Editing the Truth

GENOME EDITING IS NOT A SOLUTION TO CLIMATE CHANGE

REPORT | October 2021

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for the **people** | for the **planet** | for the **future**

sag Schweizer Allianz Gentechfrei

Friends of the Earth Europe

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Friends of the Earth Europe is the largest grassroots environmental network in Europe, uniting more than 30 national organisations with thousands of local groups. We are the European arm of Friends of the Earth International which unites 74 national member organisations, some 5,000 local activist groups, and over two million supporters around the world. We campaign on today's most urgent environmental and social issues, challenging the current model of economic and corporate globalization, and promoting solutions that will help to create environmentally sustainable and socially just societies. We seek to increase public participation and democratic decision-making. We work towards environmental, social, economic and political justice and equal access to resources and opportunities on the local, national, regional and international levels.

SAG – Swiss Alliance for a GMO-free Agriculture Zurich based SAG (Schweizer Allianz Gentechfrei– Swiss Alliance for a GMO-free Agriculture) understands itself as critical forum on all questions relating to genetic engineering. SAG is the umbrella organisation of Swiss farmers, consumer, environmental, development cooperations and animal welfare associations with the aim to encourage discussions and political opinion forming in the field of genetic engineering. The SAG, founded in 1990, is a non profit organisation financially supported by members, a variety of Swiss associations and donators.

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Introduction: Genome editing is NOT a solution to climate change

Agriculture is both a driving force for and a victim of climate change. On one hand, industrial agriculture is responsible for a significant proportion of the climate-relevant gas emissions, particularly because of intensive animal farming and the production of concentrated feeds associated with it. On the other, agriculture is inextricably linked to nature and is thus inevitably affected by the rise in average temperatures and increasingly extreme weather conditions. In tune with this dual role, twin-track solutions have to be found to prevent the negative effects of dominant agricultural practices as well as to adapt production to the negative consequences of climate change.

Instead of seeking system-oriented, sustainable solutions, agribusiness relies on profit-oriented market processes and technologies such as genetic engineering and promotes them as panaceas. In so doing, issues are only partially addressed, and only in the short-term - with scant regard for the long-term impact of the use of such technologies on climate and nature.

Similarly, to what it has been doing for the past 20 years with first-generation GMO technology, the gene-tech lobby is now promoting genome editing - rebranded as "new breeding techniques" - as an answer to the most pressing environmental problems in today's world. Genome editing is, however, merely treating some isolated symptoms caused by intensive farming. The goal is not to change the existing system, but to carry on farming focusing on performance, yield and profit.

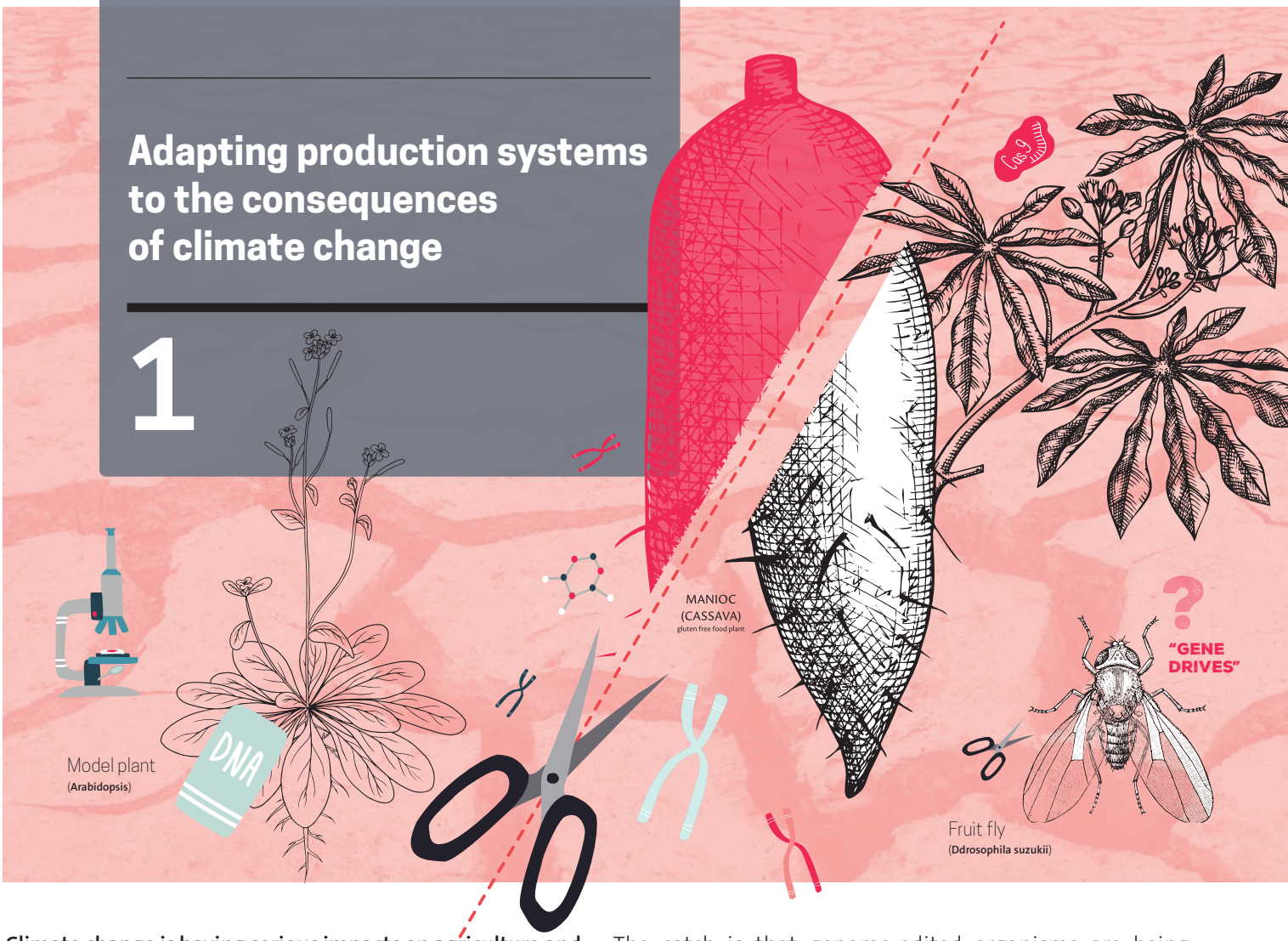
Agroecological farming techniques are the better option to ensure global food security, especially against the backdrop of climate change. Unlike genetic engineering, agroecology is not just a box of different tools but rather a holistic, interdisciplinary approach based upon practical cooperation between the scientific community, **farm operators and social movements. It's the approach that is practiced by a majority of the over 500 million smallholder family farms that produce most of the world's food.[1] Widely deployed and practised in the field for decades, agroecological methods are especially sustainable, because they leverage our ability to adjust to climate change.** The basis for agroecology is diverse local production adapted to regional conditions. The diversification of farming systems is key to agroecological transitions needed to face the challenges of climate change and to find a way to feed the growing world population sustainably.[2]

SWISS ALLIANCE FOR A GMO-FREE AGRICULTURE (SAG) & FRIENDS OF THE EARTH EUROPE (FOEE) ARE CALLING FOR:

- Decision makers need to adjust their perception of potential of new GMOs. The long list of promises about the potential benefits of new GM are not based on substantial evidence whilst a long list of negative Impacts and side effects of new GMO is downplayed in public debates
- A shift in priorities is needed to support real solutions for climate change in public policies like agriculture, research and environmental legislations. Farming systems like agroecology and organic farming have huge evidence to cut emissions from farming sector, increase soil health with positive impacts on natural carbon sequestration in the soil.
- Keep new GM regulated as GMO to ensure freedom of choice for consumers, farmers and breeders and ensure that new technologies can't be marketed without stringent safety checks and labelling.

Adapting production systems to the consequences of climate change

1



Climate change is having serious impacts on agriculture and food production around the world. Summer droughts, for example, are predicted to increase sharply in Central Europe during the second half of the century, which will affect a further 40 million hectares of agricultural land.[3] Southern developing countries that have less capacities to adapt will be hit particularly hard by the negative effects of climate change such as decreased yields.[4, 5]

Yield stability is reduced by a number of different factors including increased pest pressure, milder winters, extreme weather conditions and water shortages. It is clear that solutions are urgently needed to address these future challenges. The agricultural biotechnology industry sees the solution mainly in genetic engineering. Genetic "improvements" are claimed to accelerate breeding of resilient, disease-resistant and stress-tolerant plants. The industry also claims that they will sustainably increase food supply and the availability of other agricultural produce, thereby improving food security.

The catch is that genome-edited organisms are being developed within the context and logic of industrialised agriculture. This has numerous negative consequences that cannot be neglected. On the one hand, these profit-driven approaches increase farmers' dependency on patented seeds from just a handful of large seed corporations. On the other hand, trying to adjust some isolated sites in the genome considered to be important has, regardless of the degree of precision of the methods used, very often proved to be harmful to the organism as a whole. Instead of focusing on the cultivation of a few genome-edited crops on large areas, systemic change is needed to sustainably increase the resilience of cropping systems.

Footnotes:

3 Hari V, Rakovec O, Markonis Y, Hanel M, Rohini K 2020 Increased future occurrences of the exceptional 2018–2019 Central European drought under global warming. Scientific Reports 10, 12207. https://doi.org/10.1038/s41598-020-68872-9

4 Lobell DB, Schenkler W, Costa-Roberts J 2011 Climate Trends and Global Crop Production Since 1980. Science 29, 333 (6042): 616-620.

5 Jones N 2011 Climate change curbs crops. Nature News: doi:10.1038/news.2011.268 https://www.nature.com/news/2011/110505/full/news.2011.268.html

1.1

Yield reductions due to the increased occurrence of weather extremes and the prevalence of new pests and diseases

The problem: with climate change, agriculture has to face new challenges. The accumulation of greenhouse gases in the atmosphere is causing various ongoing changes in the climate system. According to experts, as a result of this process an increase in weather extremes is to be expected. Models show that global mean temperatures will continue to rise for decades to come.[6, 7] Periods of extreme **heat and drought** are set to become more frequent and to last longer. In developing countries, the direct losses in agriculture caused by drought between 2005 and 2015 amounted to USD 29 billion.[8] One must also consider, that more than 70 percent of the world's fresh water is already used to irrigate agricultural land.[9]

Drought is, however, just one of the negative effects of climate change. Extreme weather events such as severe storms, **heavy precipitation** with resultant flooding are also expected to increase in frequency – both in the mid-latitudes and in humid tropical regions. Furthermore, we are witnessing an increase in the land area on which only saline-tolerant crops can thrive. The Intergovernmental Panel on Climate Change IPCC forecasts about one metre of sea **rise** by 2100.[10] Even if half that level is reached, about two million hectares of land will be covered by salt water. This will affect in particular rice cultivation. In /richer countries in the Global North, it is intensive farming that increases soil salinity.

These extreme events cause soil erosion, desertification and **salinisation**, resulting in harvest losses and endangering global food production. Biotechnology companies suggest that genome editing - aka new breeding techniques - is the only way to effectively maximise food production in order to feed the world's growing population.[11] What is certain is that the current agricultural system needs to be adapted to the new challenges. However, promoting sustainable, system-oriented approaches that are not based on genetic modifications and have proven their effectiveness for many decades would be far preferable to unproven techno-fixes.

Insect pests from warmer areas benefit from the projected rise in average temperatures. Higher temperatures allow them to spread over former geographic barriers and to thrive and multiply in the temperate zones, becoming invasive species. **Similarly, new plant diseases** are expected to spread more quickly, threatening harvests even in places where they have not previously occurred.[12]

1.1.1 Does genome editing produce stress-tolerant, robust plants?

Genome editing to counter abiotic stress

As a response to increasing abiotic stress load, the agricultural biotechnology industry primarily promotes the development of genome-edited plant varieties, claimed to be able to produce higher yields even under unfavourable conditions. According to its proponents, the advantages of genome editing techniques over conventional breeding mainly lie in their widely-promoted higher degree of precision and fast use.

Footnotes:

6 Collins M, Knutti R, Arblaster JM et al. 2013 Long-term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker TF, Qin D, Plattner G-K et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

7 IPCC, 2018: Summary for Policymakers. In: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte V, Zhai P, Pörtner HO et al. (eds.)]. World Meteorological Organization, Geneva, Switzerland,32 pp.

8 FAO 2017 The impact of disasters and crises on agriculture and food security. Rome http://www.fao.org/3/I8656EN/i8656en.pdf

9 OECD 2017 Water Risk Hotspots in Agriculture. https://doi.org/10.1787/9789264279551-en

10 Oppenheimer M, Glavovic BC, Hinkel J et al. 2019 Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [Pörtner H-O, Roberts DC, Masson-Delmotte V et al. (eds.)]. https://www.ipcc.ch/srocc/chapter/chapter-4-sea-level-rise-and-implications-for-low-lying-islands-coasts-and-communities/

11 Haque E, Taniguchi H, Hassan MM, et al. 2018 Application of CRISPR/Cas9 Genome Editing Technology for the Improvement of Crops Cultivated in Tropical Climates: Recent Progress, Prospects, and Challenges. Frontiers in Plant Science 9: 617. doi: 10.3389/fpls.2018.00617 https://www.frontiersin.org/articles/10.3389/fpls.2018.00617/full

12 Juroszek P, Racca, P, Link S, Farhumand J, Kleinhenz B 2019 Overview on the review articles published during the past 30 years relating to the potential climate change effects on plant pathogens and crop disease risks. Plant Pathology 69 (2): 179-193. Hunjan MS, Lore JS 2020 Climate Change: Impact on Plant Pathogens, Diseases, and Their Management. In: Jabran K, Florentine S, Chauhan B (eds) Crop Protection Under Changing Climate. Springer, Cham. https://doi.org/10.1007/978-3-030-46111-9_4 Trebicki, Finlay K 2019 Pests and Diseases under Climate Change; Its Threat to Food Security. In: Food Security and Climate Change Shyam Singh Yadav, Robert J. Redden, Jerry L. Hatfield, Andreas W. Ebert, Danny Hunter (eds) Food Security and Climate Change. John Wiley & Sons.

These promises are by no means new. For more than 20 years, classic genetic engineering promised the world plants that could survive periods of drought without damage and still secure high yields - and failed. This failure to produce satisfactory results has to do with the complexity of drought tolerance as a trait. Plants develop different strategies to deal with drought. These strategies are regulated by an interlocking network of genetic functions. If water becomes scarce, the plant has to focus on survival and pause all non-essential, such as growth or seed production. Due to this trade-off between stress resistance and yield, classical genetic engineering has been unable to achieve any measure of success in the production of drought-tolerant plants, genetically engineered drought tolerance usually having gone hand in hand with a loss of yield. Furthermore, an additional negative impact of the genetic modification on yield could be observed when the dry period was followed by a cool, rainy phase.[13]

By using new genetic engineering methods, biotechnologists now hope to be able to separate these interlinked genetic processes and to intervene simultaneously at several points in the genetic background of drought tolerance. Numerous characteristics that are relevant for the plants' reaction to a lack of water have already been identified in the model plant **Arabidopsis**, including early flowering, the number and genetic regulation of the stomata responsible for evaporation, the production of the cuticle, a waxy protective layer against water loss, the biochemical carbon-allocation pathways, as well as the root architecture. According to some biotechnology experts, several of these properties could theoretically be adjusted simultaneously in the most important crops by means of genome editing - without affecting the yield.

In maize plants, for example, attempts are being made to reduce sensitivity to a plant hormone called "ethylene". Ethylene plays an important role in shaping the plants' reaction to abiotic stress, such as lack of water or high temperature. Among other functions, it inhibits cell division and cell expansion. Under drought conditions a higher yield is planned to be achieved by reducing ethylene production or reducing the sensitivity of the plant to the phytohormone.[14]

In parallel to research on drought tolerance, biotechnologists are also working on increasing the salt tolerance of the most common high-yield varieties of rice.[15] Should they succeed, they argue, these genome-edited rice plants would be the most cost-effective and environmentally friendly way to control soil salinity.

Genome editing against plant diseases and pests

Genome editing is also used in research for the rapid introduction of resistance genes into crops in order to protect them against emerging diseases. For example, attempts are being undertaken to make the cassava plant – a starchy root vegetable that is a staple food in South America, Africa and Asia – resistant to a mosaic virus,[16] which is currently destroying 20 per cent of the harvest.[17]

1.1.2 Why genome editing is NOT a solution:

Reason no. 1: the yield on small plots is not the same as the yield in large-scale cultivation

The examples given show that the agricultural biotechnology industry is primarily focusing on high yields when developing stress-tolerant plants. Yield is however just one of many important traits characterising a variety.

Modifications in the laboratory and measurements in the greenhouse are based on greatly simplified models. The basic principle mainly runs along these lines: generally, plants are first deprived of water for a long time, then they are abundantly watered again. When evaluating the success of the experiment, the focus lies on yield. Other important factors such as soil moisture or plant biomass are rarely taken into account.[18] Even field trials allow only very limited conclusions for large-scale cultivation to be drawn, since cultivation practices are highly standardised and the trials are carried out in a spatially and temporally limited framework.[19] How a variety will react out in field with different soil and climatic conditions can only be deduced to a very limited extent. Should the new genetic engineering methods not be covered by EU GMO legislation, the new varieties will quickly land on the market - without solid

Footnotes:

13 Martignago D, Rico-Medina A, Blasco-Escámez D, Fontanet-Manzaneque JB and Caño-Delgado AI 2020 Drought Resistance by Engineering Plant Tissue-Specific Responses. Frontiers in Plant Science. 10:1676. doi: 10.3389/fpls.2019.01676

14 Shi J, Gao H, Wang H, Lafitte HR, Archibald RL, Yang M, Hakimi SM, Mo H, Habben JE 2016ARGOS8 variants generated by CRISPR-Cas9 improve maize grain yield under field drought stress conditions. Plant Biotechnology Journal 15 (2): 207-216. https://onlinelibrary.wiley.com/doi/full/10.1111/pbi.12603

15 Zhang A, Liu Y, Wang F, et al. 2019 Enhanced rice salinity tolerance via CRISPR/Cas9-targeted mutagenesis of the OsRR22 gene. Molecular Breeding 39: 47. https://doi.org/10.1007/s11032-019-0954-y

16 Mehta D, Stürchler A, Anjanappa RB Hirsch-Hoffmann M, Gruissem W, Vernderschuren H 2019 Linking CRISPR-Cas9 interference in cassava to the evolution of editing-resistant geminiviruses. Genome Biology 20: 80. https://doi.org/10.1186/s13059-019-1678-3

17 Rey C, Vanderschuren H 2017 Cassava Mosaic and Brown Streak Diseases: Current Perspectives and Beyond. Annual Review of Virology 4:429-452.

18 Martignago D, Rico-Medina A, Blasco-Escámez D, Fontanet-Manzaneque JB and Caño-Delgado AI 2020 Drought Resistance by Engineering Plant Tissue-Specific Responses. Frontiers in Plant Science. 10:1676. doi: 10.3389/fpls.2019.01676

19 Bauer-Panskus A, Bohn, T, Cotter J, Hilbeck A, Millstone E, Then C, Wallace H, Wynne B 2020 Zusammenfassender Abschlussbericht des Projektes RAGES, 2016-2019. https://www.testbiotech.org/sites/default/files/Zusammenfassender%20Abschlussbericht%20des%20Projektes%20RAGES.pdf Gurian-Sherman D 2019 Drought-tolerant CRISPR maize? Not yet – maybe not ever. GMWatch. https://www.gmwatch.org/en/news/18696-drought-tolerant-crispr-maize-not-yet-maybe-not-ever

knowledge about their performance under varying field conditions and without proper risk assessment.

Reason no. 2: a plant is not merely the sum of its elements

Whether the efforts to produce drought- and salt-tolerant plants or those with a higher yield by means of genome editing will ever succeed is questionable, simply because these are polygenic traits, i.e. they are controlled by several – often well over a hundred – genes.[20] Each of these genes has only a small effect on the expression of the trait: which is ultimately determined by the sum of the effect of all the components of this gene network.[21] In addition, the expression of the trait also strongly depends on the interaction of the genome and the environment. This complex network of genetic functions interconnected with the influence of environmental factors cannot be reproduced with the punctual modifications of genome editing. Not even if several modifications are carried out at the same time ("multiplexing"). In addition, multiplexing further increases the risk that other metabolic processes will also be affected, since traits influencing stress tolerance are neither independent of each other nor of other traits and metabolic pathways of the organism.

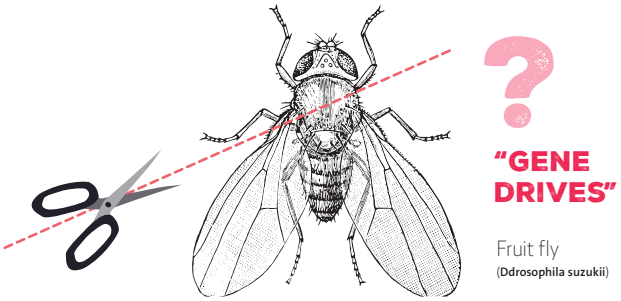
Living beings cannot be changed according to a modular design principle. In other words: tweaking a high-performance variety here and there to make it more drought-tolerant is not without consequences for the organism. An intervention in the genome, no matter how small and precise, always has an impact on other fundamental physiological processes of the plant.[22, 23, 24]

Even if genome editing succeeds in increasing yields, unintended changes affecting other properties are almost always to be expected. However, these often go undetected. Whether genetic engineering causes negative side effects (e.g. off-targets) on another level, is irrelevant for the industry; **ergo** such side-effects are rarely subjected to investigation.

In view of all these uncertainties, the focus on equipping the widespread, overbred high-performance varieties with additional tolerance genes is the wrong way to go.

Reason no. 3: Disease resistance based on a few genes is not durable

Practically all of the research projects using new genetic engineering techniques to make plants (or animals) disease-resistant are based on changing or adding a few genes. Similarly, to stress tolerance or yield, permanent resistance is determined by many genes. Monogenic forms of resistance – determined by one or only a few genes – are easy to work with but usually not durable.[25] Varieties with monogenic resistance again become susceptible to the disease after some time. This is explained by the fact that this type of resistance confers the most virulent variants of the pathogen a constant selective advantage, allowing their population to grow and overcome the engineered resistance. Resistance "breaks down". The same applies to plants that produce insecticide. Pests evolving under the selective pressure of the integrated insecticide rapidly overcome the effect of the toxin and spread - this is even true if the plant produces several toxin variants at the same time.[26, 27] There are numerous tragic examples of the development of insect resistance to Bt-toxin in classic genetic engineering, which have to this day driven a number of small farmers into ruin.[28] The only innovation that genome editing brings in this regard is that the desired genes can now be inserted more quickly. However, the old principle of pathogens and pests overcoming the genetically engineered monogenic resistance after a while still holds true, meaning that sooner or later, significant setbacks are to be expected, even in the case of the new techniques.



Footnotes:

20 Varoquaux N, Cole B, Gao C, et al. 2019 Transcriptomic analysis of field-droughted sorghum from seedling to maturity reveals biotic and metabolic responses. Proceedings of the National Academy of Sciences 116 (52): 27124-27132. https://doi.org/10.1073/pnas.1907500116
21 Becker H 2011 Pflanzenzüchtung. Ulmer, Stuttgart.
22 Bundesamt für Naturschutz Deutschland (BfN) 2017 Neue Verfahren in der Gentechnik: Chancen und Risiken aus Sicht des Naturschutzes. Stand Juli 2017. https://www.bfn.de/fileadmin/BfN/agrogentechnik/Dokumente/17-07-13_Hintergrundpapier_Neue_Techniken_end_online_barrierefrei_01.pdf
23 Kawall K 2019 New Possibilities on the Horizon: Genome Editing Makes the Whole Genome Accessible for Changes. Front. Plant Sci. 10:525. doi: 10.3389/fpls.2019.00525
24 Katharina Kawall 2019 Die neuen Gentechnikverfahren. Eine Bewertung aus naturwissenschaftlicher Sicht. In: Kritischer Agrarbericht
25 Becker H 2011 Pflanzenzüchtung. Ulmer, Stuttgart.
26 Fabrick JA, LeRoy DM, Unnithan GC, Yelich AJ, Carrière Y, Li X, Tabashnik BE 2020 Shared and independent genetic basis of resistance to Bt Toxin Cry2Ab in two strains of pink bollworm. Scientific Reports 10: 7988. https://www.nature.com/articles/s41598-020-64811-w
27 Strydom E, Erasmus A, du Plessis H, Van den Berg J 2018 Resistance status of Busseola fusca (Lepidoptera: Noctuidae) populations to single- and stacked-gene Bt maize in South Africa Journal of Economic Entomology 112 (1): 305-315. https://doi.org/10.1093/jee/toy306
28 Robinson C 2020 Push for GM cotton in Africa is "cause for alarm", says nonprofit. GMWatch. https://www.gmwatch.org/en/news/latest-news/19435-push-for-gm-cotton-in-africa-is-cause-for-alarm-says-nonprofit

Another catch is that the plants that biotechnologists are trying to equip with individual resistance genes are mostly highly-bred varieties which are very dependent on chemicals such as pesticides. Due to bottlenecks from domestication and selective breeding they have a very limited genetic diversity. An extreme example is the banana generally sold all over the world for fresh consumption - belonging to only one variety – mostly grown in huge monocultures.[29] If this variety is threatened by a fungus, as it is currently the case, tinkering with CRISPR/Cas is not a viable solution. Such fragile constructs and systems lacking genetic diversity cannot be saved by inserting a few genes. A single gene added regardless of the context of the genetic information – irrespective of how quickly it is incorporated – cannot compensate for the lost genetic diversity and therefore confers only short-term protection.

There is so far little information on the unwanted side effects of resistances introduced using genome editing. However, interfering with the complex gene network of the genome can have serious negative consequences, as the example of a genome-edited cassava variety shows. There, the use of CRISPR technology led to the emergence of new mutated viruses that could have threatened the entire cassava production.[30]

Reason no. 4: predefined reaction patterns are not flexible

If the weather events resulting from climate change – such as periods of drought – were predictable, it would perhaps be possible to increase the plant's tolerance by quickly introducing some genes. However, weather events cannot be forecasted in this way. It is exactly this unpredictability of the different weather phenomena that characterises climate change. A very wet winter is sometimes followed by a long summer drought, but the water supply can sometimes be scarce even in winter, a drought period can promptly be followed by flooding. In each of these cases the plant has to adapt and react differently.[31] This ability to adapt cannot be ensured by inserting a uniformly- engineered genetic programme.

Another problem is the dependence of farmers on genetically engineered seeds. Patent-protected seed has to be purchased fresh each year. Whether or dry periods will occur or how long for cannot be predicted. The benefits of the genetically-engineered traits are also doubtful, depending on the duration and nature of these periods. In the light of so many uncertainties, it is questionable whether it is worth purchasing expensive genome edited seeds.

Reason 5: Gene drives - once released into nature, cannot be retrieved

So-called "gene drives", a particularly controversial application of genome editing, use molecular scissors to copy a synthetically inserted trait into all offspring during reproduction.[32] The modified sections of the genetic material are passed on to all offspring – even if they are unfavourable or lethal to the individual. This is of concern as there is currently no internationally recognised procedure for assessing the risks of the release of gene drive organisms. Once such an organism is released, it is almost impossible to control or reverse its impacts on the ecosystem. This kind of genetic modification could be applied to wild plants or animal species and therefore poses a significant risk to biodiversity.[33] Research on gene drive insects, for example, is already at an advanced stage.

Gene drives are being developed to - among other purposes - fight the spotted wing drosophila (**Ddrosophila suzukii**), a fruit fly species native to Asia, recently causing serious damage to soft fruits and berries in Europe. Besides the spotted wing drosophila, gene drives are being developed in more than a dozen other insect species.

Considering the various risks associated with the release of gene drive organisms, it is crucial to consider carefully whether it is responsible to use this technology as long as it is unclear what impact it will have on natural ecosystems. The efficiency of the technology also depends on many factors, including population dynamics of the pest and the frequently observed development of resistance against the gene drive mechanism.[34]

Footnotes:

29 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4404971/
30 Mehta D, Stürchler A, Anjanappa RB Hirsch-Hoffmann M, Gruissem W, Vernderschuren H 2019 Linking CRISPR-Cas9 interference in cassava to the evolution of editing-resistant geminiviruses. Genome Biology 20: 80. https://doi.org/10.1186/s13059-019-1678-3
31 Wember Q 2018 Der Dürresommer 2018 – Brennende Argumente der Gentechniklobby. Dreschflegel e.V. http://www.dreschflegel-verein.de/_pdf/2018-der-duerresommer-brennende-argumente-der-gentechniklobby.pdf
32 CSS, ENSSER, VDW 2019 Gene Drives. A report on their science, applications, social aspects, ethics and regulation. https://genedrives.ch/wp-content/uploads/2019/10/Gene-Drives-Book-WEB.pdf
33 Evans BR, Kotskiozi P, Costa-da-Silva AL et al. 2019 Transgenic Aedes aegypti mosquitoes transfer genes into a natural population. Scientific Reports 9: 13047. https://doi.org/10.1038/s41598-019-49660-6
34 See footnote 32

1.1.3 Sustainable alternatives to genome editing

Alternative 1: Broad-based adaptability based on diversity

Environmental changes challenge plants and drive adaptation to new conditions. The most important prerequisite for adaptability is diversity, which includes genetic diversity, the diversity of varieties as well as the diversity of farming systems. Biodiversity protects against the negative consequences of climate change,[35] diversity being the not only essential for breeding but also for resilient agroecosystems. Long-term stability of production can only be guaranteed in healthy and diverse agroecosystems. In other words, it is not enough to just modify some isolated gene sequences of a selected species. To increase resilience of agricultural production systems, the key underpinning principles are genetic diversity and an integrated systems approach-based shift towards diversification. Intensive agriculture is largely responsible for the disappearance of numerous varieties and species. Large monocultures of a single crop variety, regularly treated with pesticides offer no room for diversity. Since high-performance varieties appeared in the 1950s, the number of crops on which our diet is based has shrunk from several thousand to something over a handful.[36] Diversity not only disappears from the fields themselves; species decline can increasingly be observed even in adjacent natural habitats.[37] If this process continues at the same rate in these buffer zones with important ecosystem functions, the negative consequences of unpredictably occurring weather events will be even more devastating.

However, through the diversification of agricultural production the risks of climate change could be better mitigated and could contribute to secure enough food for the world's growing population. Diversity at the genome level as well as diversity of the species and varieties ensure adaptability. In diverse biological systems, one is more likely to find resistant species or individuals that, thanks to their specific genetic background, are better able to cope with weather extremes, diseases and invasive species.

In theory, there is still a wide range of crops available – including tens of thousands of wild plant species and locally-adapted traditional varieties.[38] Tolerance and resistance to heat and drought, as well as pest resistance will increasingly play a role in future choices of crops and varieties. The so-called "orphan crops" – plants that have played a minor role on the world market and in research – have here great potential. Plants such as millet, amaranth or okra, to name but the best known, are presently outnumbered by the four most dominant cultures (wheat, corn, rice and soya) – on which our diet is mainly based. A regrettable fact, since many orphan crops are not only more resistant than these main crops, but often also rich in healthy constituents – and are therefore definitely of interest for future breeding. The example of quinoa – a plant that was completely unknown about ten years ago outside of South America now even figuring on the menus of Western fast food chains – shows that it is well worth promoting the breeding of new varieties of orphan crops. A stable harvest would benefit small farms, and the risk of malnutrition could also be reduced by making a wider range of plant species with various nutrients are available.

The use of the broad gene pool of old varieties is also seen as an important basis for adapting to climate change.[39] Similarly to orphan crops, old varieties offer many valuable genetic traits that modern high-yield varieties are lacking, such as resistance to pathogens and pests, or to abiotic stress.[40] In addition, unlike their genetically-uniform counterparts grown in monocultures, these locally-adapted,

Footnotes:

35 Swiss Academy of Sciences (SCNAT) 2020 Variety is the source of life: Agrobiodiversity benefits, challenges and needs Fact sheet. https://scnat.ch/en/uuid/i/5505ae30-b2b3-56c9-abbd-21d2d0dd22d9-Variety_is_the_source_of_life
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37 Seibold S, Gossner MM, Simons NK, et al. 2019 Arthropod decline in grasslands and forests is associated with landscape-level drivers. Nature 574: 671-674.
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39 Mbow C, Rosenzweig C, Barioni LG, et al. 2019 Food Security. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [Shukla PR, Skea J, Calvo Buendia E, et al. (eds.)].
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traditional varieties represent dynamic populations with a diverse genetic background. As such, they are more flexible and deliver more stable yields under changing environmental conditions even without spraying chemicals.[41] There is growing evidence[42] that traditional knowledge associated with traditional varieties also contributes to effectively facing the challenges of climate change.[43] This locally-accumulated knowledge is also an important part of agroecological approaches. To develop locally-adapted, resilient varieties, innovative breeding concepts involving local farming communities are indispensable. Participative projects such as Citizen Science, in which committed members of the local population take over a part of the scientific work, make it possible to record spatial and temporal environmental variations, in order to characterise climatic reactions and to develop varieties adapted to regional needs.[44]

Alternative 2: Healthy soils, low tillage

Improved soil health can help to protect from negative effects of climate change through the enhanced storage of water and carbon. By restoring the pre-industrial state of the soil, we could capture 30 to 40 per cent of today's excess atmospheric CO_2.[45] By using less synthetic fertiliser, greenhouse gas emissions could further be curbed.[46]

Conservation soil management practices, as used in agroecological approaches or in organic farming, help to withstand the challenges of climate change in numerous different ways.[47]

Among others, they enhance soil fertility by increasing humus content. Conservation tillage helps to optimise the water balance of the soil: water can both be stored more effectively and made available to plants during dry periods. Covering the soil between main crops by green manure, soil structure can also be improved and excessive compaction of soil can also be prevented. Finally, even the susceptibility to erosion and desertification can be reduced this way.[48]

Such measures help to maintain important ecosystem services of the soil – such as the nutrient and water cycles. Without them, it is barely possible to maintain food production at today's level, let alone increase it.

Footnotes:

41 Smith P, Bustamante M, Ahammad H, Clark H, Dong H, Elsiddig EA et al. 2014 Agriculture, forestry and other land use (AFOLU). In Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the intergovernmental Panel on Climate Change. Edenhofer O, Pichs-Madruga R, Sokona Y et al. (eds.) Cambridge University Press, UK and NY USA 811-922. https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter11.pdf

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44 van Etten, de Sousa K, Aguilar A et al. 2019 Crop variety management for climate adaptation supported by citizen science. PNAS 116 (10): 4194-4199. https://doi.org/10.1073/pnas.1813720116

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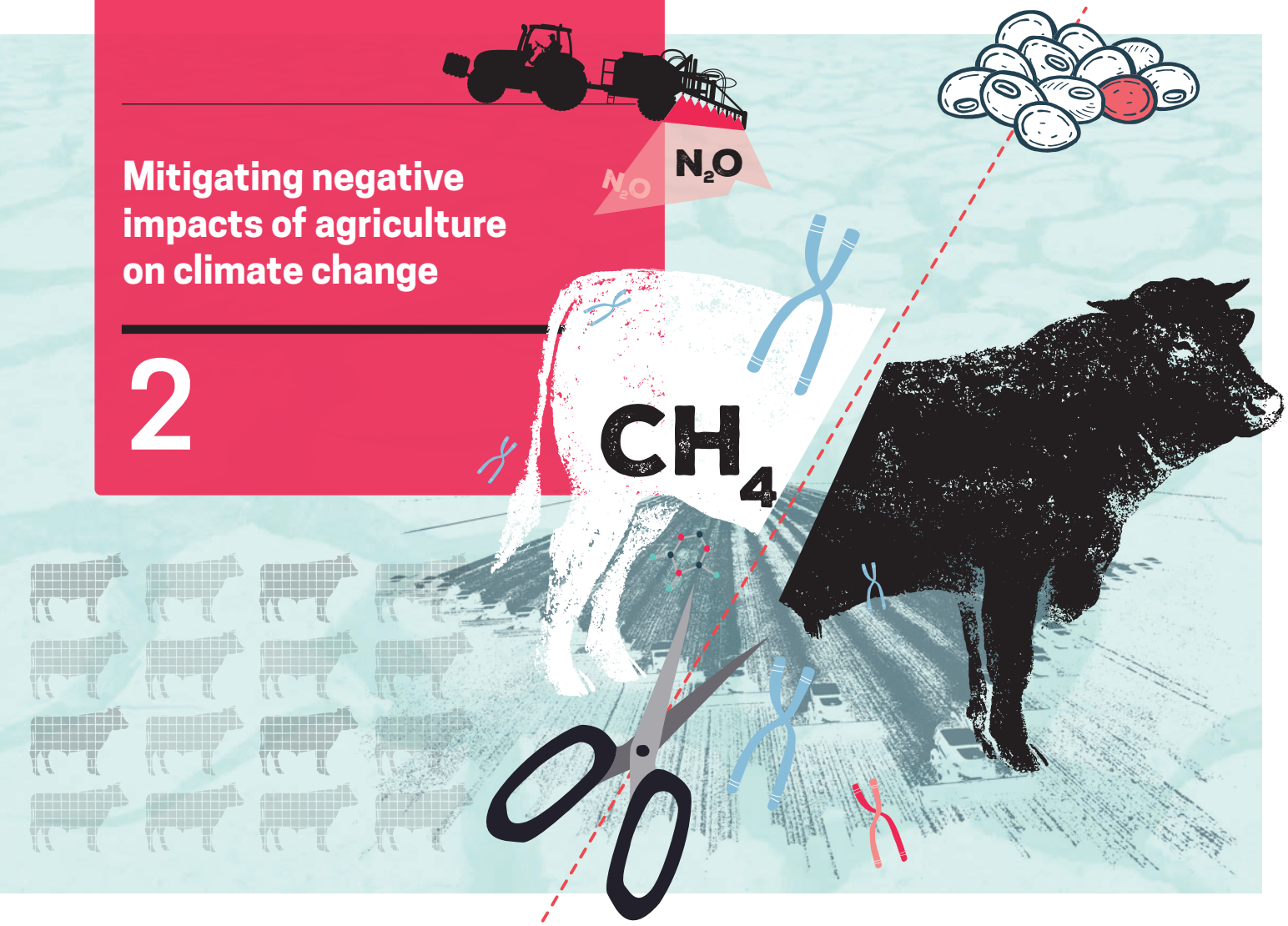
47 Mbow C, Rosenzweig C, Barioni LG, et al. 2019 Food Security. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [Shukla PR, Skea J, Calvo Buendia E, et al. (eds.)]. https://repository.cimmyt.org/bitstream/handle/10883/20607/61206.pdf?sequence=1 FAO 2015 Soils help to combat and adapt to climate change by playing a key role in the carbon cycle. Viale delle Terme die Caracalla 00153 http://www.fao.org/3/a-i4737e.pdf

48 Piraneque N, Forero SE, Reis LA 2018 Green manure: Alternative to carbon sequestration in a typic ustipsamment under semiarid conditions. Spanish Journal of Soil Science 8. 293-305. 10.3232/SJSS.2018.V8.N3.01.

Mitigating negative impacts of agriculture on climate change

2



Where do greenhouse gases in agriculture come from?

The agriculture and forestry sectors account for 20 to 25 per cent of the global greenhouse gas emissions.[49] Climate-relevant gases include carbon dioxide, methane and nitrous oxide.

Livestock production contributes 14.5 per cent of all greenhouse gas emissions originating from human activity. Almost half (45 per cent) of all livestock-related emissions come from producing and processing feed, including deforestation linked to expansion of pasture and feed crops. Methane emissions from digestive processes in ruminants like cattle, contribute a further 39 per cent, and manure storage and processing contribute 10 per cent.[50]

Carbon dioxide (CO_2) is the best-known greenhouse gas. In agriculture, carbon dioxide emissions result from energy use, land use change (e,g, deforestation) and from the decomposition of organic matter as a result of land use. However, methane and nitrous oxide are much more potent greenhouse gases. Emissions of the two latter are associated with intensive animal farming and the linked production of concentrated feeds. The biggest source of methane (CH_4), for example, is enteric fermentation (i.e. digestive processes) of ruminants like cattle, followed by methane formation from manure storage.

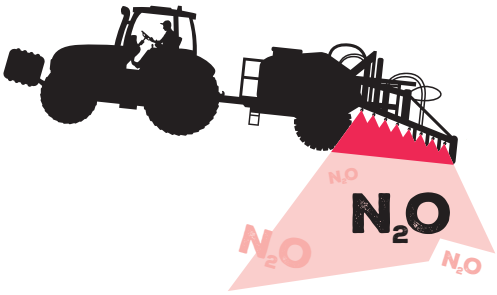
Footnotes:

49 Smith P, Bustamante M, Ahammad et al. 2014: Agriculture, Forestry and Other Land Use (AFOLU). In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer O, Pichs-Madruga R, Sokona Y et al. (eds.)]. Cambridge University Press, Cambridge, UK and NY. https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter11.pdf Shukla PR, Skea J, Slade et al. 2019 Technical Summary. Shukla PR, Skea J, Calvo Buendia E, et al. (eds.) 2019 Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. https://www.ipcc.ch/site/assets/uploads/sites/4/2019/11/03_Technical-Summary-TS.pdf FOEN 2020 Switzerland's Greenhouse Gas Inventory 1990–2018: National Inventory Report and reporting tables (CRF). Submission of April 2020 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Federal Office for the Environment, Bern. https://www.bafu.admin.ch/bafu/en/home/topics/climate/state/data/climate-reporting/latest-ghg-inventory.html http://www.fao.org/faostat/en/#data/EM/visualize

50 Gerber, P. J. et al. (2013) at xii and 20. http://www.fao.org/3/a-i3437e.pdf

In the case of nitrous oxide (N_2O) emissions, animal farming contributes mainly indirectly, through the production of fodder crops, though also through farmyard manure management. The most significant source of nitrous oxide emissions from agriculture is soil management, especially the decomposition process of synthetic nitrogen fertilisers, but methane and nitrous oxide also escape during fertiliser production. Negative impacts of the production process are, however, massively underestimated by the fertiliser industry itself.[51]

In order to find a sustainable way to mitigate the negative impacts of the current global agricultural system on climate change, it is important to consider that the various greenhouse gases produced by agricultural processes interact with each other. Consequently, human interventions into this complex system have diverse effects on the climate system. Nitrogen fertilisers, for example, stimulate the growth of plants, thus increasing sequestration of carbon dioxide from the atmosphere – a climate-friendly effect unfortunately outweighed by the negative impacts of the nitrous oxide being released from fertilised soils.[52] Therefore, a coupled view of the different cycles is of utmost importance: in other words, a system-oriented approach is needed to curb agricultures greenhouse gas emissions. Merely technological approaches based on extremely simplified models and only intervening in the system at some distinct points, such as genome editing does, do not lead to sustainable solutions.



2.1 Methane

The problem: a cow produces between 70 and 120 kilograms of methane per year.[53] Methane is more than 20 times more potent as carbon dioxide: emitting 100 kilograms of methane thus corresponds to the amount of CO_2 that would be produced by burning 1,000 litres of petrol in an internal combustion engine (about 2,300 kilograms), a volume enough to drive the distance from the most eastern point of Europe to its most westerly point three times. In the EU, 53% of anthropogenic methane emissions come from agriculture. After some decrease in emissions since the 1990, now with growing numbers of animal farmings, the emissions slightly grow again.[54]

2.1.1 Using genome editing to reduce methane emissions

The intestinal tract of cattle is home to thousands of different microorganisms, but only 3 per cent of them produce methane.[55] These methanogenic organisms are tiny bacteria-like microbes that are able to produce methane from organic substances. Biotechnologists want to modify the genome of such microorganisms so that less methane is produced during enteric fermentation. At the same time, research is being conducted to find out which genes are involved in the process that favours these methanogenic organisms being passed on to offspring.[56] In a further step, the ruminants themselves are to be "optimised" using molecular scissors.[57]

In order to reduce the negative impacts of meat consumption on climate, a new trend has recently emerged. Deceptively real tasting meat alternatives with genetically modified ingredients are claimed to curb methane emissions. One of these, the Impossible Burger, features a meat-typical red colour that results from adding leghaemoglobin. This is a protein originally found in soy

Footnotes:

51 Zhou X, Passow FH, Rudek J. 2019 Estimation of methane emissions from the U.S. ammonia fertilizer industry using a mobile sensing approach. Elementa 7 (1): 19.
52 Zaehle S, Ciais P, Friend AD, Prieur V 2011 Carbon benefits of anthropogenic reactive nitrogen offset by nitrous oxide emissions. Nature Geoscience 4: 601-605. https://www.mpg.de/4387747/stickstoff_duenger_klimawandel
53 Bannink A 2011 Methane emissions from enteric fermentation in dairy cows, 1990-2008. Bericht. Wageningen UR, Animal Sciences Group, Wageningen. https://library.wur.nl/WebQuery/wurpubs/fulltext/188030 Wallace RJ, Sasson G, Garnsworthy PC et al. 2019 A heritable subset of the core rumen microbiome dictates dairy cow productivity and emissions. Science Advances 5 (7) https://advances.sciencemag.org/content/5/7/eaav8391
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55 Kong Y, Xia Y, Seviour R, Forster R, McAllister TA 2013 Biodiversity and composition of methanogenic populations in the rumen of cows fed alfalfa hay or triticale straw. 2013 FEMS Microbiology Ecology 84 (2): 302-315. https://doi.org/10.1111/1574-6941.12062 Kim M, Morrison M, Yu Z 2011 Status of the phylogenetic diversity census of ruminal microbiomes. FEMS Microbiology Ecology 76 (1): 49-63. https://doi.org/10.1111/j.1574-6941.2010.01029.x
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57 Giddings LV, Rozansky R, Hart DM 2020 Gene editing for the climate: Biological solutions for curbing greenhouse emissions. Information Technology and Innovation Foundation. Bericht. http://www2.itif.org/2020-gene-edited-climate-solutions.pdf

roots that is very similar to human haemoglobin. For production in large quantities, leghaemoglobin is produced using genome-edited yeast strains to reduce the costs of production. According to a life cycle analysis (LCA) by the consultancy Quantis, the production of the Impossible Burger releases 89 per cent less greenhouse gas (mainly methane) than the production of conventional beef.[58]

2.1.2 Why genome editing is NOT the solution

Reason 1: the composition of gut flora affects immunity

Tinkering with the microbiota inhabiting the rumen of cattle is not without risks. These organisms have co-evolved with their host over millennia: they have thus adapted to each other.

This relationship is so close that it is even reflected in the composition of the bovine genome.[59] Moreover, passing on of these beneficial microbes to offspring does not just happen by chance; this process is co-steered by certain regions of the bovine DNA.[60] The microorganisms living in the gut not only play an important role in breaking down undigested carbohydrates, they also help to maintain gut health. Changes in the composition of the gut flora can therefore have a major impact on the general well-being and health of cattle.[61] Increased susceptibility to diseases, for instance, cannot be ruled out.

Many other, non-biotechnological methods of reducing methane production already exist.[62] Among other techniques, classical breeding is also able to produce breeds that emit less methane – even if, as a process, it takes a little longer to develop new races. In addition, there are selected vaccines that prevent methane building microbes from thriving in the intestinal tract. Changes in feed, such as the addition of seaweed or certain feed additives, also reduce methane production. But, similarly to the case of genetic modification, little is known so far about how these interventions affect the animals' immune system.

Reason 2: genetic engineering intensifies agricultural production

Genome editing, as well as the alternative methods for reducing methane production, mentioned above, result in as many or even more cattle being kept in the same intensive farming systems without increasing total methane emissions. This will, however, not solve the climate problem, because – as has been pointed out – methane is not the only harmful greenhouse gas linked to intensive animal farming relying on high-performance breeds. Such breeds are upping demand for concentrated feed. The production of fodder crops is coupled with high emissions of nitrous oxide from liberally applied synthetic fertilisers (see chapter 2 on nitrous oxide), an even more potent greenhouse gas than methane. In addition, land use change releases huge amounts of CO_2, i.e. when forests and grassland are converted into arable land for feed production, as is happening in Brazil. The area required to grow plants for animal feed concentrates to supply the needs of intensive animal farming in Europe is already enormous – and is often outsourced to other continents, such as South America. About half the concentrated feed used in Europe is imported from other continents. The emissions associated with transport are correspondingly high. Herbicide-resistant GM soya is now growing on millions of hectares of land[63] and the development of new genome edited varieties is already at an advanced stage.[64] Unfortunately, it is not the climate that benefits from such plants, but the agrochemical and seed companies as well as their customers and cattle farmers eager to produce cheap meat.[65]

Footnotes:

58 Khan S, Loyola C, Dettling J, Hester J, Moses R 2019 Comparative environmental LCA of the Impossible Burger with conventional ground beef burger. Quantis/Impossible Foods. file:///Users/zsofia.hock/Downloads/Impossible_foods_comparative_LCA-2.pdf

59 Li F, Li C, Chen Y et al. 2019 Host genetics influence the rumen microbiota and heritable rumen microbial features associate with feed efficiency in cattle. Microbiome 7:92 https://microbiomejournal.biomedcentral.com/articles/10.1186/s40168-019-0699-1

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64 Application of CRISPR/Cas9-mediated gene editing for the development of herbicide-resistant plants. Plant Biotechnology Reports 13 (5)

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2.1.3 Sustainable alternatives to genome editing

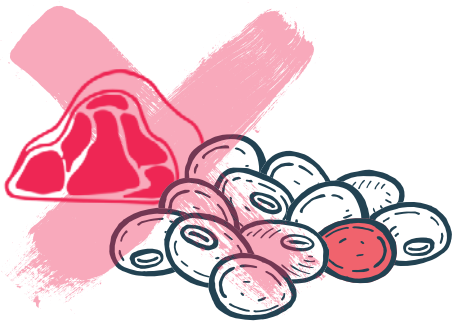
Alternative 1: grass instead of concentrated feed

Precisely because ecological balances are so very complex, it is not enough to adjust a few isolated aspects of the production chain. Even though the 1.5 billion cattle kept worldwide emit significant amounts of methane, they are also capable of exploiting a significant resource that would otherwise go unused: grass. After all, about 70 per cent of the earth's agricultural land is grassland.[66] This resource is not used optimally at present though: only about 30 per cent of cattle are raised on extensive pastures.[67] If grassland areas were grazed sustainably, soil fertility and resistance to erosion would both increase. Root growth and, consequently, sequestration of atmospheric carbon via plant roots would also be enhanced – with significant benefits for the climate. To support this process, a shift from intensive animal farming to smaller, ecological farming systems with extensively used pastures would have significant impacts on reducing agricultural related GHG emissions. By freeing up valuable arable land to grow crops for human consumption, grassland-based milk and meat production could also reduce land use competition between food and feed production, as well as the competition for food between humans and ruminants.[68] Given that more than 30 per cent of the world's arable land is currently used for feed production,[69] this could also put an end to the increased demand of land for animal farming associated with high CO_2 emissions. Methane production in the rumen also bears a correlates with feeding regimes: feeding more concentrates (soy, maize, cereals) favours a microflora that produces greater quantities of methane.[70] A diet based on roughage like grass most closely meets the needs of the species and minimises methane emissions. As a bonus, emissions from transporting feed are also eliminated.[71]

Alternative 2: reduce meat consumption

Agricultural intensification has greatly increased the availability of animal food products as a dietary component in recent decades, also increasing the demand for animal products such as meat, eggs and milk compared to plant based foods. Especially in emerging countries such as China or Brazil, this trend is due to income development rather than to population growth.[72] If there are no changes in global production and consumption patterns, this is a trend that is set to continue.

However, the climate footprint of animal products from indoor production systems highly depending on concentrated feed is large, with animal products accounting for almost 70 per cent of the direct emissions of greenhouse gases related to food.[73] As a result, greenhouse gas emissions could be most effectively curbed by reducing the consumption of animal food.[74] Switching to eating less meat of better quality is not only good for the climate and natural resources, a diet with reduced amounts of meat is also healthier. From a nutritional point of view, it makes more sense to eat field crops directly than to consume them via the detour of converting them from concentrates to meat, the latter leading to a tremendous number of calories getting lost.[75] A general switch to a less meat-based diet would slash the demand for concentrated feeds.



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68 Stolze M, Weisshaidinger R, Bartel A, Schwank O, Müller A, Biedermann R 2019 Chancen der Landwirtschaft in den Alpenländern. Wege zu einer raufutterbasierten Milch- und Fleischproduktion in Österreich und der Schweiz. pp 173. Haupt Verlag, Bern.
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73 Noleppa S 2012 Klimawandel auf dem Teller. WWF Deutschland, Berlin https://www.wwf.de/fileadmin/user_upload/Klimawandel_auf_dem_Teller.pdf
74 Poore J, Nemecek T 2018 Reducing food`s environmental impacts through producers and consumers. Science 360 (6392): 987-992. https://josephpoore.com/Science%20360%206392%20987%20-%20Accepted%20Manuscript.pdf
75 IAASTD synthesis report 2009 Agriculture at a Crossroads. International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). Library of Congress, ISBN 978-1-59726-550-8, 106 pp. https://www.weltagrarbericht.de/themen-des-weltagrarberichts/fleisch-und-futtermittel.html

Alternative 3: longer-living cows

Genetic engineers want to create high-yielding dairy cows to maximise milk production. This quickly overloads the animals, and makes them susceptible to disease. Factoring in their unnatural diet based on high amounts of concentrated feed, they age fast and have to be slaughtered at a younger age: on average at the age of five years - with the consequence that during the second half of a dairy cow's lifetime, a young animal has to be reared to replace her. The period during which both cause emissions at the same time is long. Local breeds adapted to roughage kept in sustainable production systems don't wear themselves out as fast, their productive lifetime being therefore longer. This way, the time window of double emissions can significantly be reduced.[76]

Alternative 4: Agroecology agriculture instead of GM meat substitutes

A comprehensive life cycle analysis carried out by Quantis demonstrates that there is a range of practicable climate-friendly alternatives to meat substitutes from genetic engineering.[77] The study shows that beef from agroecology (holistic grazing) positively influences CO_2 balance, compensating for the methane emissions from enteric fermentation. In the system of agroecological farming available pasturage is split into smaller areas in proportion to the size of the herd to allow each area to recover for an optimal amount of time before the grazing animals are allowed to return to that spot (rotational grazing). This allows the grasses to build enough leaf area to store a large amount of carbon in their root system as well as to return it to the soil via soil microbes. These rest periods are an effective way to offset the methane emissions of grazing ruminants.

2.2 N_2O

Nitrous oxide

The problem: nitrous oxide is the most potent greenhouse gas. It is nearly 300 times as potent as carbon dioxide and it remains in the atmosphere for over a hundred years. Nitrous oxide is a by-product from microorganisms breaking down nitrogenous compounds in the soil. The Intergovernmental Panel on Climate Change (IPCC) puts agriculture's share of global nitrous oxide emissions at about 60 per cent overall.[78] The issue of nitrous oxide emissions is a complex one: agriculture contributes to these emissions at least at three different levels: soil management, animal farming and fertiliser production.

Nitrous oxide from soil management

Soil is the main source of agriculture's nitrous oxide emissions. These emissions arise from the use of organic and synthetic fertilisers, biological fixation of atmospheric nitrogen by certain crops (grain legumes) and from the crop residues that are ploughed back into soil. Nitrous oxide emissions from moist, over-fertilised soils are particularly high.

Plants do need nitrogen to thrive. They can, however, only make use of nitrogen (N_2) in chemically-bound form (ammonium, but mainly as nitrate), but not of the unbound nitrogen occurring abundantly in the air. The transformation of elemental nitrogen into compounds that are available for plant life is done by bacteria. In the case of intensive land use (e.g. monocultures of genetically modified plants), synthetic nitrogen fertilisers must be distributed over large areas to provide the plants with sufficient nitrogen. However, if the plants do not absorb all of the nitrogen fertiliser applied, the surplus is released into the air as nitrous oxide.[79]

Footnotes:

76 Idel A 2009 Von Hirtennomaden und Hochleistungszucht. Nutztiere in Zeiten des Klimawandels – Konsequenzen aus dem Weltagrarbericht IAASTD. Statement, Tagung der Allianz für Tiere. Berlin. Idel A, Beste A 2018 Technikgläubigkeit und Big-Data. Vom Mythos der klimasmarten Landwirtschaft - oder warum weniger vom Schlechten nicht gut ist. Die Grünen/Europäische Freie Allianz. Martin Häusling, MdEP, Wiesbaden https://www.weltagrarbericht.de/fileadmin/files/weltagrarbericht/Weltagrarbericht/15KlimaEnergie/2018Klimasmart.pdf

77 Thorbecke M, Dettling J 2019 Carbon footprint evaluation of regenerative grazing at white oak pastures. Quantis. https://blog.whiteoakpastures.com/hubfs/WOP-LCA-Quantis-2019.pdf

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79 Idel A, Beste A 2018 Technikgläubigkeit und Big-Data. Vom Mythos der klimasmarten Landwirtschaft - oder warum weniger vom Schlechten nicht gut ist. Die Grünen/Europäische Freie Allianz. Martin Häusling, MdEP, Wiesbaden https://www.weltagrarbericht.de/fileadmin/files/weltagrarbericht/Weltagrarbericht/15KlimaEnergie/2018Klimasmart.pdf

Nitrous oxide from animal farming

Crops grown in large-scale monocultures - such as soy, occupying about 125 million hectares globally - are mainly cultivated for the production of concentrated feeds.[80] About a quarter of synthetic fertilisers is being used to grow fodder crops.[81] Intensive animal farming thus makes a significant indirect contribution to global nitrogen emissions. Fodder crops capable of binding nitrogen from the air (e.g. soybeans) which require very little fertiliser can't solve this problem in a sustainable way, because they don't change the various other negative effects of intensive farming systems. The natural decomposition process of solid manure from animal farming also contributes to nitrous oxide emissions.[82]

Nitrous oxide from fertiliser production

The price to achieve high field productivity is high resource input. The production of synthetic fertilisers - a highly energy-intensive process - also contributes to nitrous oxide emissions. This process requires immense amounts of fossil gas – a non-renewable fossil energy source consisting primarily of methane – and accounts for approximately half of the total energy consumption in agriculture, let alone the escaped emissions from the production and transport of the methane used.[83]

2.2.1 Genome editing to reduce nitrous oxide emissions?

Agribusiness companies promote genome-edited plants as the solution for the future, parading genetic engineering as the way to achieve high productivity with less synthetic fertilisers. Many possible approaches are put forward. One of these is to engineer fertiliser-saving plants such as semi-dwarf fruit trees that can be planted very close together due to their genetically-modified growth trait. This way fertilisers would have to be applied to a smaller area. Another approach focuses on creating genome edited plants that can take up nitrogen compounds from the soil more efficiently.

From the viewpoint of the agricultural industry, enabling plants to turn bacteria to profit and directly capture nitrogen out of air similarly to grain legumes could also be of interest. Some projects are even flirting with intervening in the photosynthetic pathway of certain crops (e.g. rice) without additional fertilisers.[84]

2.2.2 Why genome editing is NOT the solution

Significantly altering metabolic pathways of plants using genetic engineering is not feasible, because these pathways are regulated by complex networks consisting of a multitude of interconnected genetic elements. The activity of the genes within these networks greatly depends on local conditions in the fields. Developing such plants by just adding or modifying a few individual genes is therefore unfeasible, no matter the enormous amount of money invested into such research. Accordingly, biotechnologists have not been able to bring a single such plant to market to date. The focus remains on higher productivity and thus even more agricultural intensification, rather than working towards systemic change.

Reason 1: "Fertiliser-saving" genome-edited plants do not reduce resource-intensive agricultural production - nor collateral damage

Genome-edited plants that produce higher yields with less fertiliser don't help to change the agricultural production system itself. On the contrary, they even strengthen the industrial production system, which is geared towards achieving high yields while environmental aspects are mainly being neglected. Such genetically-modified crops represent a monocausal response to just one of the many problems arising from the monoculture farming regime - a production system that provides only 30 per cent of the world's food,[85] but produces significant fossil fuel emissions and is responsible for a high proportion of agricultural water use.

Footnotes:

80 USDA 2020 World Agricultural Production. United States Department of Agriculture. https://apps.fas.usda.gov/psdonline/circulars/production.pdf

81 Smith P, Bustamante M, Ahammad H, Clark H, Dong H, Elsiddig EA et al. 2014 Agriculture, forestry and other land use (AFOLU). In Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the intergovernmental Panel on Climate Change. Edenhofer O, Pichs-Madruga R, Sokona Y et al. (eds.) Cambridge University Press, UK and NY USA 811-922. https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter11.pdf

82 Bundesamt für Umwelt BAFU 2019 Landwirtschaft als Luftschadstoffquelle. https://www.bafu.admin.ch/bafu/de/home/themen/luft/fachinformationen/luftschadstoffquellen/landwirtschaft-als-luftschadstoffquelle.html

83 Woods J, Williams A, Hughes JK, Black M, Murphy R 2010 Energy and the food system. Philosophical Transactions of the Royal Society of London B Biological Sciences 365 (1554): 2991-3006. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2935130/

84 Batista-Silva W, Fonseca-Pereira P, Martins A et al. 2020 Engineering improved photosynthesis in the era of synthetic biology. Plant Communications 1 (2) https://reader.elsevier.com/reader/sd/pii/S2590346220300134?token=4021CB496A740D2B7924E9F86FDBD91AE59CF6BC3DA5BDDB3D635E6123F48804CC34B33E647BFA11A98C3BB8ED0BD82D https://reader.elsevier.com/reader/sd/pii/S2590346220300134?token=4021CB496A740D2B7924E9F86FDBD91AE59CF6BC3DA5BDDB3D635E6123F48804CC34B33E647BFA11A98C3BB8ED0BD82D

85 GRAIN 2014 Hungry for Land. Small farmers feed the world with less than a quarter of all farmland. Report, pp. 22. https://www.grain.org/media/W1siZiIsIjIwMTQvMDYvMDQvMDdfMjIfMjNfODc0X0dSQUlOX0h1bmdyeV9mb3JfbGFuZC5wZGYiXV0

Genome-edited semi-dwarf fruit and nut trees, for example, are supposed to save land and thus fertiliser because they allow higher planting density.[86] But this high density increases is the susceptibility of the plantations to diseases and pests. In addition, such a system massively reduces biodiversity: even affecting beneficial insects and birds that fail to find suitable niches or food.

Reason 2: engineering nitrogen-fixing symbiosis - a utopian vision

The agricultural industry would also benefit from genome-edited plants that - similarly to clover, peas or other legumes - work together with bacteria to fix nitrogen from the air and thus operate self-sufficiently at least as far as nitrogen supply is concerned. This way, they hope to avoid a shift towards more extensive, traditional farming practices that don't rely on synthetic fertilisers. Although the idea is almost 40 years old,[87] it has not been realised to date and it is highly unlikely that new genetic engineering techniques will turn this vision into reality. The ability of plants to fix nitrogen depends on a complex symbiotic relationship between the plant and the bacteria living in its root nodules. Both symbiotic partners co-evolved for millions of years[88] and only limited progress has been made to date in deciphering the genes and metabolic pathways that predispose a plant to symbiosis. Some plants, such as hornbeam, used as a timber species, or the twisted block bean, popular as a food plant in Asia, possess the genetic equipment for symbiosis with nitrogen-fixing bacteria, but don't use it.[89] In theory, genetic engineering could manipulate the hereditary traits enabling them to embark on symbiosis. However, the most important cereal grain crops do not possess this genetic predisposition. Experts at the Max Planck Society are sceptical as to whether biotechnology could ever enable such crops to fix nitrogen with the help of nodule bacteria.[90]

Research projects[91] to decipher the genetic background of this symbiosis therefore rather serve to better understand its role in the global nitrogen cycle and how it is influenced by climate change.

Reason 3: accelerating evolution to boost photosynthesis in rice is using far more resources than it is producing results

The efficacy of an international research project funded by the Bill and Melinda Gates Foundation is also doubtful. The goal of the project headed by Oxford University (C4 Rice project) is to double rice yields without any fertilisers, merely by altering the plant's photosynthethic pathways using genetic engineering.[92]

C4 plants have adapted to warm, dry regions with high light intensity and enables them to produce more biomass and yield despite lower availabilities of water and nutrients. However, to convert a C3 plant to a C4 plant, not only does one need to manipulate the complex processes of photosynthesis, the entire leaf anatomy has to be changed as well. These traits are the result of a long, drawn-out process of evolution that cannot be reproduced by simply adding a few genes. The genome-edited rice is primarily supposed to help farmers in developing countries boost yields so they can feed themselves and the world's growing population.

The problem here is that small farmers cannot afford to purchase expensive but unproven patented products of the biotech companies on a yearly basis as illustrated by the example of GM cotton.[93] Contrary to the industry's promises, genome-edited plants would mainly increase their dependence on the agricultural corporations.

Footnotes:

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88 Werner GDA, Cornwell WK, Sprent JI, Kattge J, Kiers ET 2014 A single evolutionary innovation drives the deep evolution of symbiotic N2 fixation in angiosperms. Nature Communications 5: 4087. https://www.mpg.de/8278959/symbiose_pflanzen_knoellchenbakterien
89 Batista-Silva W, Fonseca-Pereira P, Martins A et al. 2020 Engineering improved photosynthesis in the era of synthetic biology. Plant Communications 1 (2) https://reader.elsevier.com/reader/sd/pii/S2590346220300134?token=4021CB496A740D2B7924E9F86FDBD91AE59CF6BC3DA5BDDB3D635E6123F48804CC34B33E647BFA11A98C3BB8ED0BD82D
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92 Batista-Silva W, Fonseca-Pereira P, Martins A et al. 2020 Engineering improved photosynthesis in the era of synthetic biology. Plant Communications 1 (2) https://reader.elsevier.com/reader/sd/pii/S2590346220300134?token=4021CB496A740D2B7924E9F86FDBD91AE59CF6BC3DA5BDDB3D635E6123F48804CC34B33E647BFA11A98C3BB8ED0BD82D
93 GRAIN 2007 Bt cotton – the facts behind the hype. Seedling: 18-24. https://www.grain.org/media/W1siZiIsIjIwMTEvMDcvMjEvMDRfMjJfNTlfMzg5X29yaWdpbmFsLnBkZiJdXQ

2.2.3 Sustainable alternatives to genome editing

Alternative 1: Variety of choice and agroecological farming systems

Conventional breeding has already produced convincing results in increasing the nitrogen efficiency of a number of plant varieties.[94] In addition, various studies show that nitrogen efficiency is generally higher in organic farming than in conventional farming systems.[95] Growing nitrogen-fixing grain legumes in crop rotation, either as a main, catch or cover crop provides rich source of nitrogen. Helped by bacteria in their root tubers, they can fix enough nitrogen to replace the quantities of synthetic fertiliser presently used.[96]

Agroecological approaches have the advantage of effectively reducing the leaching of nitrates from excess nitrogen fertiliser not taken up by crops to groundwater. Low-input extensive, sustainable, organic farming systems are therefore key to solving the nitrogen problem.[97]

Alternative 2: Eating less but better animal products

Reducing the consumption of animal products and the corresponding numbers of animals also have the effect of reducing nitrous oxide emissions. Fewer animals require less concentrated feedstuffs, which means that less intensively managed land is needed to produce them.[98]

Alternative 3: Healthy soil

Nitrogen surpluses can be avoided by determining the fertiliser needs of plants, while taking into account the humus balance of the soil and analysing the nutrient content of organic fertilisers. Alternative approaches have proved to successfully reduce the emissions of nitrous oxide from agricultural soil management. To give just one example, vegetable coal, which is produced from organic waste materials by means of pyrolysis, positively influences the soil nitrogen cycle and, given its high stability in the soil, also functions as a CO_2 sink.[99] Research projects that are aimed at improving our understanding of the factors enhancing nitrous oxide production such as climate, temperature and cyclical soil processes,[100, 101] build an important basis for the development of a sustainable agricultural production system and should therefore receive more government support.

Footnotes:

94 Lammerts van Bueren ET, Struik PC 2017 Diverse concepts of breeding for nitrogen use efficiency. Agronomy for Sustainable Development 37: 50.
95 Lin H, Huber JA, Gerl G, Hülsbergen K-J 2016 Nitrogen balances and nitrogen-use efficiency of different organic and conventional farming systems. Nutrient Cycling in Agroecosystems. 105: 1–23. https://doi.org/10.1007/s10705-016-9770-5
96 Arncken C, Schmack A-K, Spiegel K et al. 2014 Leguminosen Nutzen. Naturverträgliche Anbaumethoden aus der Praxis. Bundesamt für Naturschutz (BfN), Bonn. https://www.fibl.org/fileadmin/documents/shop/1655-leguminosen.pdf
97 HLPE 2019 Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome http://www.fao.org/3/ca5602en/ca5602en.pdf
98 Uwizeye A, de Boer IJM, Opio CI et al. 2020 Nitrogen emissions along global livestock supply chains. Nature Food 1: 437–446. https://doi.org/10.1038/s43016-020-0113-y
99 Hüppi R, Felber R, Neftel A, Six J, Leifeld J 2015 Effect of biochar and liming on soil nitrous oxide emissions from a temperate maize cropping system. Soil 1: 707-717 https://soil.copernicus.org/articles/1/707/2015/soil-1-707-2015.pdf
100 FAO 2017. Global database of GHG emissions related to feed crops: Methodology. Version 1. Livestock Environmental Assessment and Performance Partnership. FAO, Rome, Italy. http://www.fao.org/3/a-i8276e.pdf
101 Eidgenössische Materialprüfungs- und Forschungsanstalt 2019 Erste Feldmessungen von Lachgasisotopen. Medienmitteilung

2.3

Carbon dioxide

The problem: compared to methane and nitrous oxide, agriculture plays a relatively smaller role in emissions of the best-known of all greenhouse gases. Depending on management systems, agricultural soil either acts as a source or a sink of carbon dioxide emissions. The low net balance of carbon dioxide from agriculture can be explained by the emission and sequestration processes balancing each other out.

Net carbon dioxide emissions from agricultural soils are estimated to represent less than 1 per cent of global anthropogenic CO_2 emissions.[102] However, these estimates do not include emissions from transport, fertiliser production, heating of farm buildings and mechanical soil management - such as tractor driving. These are accounted for as emissions from the energy sector. If these indirect emissions were also taken into account, agriculture's share of the total CO_2 balance would be much higher.[103]

The largest source of CO_2 emissions in agriculture is the degradation of organic soil matter as a result of land use change: a significant proportion of these emissions is generated by converting new areas for agricultural use, i.e. conversion of grassland into cropland or drainage of peatland.[104] Large quantities of CO_2 also get released during deforestation and slash-and-burn converting of rainforests to farmland. The spreading of urea fertilisers and lime causes additional CO_2 emissions. In contrast, humus-rich soils, grasslands and forests serve as reservoirs for CO_2.

It is hard to predict the extent to which agricultural carbon dioxide emissions will develop in future. The Intergovernmental Panel of Climate Change IPCC, to take one view, believes that the rate of deforestation will remain stable or could even decline. The increasing use of low tillage soil cultivation practices could also reduce emissions or maintain them at a low level. On the other hand, CO_2 emissions resulting from transport could rise, driven by greater cross-border trade of agricultural products.[105]

2.3.1 Genome editing to reduce CO_2 emissions?

The conversion of carbon dioxide (CO_2) into organic compounds is a key process in the global carbon cycle. By intervening in the crops' metabolism, researchers believe that they can reduce the negative effects of the CO_2 emissions. To take a couple of examples, biotechnologists try to enable tree and crop root systems to store more carbon.[106] Metabolic pathways in arable plants are being altered for more effective CO_2-fixing.[107]

These kind of genetic engineering approaches are associated with so far unknown environmental risks, they are in part also difficult to carry out and they distract from the main cause of the problem: the intensive agricultural production system.

Natural-based, system-oriented agroecological approaches such as those outlined above have a track record of proven efficacy and ultimately offer a simpler, safer and more sustainable solution to human's self-made problem than quick 'techno-fixes'. However, they don't lie within the scope of the economic interests staked out by the developed world and its industrial corporations.

Footnotes:

102 Smith P, Martino D, Cai Z et al. 2007 Agriculture. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (eds), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg3-chapter8-1.pdf

103 Detailled overview can be found at EEA greenhouse gases - data viewer, https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer

104 Briefing 4, Agriculture and climate mitigation, https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/key_policies/documents/cap-specific-objectives-brief-4-agriculture-and-climate-mitigation_en.pdf Wüst-Galley C, Grüning A, Leifeld J 2015 Locating organic soils for the Swiss greenhouse gas inventory. Agroscope Science 26: 1-100. file:///Users/zsofia.hock/Downloads/bklkPTM1MzY3.pdf Bader C, Müller M, Schulin R, Leifeld J 2018 Peat decomposability in managed organic soils in relation to land use, organic matter composition and temperature. Biogeosciences 15: 703-719. https://bg.copernicus.org/articles/15/703/2018/bg-15-703-2018.pdf Smith P 2004 Engineered biological sinks on land. In: The Global Carbon Cycle. Integrating humans, climate, and the natural world. Field CB, Raupach MR (eds.). SCOPE 62, Island Press, Washington D.C., 479-491. Janzen HH 2004 Carbon cycling in earth systems - a soil science perspective. Agriculture, Ecosystems and Environment 104: 399-417.

105 Metz B Davidson OR, Bosch PR, Dave R, Meyer LA (eds) 2007 Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge UK and NY, USA. (Chapter 8). https://archive.ipcc.ch/publications_and_data/ar4/wg3/en/ch8s8-3-2.html

106 https://www.salk.edu/science/power-of-plants/

107 Naseem M, Osmanoglu Ö, Dandekar T 2020 Synthetic rewiring of plant CO2 sequestration galvanizes plant biomass production. Trends in Biotechnology 38 (4): 354-359. https://doi.org/10.1016/j.tibtech.2019.12.019 Erb, T 2016 Synthetische Kohlenstoffdioxid-Fixierung. Forschungsbericht 2016 – Max-Planck-Institut für terrestrische Mikrobiologie. https://www.mpg.de/10899435/mpi_terr_mikro_jb_2016

2.3.2 Why genome editing is NOT a solution

Reason 1: GM crops and trees as carbon-storing machines - treating symptoms while ignoring the risks

Through photosynthesis plants absorb more CO_2 from the air than they release through respiration. The absorbed carbon is then converted into oxygen and biomass. In trees the CO_2 removed from the atmosphere is stored in the wood in the long term, so that forests can effectively contribute to curbing global warming. However, CO_2 take-up is sometimes a very slow process: trees, for instance, take decades to grow to maturity. In the case of shorter-lived plants, such as crops, carbon storage is unfortunately often temporary.[108] When these plants die and decompose, much of that carbon returns to the atmosphere, which is one of the reasons why biotechnologists are keen to give the process a boost using new, genetically engineered "super crops". To take an example, the people at the "Harnessing Plants" project being run by California's Salk Institute for Biological Studies are working on the "ideal plant": a crop modified using gene scissors to build denser, deeper roots.[109] The increased root mass and depth is supposed to take up more CO_2 from the atmosphere, and reduce erosion. Increasing suberin content of the roots through genetic engineering are meant to ensure that the CO_2 absorbed by the plant isn't released back into the air too quickly. Suberin, or cork, decomposes at a very slow rate, thus keeping the fixed CO_2 longer in the soil.

Despite large investments, the feasibility of bringing such projects to market is questionable. To begin with, the genetically modified alteration has only been tested on thale cress (**Arabidopsis**), a model plant commonly used in laboratory studies. Much time could yet elapse before the method could be transferred to other species and the genetically engineered crops are ready to be grown in fields. Moreover, no one knows how much CO_2 is fixed by plants under changing environmental conditions. Warmer temperatures, for example, make trees use more water and photosynthesise less. As climate change intensifies, it is even possible that there will be a net increase in CO_2 emissions from trees as their metabolism could change.[110] Given the long and often complex life cycle of trees and their diverse forms of interaction with their environment, the environmental risks associated with the release of genome-edited trees outnumber those that might be posed by a genome-edited arable crop that is harvested at the end of the growing season. In addition, risk assessment for the slow-growing, long-lived genome-edited trees would take decades.

Reason 2: engineering new synthetic ways of CO_2 fixation – too many uncertainties

The so-called Calvin cycle, which the majority of plants use to fix CO_2, is only one of the numerous natural metabolic pathways for CO_2 fixation. Some enzymes recently discovered in bacteria, for example, fix CO_2 much faster and more reliably. Synthetic biology is supposed to help customise these enzymes, in order to assemble artificial metabolic pathways from scratch that are superior to their natural counterparts.[111]

The fact that the enzymes combined to engineer a completely new metabolic pathway are partly produced synthetically and partly originate from completely different organisms is an almost insurmountable obstacle to realisation. Undesirable side reactions with metabolic products the newly combined enzymes never came into contact with in the course of evolution are pre-programmed and can only be avoided by further genetic manipulation - with presumably even more side effects. In addition, there is a lack of knowledge about how the new synthetic cycle would fit into the complex metabolism of the host cell. Therefore, it is questionable whether the new metabolic pathway, which works in the test tube, can ever be transferred to living organisms.

Footnotes:

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109 https://www.salk.edu/harnessing-plants-initiative/

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Reason 3: GE tree plantations as an alternative source of timber to stop deforestation: negative impacts outweigh benefits

Deforestation is the cause behind one quarter of all man-made CO_2 emissions.[112] Deforestation is - among other reasons, such as land clearing for soy production to feed livestock - necessary to harvest timber for manufacturing wood products, such as paper. Biotechnologists working for the paper industry claim to protect natural areas by upping the productivity of tree plantations. This would increase the quantity of paper pulp that could be extracted per area, they argue. The basic idea is the faster the trees grow; the less area is needed to produce the same amount of paper.[113] One of the ways to engineer faster growth is to alter the hormonal balance of the main tree species felled to make paper (e.g.eucalyptus or poplar), by modifying the genes responsible for the secretion of growth hormones.[114]

Unfortunately, the industry is on the wrong track with this approach, since it distracts from other alternative solutions to protect natural forests, such as reduced consumption of wood-based products and encouraging reuse of already processed wood material.

Genome-edited trees primarily benefit the plantation, pulp and paper industries. The negative impacts of genome-edited plantations are largely unaccounted for: as such intensification comes with an increase in the already known negative impacts of industrial tree plantations on land, water and biodiversity, as well as on working conditions on plantations. Genome-edited trees are known to raise water consumption and to increase the use of agrotoxins. The far-flying seeds and pollen of trees pose a further risk: it is hardly conceivable that the artificially inserted genetic information would not be further propagated in the ecosystem.

2.3.3 Sustainable alternatives to genome editing

Alternative 1: Climate-friendly soil management – protecting and promoting natural carbon storage in the soil

The International Assessment of Agricultural Knowledge, Science and Technology for Development report (IAASTD) underlines the huge potential of adopting a climate-friendly approach of soil management.[115] Farmland represents more than half of the European Union's total territory. The intensification of agriculture has led to the destruction of 30 to 75 per cent of the organic matter in soil in arable land and 50 per cent on pasture land.[116] Using agroecological approaches that have proved to be successful over centuries[117] humus content of agricultural soils could be increased again and up to two-thirds of the current surplus of CO_2 in the atmosphere could be returned to the soil.[118] Soils rich in humus not only sequestrate more carbon, they also hold water longer, making them less vulnerable to erosion and more fertile than soils with a lower humus content.[119] Soil humus content can be improved by keeping agricultural land covered all year and by switching to low- or no- till soil management.[120] The latter not only reduces tillage-induced CO_2 emissions but also - production costs for the farmers,[121] making conservational tillage more and more attractive - gradually leading farmers to adopt this method.

Footnotes:

112 Smith P, Bustamante M, Ahammad H, Clark H, Dong H, Elsiddig EA et al. 2014 Agriculture, forestry and other land use (AFOLU). In Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the intergovernmental Panel on Climate Change. Edenhofer O, Pichs-Madruga R, Sokona Y et al. (eds.) Cambridge University Press, UK and NY USA 811-922. https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter11.pdf Bastin JF, Finegold Y, Garcia C et al. 2019 The global tree restoration potential. Science 365 (6448): 76-79. https://science.sciencemag.org/content/365/6448/76

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Incorporating crop residues into the soil has the advantage of emitting less CO_2 emissions that would be produced by burning them. Considerable areas of grassland have been sacrificed to the cultivation of arable crops, which are mainly used for the production of concentrated feed. When converting grassland into arable land, a significant proportion of the carbon stored in the soil gets lost in the form of CO_2.[122] Taking into account that grasslands store twice as much carbon as arable soils, the renaturation of degraded soils and converted peatland is another promising strategy to reduce CO_2 emissions.[123]

Improved management of pasture land can also promote carbon storage. Rotational grazing, allowing the vegetation to regenerate after grazing, helps retain organic matter and carbon in the soil for longer periods of time.[124]

Alternative 2: Afforestation and agroforestry instead of genetically-engineered trees

Leaving aside land used for other purposes (i.e. agricultural land and residential areas), about 0.9 billion hectares of former forest land could potentially be restored, neutralising two thirds of anthropogenic CO_2 emissions.[125]

Agroforestry practices also offer a good way to compensate for agricultural CO_2 emissions. Agroforestry is a systems-based farming approach that combines the production of tree biomass with crops, grassland and animal farming on the same area of land. Agroforestry helps to use existing agricultural land more efficiently and, most importantly, in a more climate-friendly way. The environmental benefits of agroforestry are already widely recognised. Such systems sequestrate large amounts of CO_2, which is stored both in wood and in soil humus for a long period of time.[126] Further advantages of the system are its positive effects on soil erosion, nitrate losses and biodiversity.[127] Greenhouse gas emissions can be curbed using the wood sourced from agroforestry systems for construction, furniture or to substitute fossil fuels. Agroforestry doesn't only function in developing countries, where it was originally applied to use forest land for farming. If agroforestry were introduced on 9 per cent of European agricultural land, up to 43 per cent of greenhouse gas emissions from agriculture could be compensated.[128]

Footnotes:

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Glossary of terms

Agroecology: agroecology approaches are based on the diversity of agricultural systems. By combining scientific thinking, traditional knowledge and modern management systems, it strives for a change towards sustainable and productive farming like agroforestry or permaculture.

Soil erosion: in agriculture, soil erosion is the wearing away of the topsoil by wind, water or mechanical interventions associated with farming activities such as tillage or overgrazing. Degradation conditions such as low humus content, soil compaction or loss of soil structure can accelerate this process.

Gene: a section of genetic material that, in conjunction with other sections of genetic material and environmental influences, contributes to the formation of proteins in an organism and its, his or her defining characteristics.

Genome: the entire genetic information relative to a cell, sometimes referred to as "heritable information".

Genome editing: recently developed methods of genetic engineering that enable quick, far-reaching modification of genetic material (for example the CRISPR/Cas9 gene scissors). The risks of such methods in the context of agriculture are largely unexplored.

Genome: the entire set of genetic information in an organism cell, also called "heritable information".

Gene pool: the totality of all genetic variants in a population. Decades of selection tend to reduce a species' gene pool, whereas new mutations and crosses with external populations increase it.

CRISPR/Cas9 molecular scissors: enzymes that are able to recognize and to cut particular locations of the DNA of an organism. The break they cause in the double stranded DNA is then repaired by the cell's own repair mechanisms: an error-prone process that might lead to unintended side-effects. Originally, molecular scissors are used by bacteria to fight invading viruses. They have recently been adapted by scientist for laboratory use as a genetic engineering tool.

Invasive species: Invasive species are organisms (e.g.. plants and animals) from another region of the world that are transported (by water, wind, other organisms or humans) to new environments where they don't belong to. Invasive species can pose a threat to biodiversity and to local agriculture by leading to the extinction of native species or by introducing diseases.

Classic genetic engineering: modification of a genome by inserting individual genes influencing a desired trait in an organism, in an undirected manner. These genes often originate from another species as the targeted one.

Climate footprint: Human influence on global warming (the amount of greenhouse gas emissions caused by various human activities).

Land competition: The competition for land between different forms of use, for example competition between cultivating food and feed crops.

Patent on seeds: By patenting genetically modified seeds, the few global agribusiness corporations aim to extend their influence on global food production and to further monopolise global food chains. Smaller farms thus become dependent from the big agribusiness companies, as they are not allow to reuse patented seed and have to buy them on a yearly basis.

Resilience: Ability of an ecosystem to return to its initial state after a disturbance. E.g., ability to adaptively respond to climate-related stress in ecosystems, ability to regenerate after stress impacts.

Synthetic fertiliser: Fertiliser produced by applying technology during the processing of natural raw materials. The production of synthetic fertiliser is very energy-intensive, involves the consumption of large quantities of fossil fuel (natural gas) and increases greenhouse gas emissions.

SWISS ALLIANCE FOR A GMO-FREE AGRICULTURE (SAG) & FRIENDS OF THE EARTH EUROPE (FOEE) ARE CALLING FOR:

- Decision makers need to adjust their perception of potential of new GMOs. The long list of promises about the potential benefits of new GM are not based on substantial evidence whilst a long list of negative Impacts and side effects of new GMO is downplayed in public debates
- A shift in priorities is needed to support real solutions for climate change in public policies like agriculture, research and environmental legislations. Farming systems like agroecology and organic farming have huge evidence to cut emissions from farming sector, increase soil health with positive impacts on natural carbon sequestration in the soil.
- Keep new GM regulated as GMO to ensure freedom of choice for consumers, farmers and breeders and ensure that new technologies can't be marketed without stringent safety checks and labelling.

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