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Biotechnological models for soil health restoration to enhance the soil health and sustainable agriculture: present condition and future research

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Abstract

Objective

Degradation of land quality is a major concern for the United Nations Environment Programme (UNEP) since it harms human health and food security. Restoring healthy soil is a primary goal of sustainable agriculture (SA), as it is essential for crop yields and other ecosystem services. This can be overcome by engineering GMOs to produce materials or enzymes that aid in the breakdown of soil pollutants. In this work, we look at the possibility that GMOs can speed up the bioremediation process and increase efficiency in the removal of toxic contaminants from soil.

Materials and methods

The study occurred in the Nilokheri part of the Karnal area in Haryana, India. During the field trip, data was collected by interviewing 150 residents in 32 communities of the Nilokheri division in the Karnal area. Information collected included cultivation methods, farming history, varieties utilized, mean yield, thickness, location of irrigation water, and the amount and kind of fertilizers used.

Results

The research suggests a long-term solution to soil health problems by integrating GMOs, rhizobacteria, and other soil treatments into a single strategy. Within a decade, this integrated approach may have restored soil fertility and reduced pollution impacts, guaranteeing that agricultural land will be sustainable in the long run. Genetically modified organisms (GMOs) have the potential to quicken the land's natural recovery process, which in turn increases the land's production and resistance to persistent environmental threats.

Conclusions

Finally, this study shows that genetically modified organisms (GMOs) have the potential to improve soil health through better bioremediation, which would lead to more sustainable agriculture. Nevertheless, it also stresses the need to evaluate the advantages of GMOs against their possible ecological dangers and to support a careful, regulated strategy for their use in environmental contexts.

Keywords: Biotechnology, Genetically Modified Organisms, Soil Health Restoration, Sustainable Agriculture

Paper Type: Research Paper.

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Introduction

Soil is a natural resource that can't be lived without (Lehmann et al. 2020). The biological, chemical, and physical processes in soils are complicated. Understanding and predicting how a soil system will change after Sustainable Agriculture (SA) activities is challenging. Soil health refers to the condition of the systems and processes within a specific soil, determining its ability to function as a vital ecosystem. In soil wellness (formerly known as soil condition), the soil is regarded as an ecosystem in which a soil structure can be effectively managed to enhance its overall health (Timmis & Ramos 2021). Healthy soil is easier to work with, lasts longer, and stays stable. It gives plants the necessary nutrients, effectively collects and holds water, and gives microbes a better place to live than dangerous dirt. Conventional Tilting (CT) is a very intense farming method that can cause several problems (Zheng et al. 2020). Some of these problems are a lack of water and workers, land that keeps breaking down, more oxidation that lowers Soil Organic Carbon (SOC) and raises Greenhouse Gas (GHG) levels, loss of essential plant nutrients, bad soil health, and a drop in sustainable farming (Jeffry et al. 2021). Soils are worsening worldwide, and in South Africa, they are in danger of dying completely. Reduced agricultural production and food insecurity are consequences of soil degradation in Africa, which is caused by causes like deforestation, overgrazing, unsustainable farming practices, climate change, and inadequate water management. Ecologically sound land management and preservation strategies are essential to solving these problems. Because of this, scientists need to develop advanced ways to protect soils while still allowing plants to grow and improving the soil overall. Concerns about the long-term survival of agriculture worldwide have led to the rise of Conservation Agriculture (CA) (Cárceles Rodríguez et al. 2022; Angin et al. 2020). The soil's health depends on how well it works and how well the ecosystem is balanced (Bobir et al. 2024). These factors are affected by the soil's porosity, wetness, structure, and other physical traits. Many people know that soil damage can be caused by natural events, things that happen infrequently, like rain and wind, and disasters like floods and earthquakes. Soil damage is caused by things people do, like mining, cutting, farming with chemical fertilizers, developing chemically-induced acidity, alkaline conditions, salinity, and oil spills (Zhao et al. 2023). Deforestation and other forms of excessive land clearance degrade soil because they eliminate vegetation, which exposes the soil to wind and water erosion. Soil erosion, nutrient loss, decreased fertility, and greater susceptibility to further degradation are all consequences of soil that lacks plant roots to stabilize it. It is essential to develop plans immediately to deal with the problems these issues cause (Nabeesab Mamdapur et al. 2019). To improve the health of the soil, dangerous substances can be removed, and more nutrients can be added to make it better (Gladkov & Gladkova 2021). To restore soil health, bacteria can add nutrients that make the soil more productive while also getting rid of or reducing the effects of harmful xenobiotics (Rebello et al. 2021). The article looks at how bacteria might be able to remove, change, and fix many toxic chemicals in the soil, which would make it more fertile in South Africa (Maqsood et al. 2023). Moreover, data generation in agriculture and biotechnology has greatly increased in recent years due to the very rapid development of high-performance technologies (Mohammadabadi et al. 2024). These data are obtained from studying products, foods, and biological molecules to understand the role of different aspects of agriculture in determining the structure, function, and dynamics of living systems (Pour Hamidi et al. 2017). Artificial neural networks have been proposed to alleviate limitation of traditional methods and can be used to handle nonlinear and complex data, even when the data is imprecise and noisy (Pour Hamidi et al. 2017). Agricultural data can be too large and complex to handle through visual analysis or statistical correlations. This has encouraged the use of machine intelligence or artificial intelligence (Ghotbaldini et al. 2019). Thus, the main goal of this study was to find effective ways to quickly restore soil health by using Genetically Modified Organisms (GMOs) to speed up the cleansing process and make them work better.

Materials and methods

Study site features: The study occurred in the Nilokheri part of the Karnal area in Haryana, India (Figure 1) (Nilokheri is a town and a municipal committee). The climate in the area is dry, with hot summers, cold winters, and dry conditions. A subtropical western monsoon blows through the area. The summer rain starts in late June, and the southwest rain is the primary type of rain from July to September. There are big changes in temperature and dry air rules for most of the year (Surendar et al. 2024). The region had a mean yearly rainfall of 780 mm between 2014 and 2020, with a mean of 48 wet days per year. In 2019, the total amount of rainfall was approximately 1400 mm. The measured air temperatures for December and July were 7.3°C and 38.5°C, respectively, representing the mean lowest and highest values. The research area's soil is classified as Indo-Gangetic Alluvium, the dominant soil category. The texture ranges from sandy clay loam to clay-like soil. Finally, the availability of nutrients and plant growth are impacted by soil pH and EC, which are critical markers of soil health. In order to keep the soil in the best possible condition for farming, it is essential to regularly monitor and manage these attributes. The soil is classified as an Entisol, specifically a fluvent suborder, and falls under the Ustifluvents significant grouping.

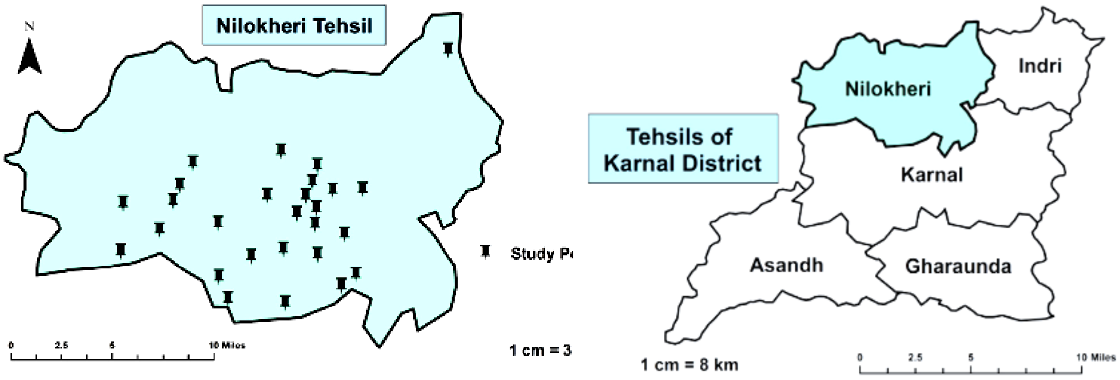

Figure 1. Location of the study area

Treatments and experimental structure: During the field trip, data was collected by interviewing 150 residents in 32 communities of the Nilokheri division in the Karnal area.

Information collected included cultivation methods, farming history, varieties utilized, mean yield, thickness, location of irrigation water, and the amount and kind of fertilizers used. The survey indicated that the duration of practicing CA differed among various communities. Based on the survey data, the 32 villages were categorized into three categories according to the duration of CA adoption. The research region was subject to continuous rice cultivation during the Kharif period and wheat cultivation throughout Rabi. The rice was transferred using the puddling method, while the wheat was sown using drill sowing in zero-till settings. The crop remnants were left on the soil surface. The size of the 32 communities ranged from 120 to 2060 hectares. During the grain growing, soil specimens were obtained from CA and CT village fields. The specimens were taken from two different soil levels: 0-12 cm and 12-35 cm. For every community, 5-8 soil specimens were gathered under CA conditions. These specimens were combined to create a single composite specimen for that village. Sixty soil specimens were obtained from farms in CT and CA, encompassing both soil levels. To analyze multiple variables, the soil specimens were dried outdoors in the shading, pulverized using a pestling device and mortar, and kept in plastic containers.

Measurement of soil features: The soil Bulk Density (BD) measurement was conducted using the core auger technique (Panagos et al. 2024). The core technique is suggested for measuring soil BD in large pieces that comprise less than 30% of the total volume. Coarse granules refer to particles with a diameter of more than 3 mm. A core cutter with a length of 6.2 cm and a height of 16 cm was utilized. This approach involves the utilization of a double cylindrical drop hammering sampler equipped with a core to extract a cylinder-shaped specimen from the soil. The soil component was subjected to oven drying at 108 °C for 16-22 hours, after which its weight was measured. The bulk volume was determined by splitting the mass of the soil by measuring the device's core.

Microbial Biomass Carbons (MBC): The Fumigation-extraction technique was used to determine the concentration of MBC, which accounts for 1-6% of the total charcoal (Lepcha & Devi 2020). The microbes found in the soil specimen were eliminated by fumigating night using formaldehyde. The soil specimens, both disinfected and chilled non-fumigated, underwent digestion utilizing a mixture of 0.3 $NK_2Cr_2O_7$, focused H_2O_4, and orthophosphoric acid. After adding a ferroin indication, the solution was titrated with a 0.006 N ferrous ammonia sulfate solution until the brick-red end-point was achieved.

Dehydrogenase action: A 0.4 mL of Triphenyl Tetrazolium Chloride (4% TTC) was introduced to 1 g of soil that had been dried in the air (Jaconis et al. 2021). A 0.6 mL glucose suspension with a concentration of 2% was included and incubated at 29.2 °C for 24 hours. Following the incubation period, 15 ml of alcohol was introduced and violently agitated before being left undisturbed for 8 hours. A transparent pink fluid was obtained from the fluid remaining after sedimentation, and measurements were taken using a spectrophotometer at 490 nm.

Acid and alkaline phosphatase action: This procedure involved collecting two sets of soil specimens weighing 1 gram. To each set, 0.3 mm of toluene and 5 mm of Modified Universal Buffers (MUB) at pH 6.8 and 10.5 were included, respectively. A 1 ml dose of p-nitrophenyl phosphatase was incorporated into one of the pairs and incubated at 38°C for 60 minutes. Following the development, a solution containing 1 ml of 0.8 M NaCl and 5 ml of 0.8 N NaOH was introduced and agitated briefly. 1mm of p-nitrophenyl phosphorus was introduced to the leftover pairs. All concentrations were passed via a Whatman filtration. The magnitude of the yellow color was quantified at a wavelength of 450 nm. A standardized solution of p-nitrophenol was utilized for this test. The phosphomonoesters action was quantified as the number of micrograms of p-nitrophenol emitted per gram of soil every hour.

Glomalin volume:1 gram soil specimens of ground dry-sieved soil were used for extracting Total Glomalin (TG) using 7 mm of 25 mm citrate solution (pH 7.0) (Hossain 2021). The mixture was then sterilized at 120 degrees Celsius for 60 minutes. The protein concentration in the waste product was quantified using the Bradford test, employing bovine serum protein as the reference standard, and measured on a 96-well plate scanner.

Available N, P, K: Farzadfar et al. (2021) measured nitrogen accessibility in soils (Farzadfar et al. 2021). The approach described by Ding et al. was used to determine the substrate's phosphorus concentration (Ding et al. 2021). The approach provided by Andrews et al. was used to determine the amount of obtainable potassium in the substrate (Andrews et al. 2021).

Computation of sustainability: The environmental Sustainability Index (SI) for CA and CT networks was calculated using critical limitations. Three locations were chosen to evaluate the long-term viability of the CA and CT structures: Taraori, Gholpur, and Sambi. The SI computation was performed using 11 indicators as the basis. The parameters measured were bulk concentration, effective porousness, wilting place, soil water level at 1.5 MPa, accessible water capability up to a depth of 20 cm, soaked hydraulic conductance, substrate organic carbon, coarse fragmented portion (>1.5 mm), efficient rooting length, electrical conductance, and substrate textural category. After considering the restrictions of crop production, specific crucial values were set for each indication, along with corresponding weighting elements. The SI was calculated by adding the critical values of all indicators within a particular depth for every category separately. The soil health indicators were scored based on the SI utilizing the Technique for Order Priority by Similarities to Ideal Solutions (TOPSIS) (Zahedifar 2023). This approach is a form of choice analysis that considers multiple criteria. The process involves evaluating options by assigning weights to every criterion and determining the optimal scores for every requirement. The fundamental principle underlying TOPSIS is that the selected alternative must be the minimum length from the optimal answer and the most from the negative-ideal option.

Results and discussion

Soil Health Restoration: Due to the inherent limitations of native microorganisms in adapting to an unfamiliar setting and effectively degrading contaminants, it is advantageous to utilize GMOs for improved efficiency. These GMOs are highly effective in removing most pollutants that naturally occurring microbes cannot break down. Various molecular techniques can create GMOs, such as biolistic change, electroplating, conjugation, horizontal replication of bacterial genomes, genetic cloning, and altering protoplasts in SA. The transmission and production of new genes with a high disintegration capacity also help shorten the time required for cleanup. GMOs can address a range of substances such as benzene, octane, a substance called the chemical salicylate, and ethylene by activating genes contained in the bacterial plasmids. The authors propose four distinct methods: a) altering the enzyme's attraction and particularity, b) modifying genes and regulating pathways, c) creating and managing the method of bioremediation, and d) using sensor-based bio affinity viewers to detect contaminants, minimize toxicities, and anticipate outcomes in SA. The capacity to integrate many genes involved in xenobiotic disintegration into a single microorganism enhances the capacity of that microorganism to break down a diverse array of foreign substances.

Heavy metal removal: Removing contaminants from contaminated settings using microbes is based on biosorption and biological accumulation. Heavy metallic biosorption is a method of adsorbing and retaining pollutants into the outer lipid membranes and, in some instances, the exopolysaccharide discharges that contain living or dead heavy metal sequesters. Bioaccumulation is transporting heavy metals from the atmosphere to the microbiological cytoskeleton. Distributors facilitate this transportation, including porins, ion pathways, leading active carriers, and auxiliary transports. Once inside the microbiological cytoplasm, the contaminants are bound by metal-sequestering enzymes.

Pesticide degradation: Many genes with a significant capacity to break down insecticides have been identified, expanding the potential for creating a GMO well-suited for chemical breakdown. As the shift towards organic agriculture and the application of genetically modified crops to increase crop production continues, using biological insecticides has become crucial for ethical farming techniques. The modified microbe plays a vital role in restoring soil health by effectively breaking down pesticide residues that would otherwise persist in the soil for extended periods. The enzyme, liable for generating the atrazine chlorohydrolase, was utilized to break down the widely employed herbicide atrazine, which has a chance of harming wildlife.

Hydrocarbon degradation: In addition to other contaminants, oil contamination has emerged as a significant global concern. Oil pollution not only affects coastlines but also occurs on inland soil and waterways due to spills during transportation. The magnitude and harmfulness of the oil pollution vary based on the extent of the leak and the level of contact with other living things. The oil leak also causes harm to the soil and plants, so it is necessary to clean it up. Biological approaches offer benefits regarding soil stability and contribute to effective soil restoration. Several native strains capable of degrading hydrocarbons in oil-contaminated locations have been documented. GMOs are more effective than native strains in repairing polluted environments due to the complicated composition of oil, which consists of several hydrocarbons. Superbug growth can occur when cassettes carrying numerous genes encoding degradation enzymes get introduced into a living thing.

Challenges of GMOs for in situ applications: Ecological risk evaluation is essential for evaluating the effects of applying a group of microbial or genetically modified microbe in the area, which can alter the native soil microbiome. While synthetic microorganisms are effective for bioaugmentation, establishing and maintaining their development in surroundings is challenging due to the necessity to outcompete native organisms. Figure 2 illustrates the difficulties and potential resolutions in using GMOs to address environmental contaminants.

Other elements, including copy quantity, development rate, kind of insert, oxygen accessibility, medium elements, and surroundings, impact the recombinant plasmid's durability. Using GMOs in bioremediation encounters a significant obstacle as many frequently exhibit ineffectiveness in the natural surroundings over an extended period and struggle to withstand extreme conditions such as pH, temperatures, salinity, etc. The optimal production of biodegradation proteins necessitates integrating with chromosome genetic components rather than plasmids. Their efficacy must also be validated. The inherent fragility of plasmids is a significant obstacle in the development of artificially produced microbes for biological remediation. This issue can be effectively addressed by employing mini-transposons. The mini transposons exhibit a durable insertion of heterologous genes into the recipient's genome. Nonantibiotic-resistant selection should be used in these mechanisms to avoid the transfer of genes into the surroundings. The self-destruction gene can contribute to the regulated release of these GMOs as they become active without contaminants and eliminate the GMOs. Fermentation is an approach that can be used to reduce the danger of horizontal gene transfer. This process involves subjecting GMOs to elevated temperatures above 95°C and lowering pH levels. These conditions cause the GMOs to undergo cell lysis, releasing their DNA. This expulsion of DNA helps prevent the horizontal exchange of genes among GMOs and natural bacteria. The introduction of GMOs into land for farming can potentially impact the structure of its natural soil microbiology.

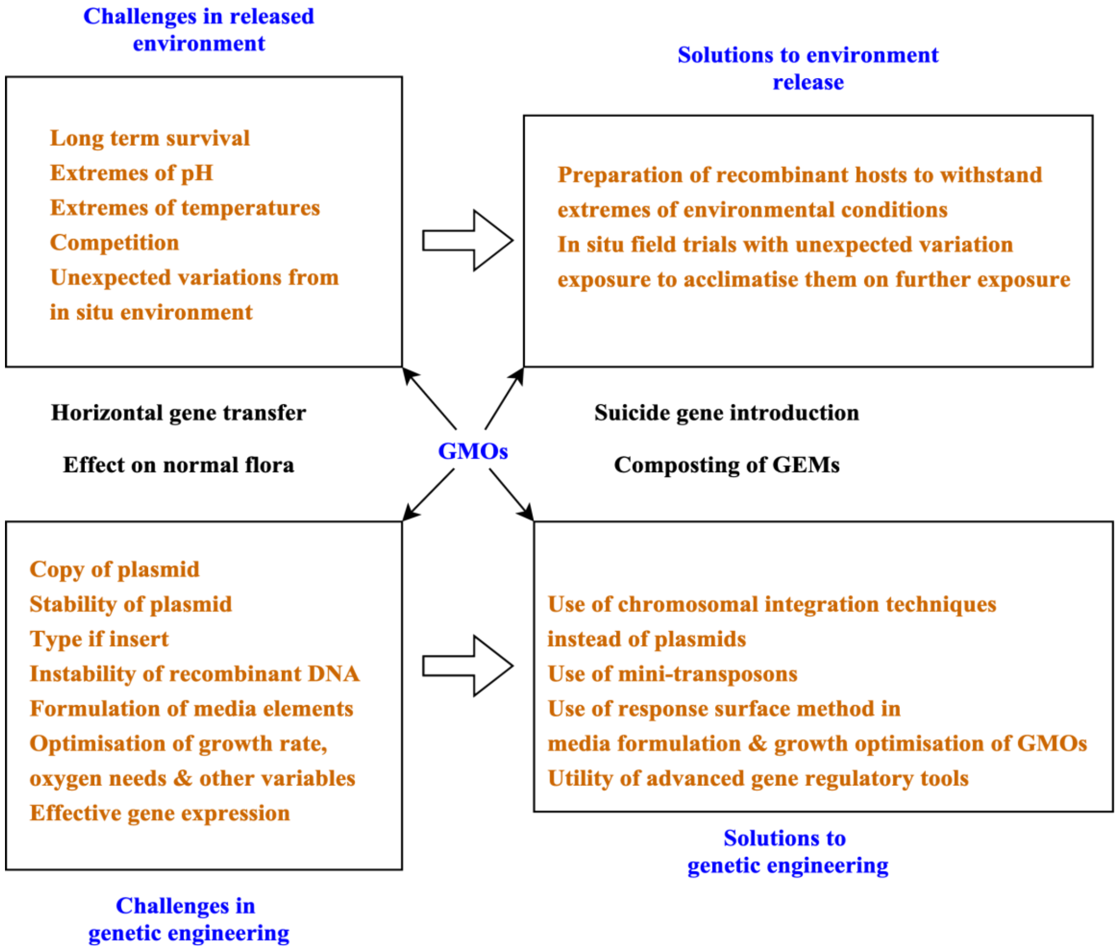

Figure 2. Challenges and potential issues of soil health restoration

An identical outcome arises when a novel species is introduced into the soil, regardless of whether there is any distinction between the natural and genetically modified variants. When GMO pseudomonas fluorescens was used to degrade polychlorinated biphenyls, there was no observable impact on the architecture and functioning of the bacterial population. The effect of adding GMOs on the organization of bacterial communities is minimal compared to the impact caused by other biological and ecological variables in SA.

Conclusions: Sophisticated sequencing techniques enhance the comprehension of the microbial flora present in the soil. This technique can reveal previously unidentified microbial populations and make them usable for the betterment of humanity in SA. Manipulating the soil microbiota has significant promise for enhancing agricultural practices. Keystone taxa, a group of microorganisms, are closely linked to the well-being of plants. The main obstacle to restoring soil health by employing GMOs is the limited production of proteins that provide essential characteristics, such as the ability to remove harmful chemicals, increased resistance and buildup of heavy metallic substances, and faster breakdown of various chemicals. Case-based technologies for botanical remediation and endophytic microorganisms in pesticide treatment have been thoroughly examined and evaluated. The effectiveness of subsequent studies in this area should be evaluated by considering the stringent restrictions governing the use and testing of GMOs. It is imperative to address the impact of contaminants, such as micro- and nanoplastics, on the overall well-being of soil and water ecosystems. The issue of soil health restoration is crucial in contaminated countries with SA, as agricultural output is a direct measure of the self-sufficiency of a developing economy. The growing population and need for additional resources necessitate the availability of fertile lands to sustain our food production and facilitate the restoration of polluted structures. Microorganisms are essential for soil development, as well as their fertility and capacity to eliminate harmful substances and sustain soil well-being. It is imperative to explore the efficacy of GMOs to expedite the procedure of rejuvenating soil health and addressing a diverse range of pollutants in SA. It is essential to promote the utilization of genetic tools that are more dependable and have minimal or no adverse effects on the natural world. It is crucial to consistently produce biodegradation genetic components linked to the chromosome rather than plasmids to achieve the desired long-term impact of restoration. Integrating the bioremediation capabilities of microorganisms with their capacity to improve soil fertility holds great promise for the sustained growth of soil in such a situation in the future.

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مدل‌های بیوتکنولوژیکی برای احیای سلامت خاک برای افزایش سلامت خاک و کشاورزی پایدار: شرایط فعلی و تحقیقات آینده

دیویا

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چکیده

هدف: تخریب کیفیت زمین یک نگرانی عمده برای برنامه محیط زیست سازمان ملل متحد (UNEP) است زیرا به سلامت انسان و امنیت غذایی آسیب می‌رساند. احیای خاک سالم هدف اولیه کشاورزی پایدار (SA) است، زیرا برای بازده محصول و سایر خدمات اکوسیستمی ضروری است. این را می‌توان با مهندسی ارگانیسم‌های اصلاح شده ژنتیکی (GMOs) برای تولید مواد یا آنزیم‌هایی که به تجزیه آلاینده‌های خاک کمک می‌کنند، غلبه کرد. در این کار، ما به این امکان نگاه می‌کنیم که GMOها می‌توانند روند تصفیه زیستی را سرعت بخشند و کارایی را در حذف آلاینده‌های سمی از خاک افزایش دهند.

مواد و روش‌ها: این مطالعه در بخش نیلوخری در منطقه کارنال در هاریانا، هند انجام شد. در طول سفر میدانی، داده ها با مصاحبه با ۱۵۰ نفر از ساکنان ۳۲ منطقه از بخش نیلوخری در منطقه کارنال جمع آوری شد. اطلاعات جمع آوری شده شامل روش‌های کشت، تاریخچه کشاورزی، ارقام مورد استفاده، میانگین عملکرد، ضخامت، محل آب آبیاری و مقدار و نوع کود مصرفی بود.

نتایج: این تحقیق راه حلی بلندمدت برای مشکلات سلامت خاک با ادغام GMOs، ریزوباکترها و سایر درمان‌های خاک در یک استراتژی واحد پیشنهاد می کند. ظرف یک دهه، این رویکرد یکپارچه ممکن است حاصلخیزی خاک را احیا کرده و اثرات آلودگی را کاهش دهد و تضمین کند که زمین‌های کشاورزی در دراز مدت پایدار خواهند بود. ارگانیسم‌های اصلاح شده ژنتیکی (GMOs) این پتانسیل را دارند که روند بازیابی طبیعی زمین را تسریع کنند که به نوبه خود باعث افزایش تولید و مقاومت زمین در برابر تهدیدات محیطی پایدار می‌شود.

نتیجه‌گیری: در نهایت، این مطالعه نشان می‌دهد که ارگانیسم‌های اصلاح‌شده ژنتیکی (GMOs) پتانسیل بهبود سلامت خاک را از طریق اصلاح زیستی بهتر دارند که منجر به کشاورزی پایدارتر می‌شود. با این وجود، همچنین بر نیاز به ارزیابی مزایای GMOs در برابر خطرات زیست محیطی احتمالی آنها و حمایت از یک استراتژی دقیق و تنظیم شده برای استفاده از آنها در زمینه های زیست محیطی تأکید می کند.

واژه‌های کلیدی: احیای سلامت خاک، ارگانیسم‌های اصلاح‌شده ژنتیکی، بیوتکنولوژی، کشاورزی پایدار

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