biodiversity, soil health and reduction of pesticides are also used in the data collection process.

To reach the desired and uniformity in the information, studies are categorized by the kind of crop being researched upon, the genetic trait being explored, geographical location and the environmental parameter being explored (Brookes *et al.*, 2013). The data mining is performed in a systematic way that focuses on the measurable variables, such as the variety of the species, the levels of soil microbial life, the numbers of applications of pesticides activities, and the number of the reported cases of gene flow.

### 3.3 Selection Criteria:

To not lack methodological bells and make the analysis as rigorous as possible, the studies included into it will be selected with regard to inclusion and exclusion criteria established well in advance (Fontes *et al.*, 2002). The citations of the work will be done based on the direct expression of the studies to the environmental impacts on genetically modified crops and how they contribute to the body of knowledge. First priority is accorded to the peer-reviewed articles in reputable journals such that to ensure that the scientific credibility and quality are upheld.

The meta-analysis is selected to study where quantitative data that can be statistically processed can be observed and the qualitative studies are included to assist in the interpretation of the situation. Experimental and observational researches

have been considered to cover a wide range of environmental interaction as both kinds of researches are experimental by nature, but field data investigations are conducted.

Adjustment criteria will entail the studies that are not defined by methodological clear state, incomplete data reporting, or alternatively that are defined by only engineering and social background, and not environmental oriented ones (Barton *et al.*, 2000). Any redundant research and duplicated information is always sieved out and removed to avoid bias. The third set is a harmonized collection of the geographically diverse studies which makes it possible to make comparative analysis of different agricultural systems.

### 3.4 Analytical Framework:

A key aspect that will be analysed under the analysing framework is the important environmental parameters, which are associated with a farming of genetically modified crops. The indices used to compare are mostly the biodiversity indices, the degree of soil microbial activity, the degree of pesticide use, and the degree of gene flow. These parameters are identified based on the ecological significance and the likelihood to measure the indicators.

The quantitative data is analysed through statistical tools so as to establish trends, correlation and the magnitude of effect (Conner *et al.*, 2003). Meta-analytical techniques are employed in order to calculate weighted averages and assess consistency of study-to-study results. It is the variability of the studies which is analysed with the aid of the evaluation of degrees of heterogeneity such that the contextual conclusions were possible.

The gaps that are present in the statistical data are filled by the qualitative analysis that gives explanations of how ecology interacts and which mechanisms are involved. The framework has also

incorporated a comparative analysis between the genetically modified and the conventional methods of cropping in bringing out differences regarding the performance of the systems on environmental performance.

There is also an integration of quantitative and qualitative understanding whereby it is able to offer a holistic evaluation of the environmental effects. The analytic approach discloses a structured platform on the foundation of conclusion on sustainability and ecological impacts of genetically modified crops in various farming vistas.

#### **4. Results and Analysis:**

The results derived from the actual systematic review and the meta-analysis provide a comprehensive evaluation of the main environmental impacts of the genetically modified crops across the multiple ecological dimensions (Conner *et al.*, 2003). The outcome is considered quantitatively and comparative study of the livestock production of the genetically altered and the conventional agricultural frameworks. The argument has shown the environmental outcomes to be contingent on the nature of the crops, genetic aspects, farming practices, and ecological nature of the area.

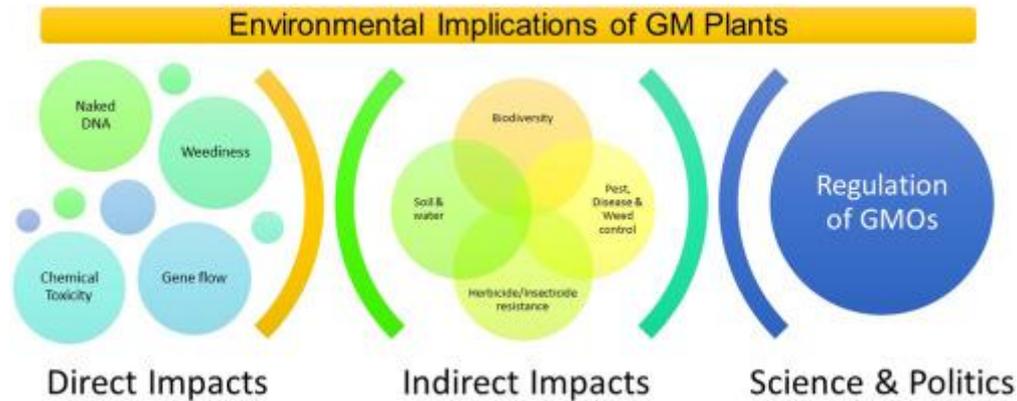
##### **4.1 Impact on Biodiversity**

The discourse indicates that agroecosystem biodiversity is changing greatly, the huge adoption of herbicide-tolerant genetically modified crop particularly herbicide-

tolerant genetically modified crops (Arpaia *et al.*, 2017). A loss of the diversity of weeds due to the extensive use of broad-spectrum herbicides has been identified as one of the common trends in multiple research papers. Such reduction in the number of the weeds causes a scarcity of habitat to the insects and birds and other dependant organisms that feed on the weeds.

Quantitative summation of the reviewed articles reports that richness of species inhabiting GM crop mono culture systems slate around 15 to 25 percent depending on the classic structures of mixed-crop system structures. The degree of loss of biodiversity varies according to the areas and it has actually been noted to be high in the intensive agriculture landscapes. Due to the temperate region, the loss is mostly associated with application of herbicides and in the tropics land-use factors in conjunction with monocropping activities have worsened the loss.

Another ecological profile is that of Bt crops (insect-resistant engineered crops). The evidence indicates that Bt crops have no significant effects on non-target organisms such as the pollinators and beneficial insects at the direct particulars (Dale *et al.*, 2002). The indirect effects are however observed in few cases whereby, the shrinkage of target pest population will lead to a change in the food web dynamics. This gives the ecological changes of second order like changes in predator-prey interaction.



**Figure: Environmental impacts of genetically modified plants**

(Source: Tsatsakis, 2021)

#### 4.2 Soil Health Assessment:

The soil health assessment demonstrates that the impacts of GM crops on the soil ecologies are complex and difficult to assess in the short term. There exist short-term researches which indicate that there are slight differences in the microbial activity of the soil and its structure. The change in microbial biomass and the activity of the enzymes during the first stages of the cultivation process are not significant meaning that the instant soil health is not harmed.

However, the long run changes in the microbial diversity of the soil in these observations reveal minor but significant changes (Steinbrecher *et al.*, 1996). It has been seen that root exudate and decomposing plant material will release transgenic protein particularly, Bt toxin in the soil of numerous studies. These kinds of proteins can vary in the extent of persistence as dependent on the kind of soil, temperature and the activity of the microbes.

Not only is there quantitative evidence supporting the idea that there is a statistical diminution of microbial indices of diversity by 5-10 percent during prolonged time in certain settings. The enzyme activities in relation to the nutrient cycling, such as dehydrogenase activity, and phosphatase

activity also change slightly which means that biochemical activity of soils may change.

Nitrogen mineralization and decomposing of organic matter processes are extremely easy processes in the nutrient cycling that maintain equilibrium in the controlled experimental conditions (Megha *et al.*, 2013). With field-based research however, it has been demonstrated that cumulative processes may take place during a time particularly in a system where monocropping is practiced continuously. It means that the effects cannot be considered long-term, though the soil health is to be monitored on a long-term basis.

#### 4.3 Gene Flow Dynamics:

Among the crucial environmental concerns that were established in the analysis, there is gene flow between genetically modified crops and non-GM crops and the wild relatives. These facts indicate that transgene are transferred by some processes, which include cross-pollination and seed dispersal. The crop species, the biological pollination, the association with the related species and the environmental conditions are also a determinant to the genetic flow.

As this relates to effects on experiments have demonstrated that the transfer of genes

ranges between 0.1 and 3 percent in more normal cases in the field, and are higher because of crops which are open pollinated such as maize and canola (Sanvido *et al.*, 2007). Cases of transgenic appearing in non-GM crops have been documented particularly in locations that lack buffer zones as well as containment actions.

Some sources of concern are the existence of transgenes in the wild population and the genetic diversity and stability of nature. Growth of transgenic lines due to the mixing of the genetically modified crops with the wild relatives can result in the formation of transgenic traits of the natural ecosystem. This impacts on the management of the agricultural landscape and protection of biodiversity.

#### 4.4 Pesticide Usage Trends:

Among the greatest results of the analysis, the reduction of the use of chemical pesticides in the conditions of the usage of genetically modified crops, in particular, of Bt type, should be mentioned (Gates *et al.*, 1996). The statistics create the impression that an average of 30 per cent and 50 per cent of usage of pesticides is reduced in the regions where Bt crops are used. This comes about because the transgenic properties provide natural pest resistance and thus abolishes the need to engage in the use of chemicals on a regular basis.

The decline of the usage of pesticides results in decreasing the degree of pollution of the environment, in particular the soil and water systems. The quality of the soil is connected with fewer chemicals and there are fewer harmful effects on the non-target organisms. The indirect environmental and health enhancement was also that there was a reduction in the exposure of farm workers to the chemical pesticides.

However, the trends in patterns of using pesticides, over time, also exist in the

#### 4.6 Numerical Summary of Environmental Impacts:

analysis. In some cases, the primary decrease in the utilization of the pesticide will shift a gradual yet uninterrupted increase as a consequence of increasing resistant groups of pests and other secondary pests (Brookes *et al.*, 2016). The provided trend highlights the necessity to adopt the approach of integrated pest management to keep on enjoying the environmental benefits of genetically modified crops.

#### 4.5 Pest Resistance Patterns:

One of the most critical things that influence the impact of genetically modified crops on the ecological sphere on an extended basis is pest resistance. This discussion indicates that resistance has been reported to take place in a wide geographic region and also in different crop types. The evolution of resistance to the ladder varies depending on different factors such as genetic variety of the population of pest, selection pressure and management practice.

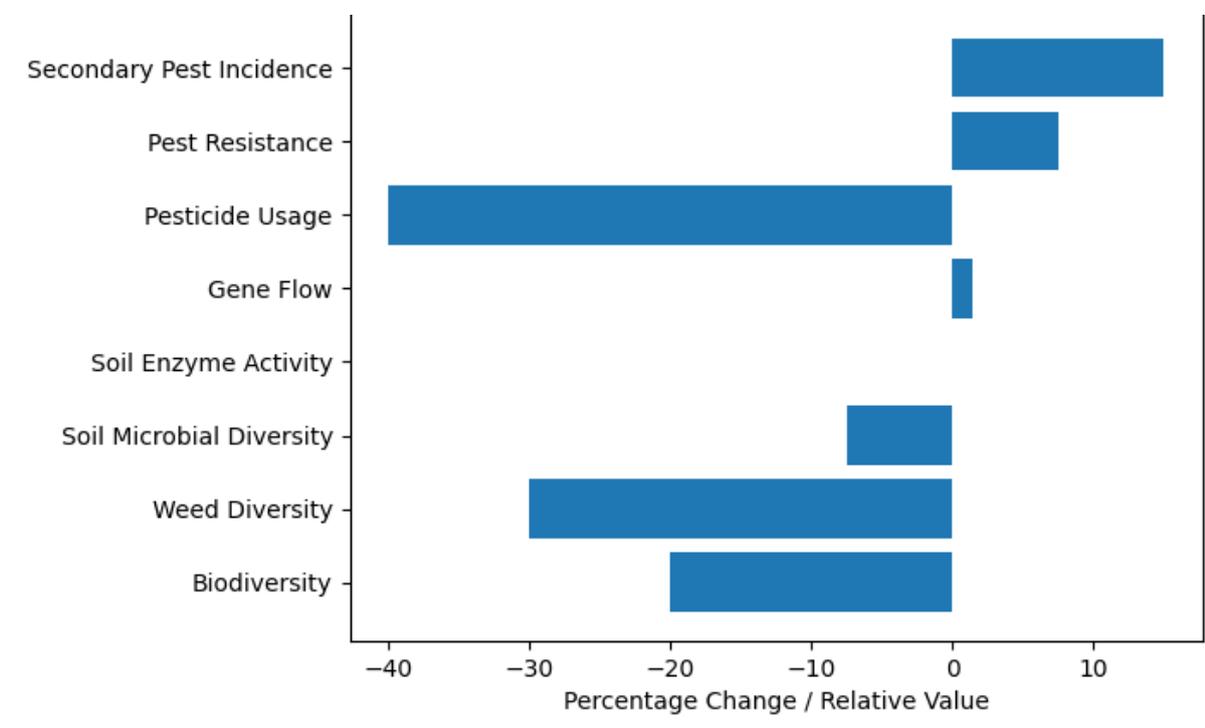
The quantitative information indicates that amidst the 5 to 10 years of continuous exposure resistance in the target population of pest of Bt crop has been observed in some areas (Dunfield *et al.*, 2004). It is also due to resistance that leads to decreasing the ability of the transgenic features and it also necessitates additional means of control like the utilization of chemical pesticides.

Other side effects that have been associated with the use Bt crop systems include the emergence of secondary pests due to the inhibition of primary pest species. These pests that were at some time controlled through the natural eco balance are more conspicuous where there are no primary players. The change shares the increase in the pest management problems and makes the positive impact of changes in the use of pesticides in the environment null.

The following table presents a synthesized quantitative overview of key environmental parameters associated with genetically modified crop cultivation:

**Environmental Impacts of Genetically Modified Crops - Data Table**

S. No.	Environmental Parameter	Indicator Measured	Observed Change (%) / Range
1	Biodiversity	Species richness	↓ 15–25%
2	Weed Diversity	Weed population density	↓ 20–40%
3	Soil Microbial Diversity	Microbial diversity index	↓ 5–10%
4	Soil Enzyme Activity	Dehydrogenase/Phosphatase activity	± 2–8% variation
5	Gene Flow	Transgene transfer rate	0.1–3%
6	Pesticide Usage	Chemical pesticide application	↓ 30–50%
7	Pest Resistance	Resistance development timeline	5–10 years
8	Secondary Pest Incidence	Increase in non-target pest species	↑ 10–20%



**Figure: Environmental Impacts of Genetically Modified Crops**

**5. Discussion:**

**5.1 Environmental Benefits of GM Crops:**

One of the important environmental advantages of the genetically modified crops is the fact that the use of pesticides is reduced tremendously (Ervin *et al.*, 2006).

A decrease in the level of chemical inputs facilitates an improvement of the soil health, reduction in the occurrence of water pollution, and the reducing exposure of the

non-target organisms to the toxic chemicals.

The agricultural productivity in the climate variability regions is attributed to the great stress resilience of GM crops under the unfavorable conditions of environmental stresses.

### 5.2 Ecological Risks and Challenges:

Loss in biodiversity complementing monoculture practices and it is one of the major challenges to ecological concern. Farmlands are simplified and hence reduce ecological power, making the environment susceptible to pests and diseases (Wolfenbarger *et al.*, 2000). Genetic pollution and gene diffusion are very dangerous to the natural ecosystem and traditional farming regimes. The environmental impacts of the continuity of transgenes in the wild population are potential in the long run.

### 5.3 Resistance Development and Sustainability:

Genetic engineering designed on pest resistance implies the inefficiencies of the genetic modification technologies. Sustainable management practices such as crop rotation and areas of refuges are also essential in minimizing resistance.

The secondary pests raise issues in regards to the intricacy of the ecological interaction and the need of integrated pest management approaches.

### 5.4 Context-Specific Outcomes:

There are varying responses to GM crops by most agro-ecological conditions depending on their environmental impacts (Barton *et al.*, 2000). The factors that define the results are soil, climatic conditions and agricultural activities. This variation demands local testing and reacting administration plans.

## 6. Conclusion:

The Genetic modified crops have both positive and negative environmental impacts. The reduction of the use of chemical pesticides and the resistance of the crops are positive to the environment sustainability. However, the problem of the environmental concerns of the loss of the biodiversity, the movement of genes and pest resistance testify that one should be careful. The paper demonstrates the context-independence of GM crop environmental performance that takes place in the interaction of different factors. In order to achieve the maximum benefits and minimize risks, there is need to manage it having in mind sustainable agricultural practices, well developed regulatory framework, and sustainable agricultural practices. The new research and investigation in the area should bend towards the ecological research over the long term, structuring of future biotechnology remedies and the additive impacts of the environment. An equal approach is required in the ecological conservation and technological innovation to achieve sustainable agricultural development.

## Reference:

- Arpaia, S., Birch, A.N.E., Kiss, J., van Loon, J.J., Messéan, A., Nuti, M., Perry, J.N., Sweet, J.B. and Tebbe, C.C., 2017. Assessing environmental impacts of genetically modified plants on non-target organisms: the relevance of in planta studies. *Science of the Total Environment*, 583, pp.123-132.
- Barton, J.E. and Dracup, M., 2000. Genetically modified crops and the environment. *Agronomy Journal*, 92(4), pp.797-803.
- Brookes, G. and Barfoot, P., 2013. Key environmental impacts of global genetically modified (GM) crop use 1996–2011. *GM crops & food*, 4(2), pp.109-119.
- Brookes, G. and Barfoot, P., 2015. Environmental impacts of genetically

- modified (GM) crop use 1996–2013: Impacts on pesticide use and carbon emissions. *GM crops & food*, 6(2), pp.103-133.
- Brookes, G. and Barfoot, P., 2016. Environmental impacts of genetically modified (GM) crop use 1996–2014: Impacts on pesticide use and carbon emissions. *GM crops & food*, 7(2), pp.84-116.
- Brookes, G. and Barfoot, P., 2017. Environmental impacts of genetically modified (GM) crop use 1996–2015: Impacts on pesticide use and carbon emissions. *GM crops & food*, 8(2), pp.117-147.
- Brookes, G. and Barfoot, P., 2018. Environmental impacts of genetically modified (GM) crop use 1996-2016: Impacts on pesticide use and carbon emissions. *GM crops & food*, 9(3), pp.109-139.
- Brookes, G. and Barfoot, P., 2020. Environmental impacts of genetically modified (GM) crop use 1996–2018: impacts on pesticide use and carbon emissions. *GM Crops & Food*, 11(4), pp.215-241.
- Conner, A.J., Glare, T.R. and Nap, J.P., 2003. The release of genetically modified crops into the environment: Part II. Overview of ecological risk assessment. *The Plant Journal*, 33(1), pp.19-46.
- Conner, A.J., Glare, T.R. and Nap, J.P., 2003. The release of genetically modified crops into the environment: Part II. Overview of ecological risk assessment. *The Plant Journal*, 33(1), pp.19-46.
- Dale, P.J., 2002. The environmental impact of genetically modified (GM) crops: a review. *The Journal of Agricultural Science*, 138(3), pp.245-248.
- Dunfield, K.E. and Germida, J.J., 2004. Impact of genetically modified crops on soil-and plant-associated microbial communities. *Journal of environmental quality*, 33(3), pp.806-815.
- Ervin, D.E. and Welsh, R., 2006. Environmental effects of genetically modified crops: differentiated risk assessment and management. In *Regulating agricultural biotechnology: Economics and policy* (pp. 301-326). Boston, MA: Springer US.
- Ferry, N. and Gatehouse, A.M. eds., 2009. *Environmental impact of genetically modified crops*. CABI.
- Fontes, E.M., Pires, C.S., Sujii, E.R. and Panizzi, A.R., 2002. The environmental effects of genetically modified crops resistant to insects. *Neotropical Entomology*, 31(4), pp.497-513.
- Gates, D.P., 1996. The environmental impact of genetically engineered crops. *Biotechnology and Genetic Engineering Reviews*, 13(1), pp.181-196.
- Megha, K. and Kaur, S.G., 2013. Ecological impact of genetically modified crops. *Research Journal of Recent Sciences SSN*, 2277, p.2502.
- Mertens, M., 2008. Assessment of environmental impacts of genetically modified plants.
- Noack, F., Engist, D., Gantois, J., Gaur, V., Hyjazie, B.F., Larsen, A., M'gonigle, L.K., Missirian, A., Qaim, M., Sargent, R.D. and Souza-Rodrigues, E., 2024. Environmental impacts of genetically modified crops. *Science*, 385(6712), p.eado9340.
- Sanvido, O., Romeis, J. and Bigler, F., 2007. Ecological impacts of genetically modified crops: ten years of field research and commercial cultivation. *Green Gene Technology: Research in an Area of Social Conflict*, pp.235-278.
- Sanvido, O., Romeis, J., Gathmann, A., Gielkens, M., Raybould, A. and Bigler, F., 2012. Evaluating environmental risks of genetically modified crops: ecological harm criteria for regulatory decision-making. *Environmental Science & Policy*, 15(1), pp.82-91.
- Sanvido, O., Stark, M., Romeis, J. and Bigler, F., 2006. Ecological impacts of genetically modified crops. *Experiences from ten years of experimental field*

- research and commercial cultivation. *ART-Schriftenreihe*, 1(1), pp.1-84.
- Steinbrecher, R.A., 1996. From green to gene revolution: the environmentally risks of genetically engineered crops. *The ecologist*, 26(6), pp.273-282.
- Stewart Jr, C.N., 2004. *Genetically modified planet: environmental impacts of genetically engineered plants*. Oxford University Press.
- Tsatsakis, A.M., Nawaz, M.A., Kouretas, D., Balias, G., Savolainen, K., Tutelyan, V.A., Golokhvast, K.S., Lee, J.D., Yang, S.H. and Chung, G., 2017. Environmental impacts of genetically modified plants: A review. *Environmental research*, 156, pp.818-833.
- Tsatsakis, A.M., Nawaz, M.A., Kouretas, D., Balias, G., Savolainen, K., Tutelyan, V.A., Golokhvast, K.S., Lee, J.D., Yang, S.H. and Chung, G., 2017. Environmental impacts of genetically modified plants: A review. *Environmental research*, 156, pp.818-833.
- Wolfenbarger, L.L. and Phifer, P.R., 2000. The ecological risks and benefits of genetically engineered plants. *Science*, 290(5499), pp.2088-2093.