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Valery Korotchenya

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Ideal Final Result for Agriculture: Striving for Sustainability

Valery Korotchenya¹[0000-0003-4426-9266]

¹ IEEE, 3 Park Avenue, 17th Floor, New York, NY 10016-5997, USA
valor99@gmail.com

Abstract. In this paper, we used TRIZ to resolve the existing contradictions between agriculture and the environment, which would make agriculture sustainable. Through the identification of strategic types of agriculture and their goals, we formulated ideal final result for agriculture. This formulation includes all the contradictions that exist between the strategic types. We proposed a strategy for the balanced development of agricultural technologies, which aims to realize the ideal final result for agriculture by resolving all contradictions between all the strategic types of agriculture. The balanced development means that in the resulting system of agriculture, the goals of all the strategic types of agriculture are achieved simultaneously. Regarding the issue of making agriculture sustainable, in accordance with the TRIZ methodology, administrative, technical and physical contradictions arising between agriculture and the environment were stated and examined. Some solutions to the physical contradictions were proposed. Based on these solutions, two main factors of making agriculture sustainable were determined: 1) making green technologies highly productive; and 2) the humane control of the growth of the world population.

Keywords: Strategic types of agriculture, Theory of inventive problem solving (TRIZ), Ideal final result, Kinds of contradictions in TRIZ, Physical contradictions, Sustainable agriculture, Balanced development of agricultural technologies.

1 Introduction

There can be different strategies for developing agricultural technology. Usually the economic motive behind them consists in boosting economic efficiency (profitability) or winning the competitive struggle, thereby increasing sales and the market share. At the same time, as a matter of fact agriculture harms the environment by changing natural ecosystems, exhausting biological resources, leading to the loss of biological diversity, polluting the soil with pesticides and mineral fertilizers, contributing to global greenhouse gas emissions and so on [1–5] (some data on these issues will be presented below). Therefore, economic reasons cannot be a sole driver for bettering agricultural technology. A more balanced way of technological development can be based on the approaches offered by the theory of inventive problem solving (TRIZ).

According to TRIZ, with evolution, technical systems become closer to ideal [6, p. 228]. Being the embodiment of ideality, ideal systems while performing their useful functions do not expend any energy/resources. Ideality also means that the harmful effect of a technical system in question must be zero [7, p. 59]. This is what we need as regards ideal agriculture.

In general, we should analyze agricultural technology in order then to formulate ideal final result for agriculture, which is supposed to involve different contradictions. Though the main contradiction implied here is between humanity and Mother Nature, we will present as many contradictions in agricultural technology as possible. The ultimate purpose is to put forward some ways of resolving the contradictions between agriculture and the environment that will make it possible to create sustainability and realize the ideal final result for agriculture in what we term “the balanced development of agricultural technologies.”

This balanced development is presumed to be a holistic strategy for developing agricultural technology because the proposed approach suggests that the contradictory goals of strategic types of agriculture (presented below) are achieved simultaneously.

Also, our approach expands the application of TRIZ. With regard to environmental issues, the TRIZ methodology is most often used for the eco-design of technical systems [8]. However, in this paper, TRIZ is applied to the entire industry.

One of the closest to our work is the paper [9], where the concept of sustainability is studied through the prism of TRIZ (for example, the notion of ideal final result is used). However, our study is entirely devoted to the subject of agriculture, while in [9] agriculture is not touched upon. Besides, in addition to the sustainability of agriculture, we consider other aspects of agricultural technology.

We should also highlight the paper [10], where TRIZ is used to design eco-innovations in biological systems such as agriculture, and the authors present their BioTRIZ axioms for eco-innovation. The difference between our work and [10] is that our approach reflects a macro approach: we look at the problem from the perspective of the entire agricultural sector, while the authors of the paper [10] study the eco-design of biological systems involving some technological features, which constitutes a micro approach.

The starting point for achieving the purpose of our research is specifying strategic types of agriculture, which is necessary for analysis of agricultural technology.

2 Strategic Types of Agriculture and Ideal Final Result for Agricultural Production

Based on the classification of aspects of agricultural technology, similar to the innovations in agriculture according to form [11, p. 209], we identify eight *strategic types of agriculture* (Table 1).

Table 1. Strategic types of agriculture.

Strategic type of agriculture	Extremely significant aspects in agricultural technology	Strategic goals (elements of the ideal final result for agriculture)
Classical agriculture (conventional agriculture): represented by mechanized agriculture based on scientific agronomy, with the use of fertilizers, pesticides, and selective breeding (but without genetic engineering)	agronomic agrochemical biological mechanical	- food security of large masses of people
Digital agriculture (smart agriculture)	informational (cyber-physical)	- maximum efficiency of agricultural production (achieved by the use of data) - full automation and intellectualization of agricultural production
Organic agriculture	healthcare-related	- food safety for human health
Green agriculture (sustainable agriculture)	ecological	- environmental sustainability of agricultural production
Climate-smart agriculture	climatic	- high adaptability to climate change and climate neutrality
Biotechnology-based agriculture (includes genetic engineering)	biotechnological	- creation of varieties of agricultural plants and farm animal breeds with the best properties, subject to the limitations of complete safety for human health and the environment
Controlled-environment agriculture (in greenhouses and buildings)	agronomic	- independence from weather and climatic conditions
Agricultural biofuel production as an alternative energy source	energy-related	- the maximum possible contribution to the development of alternative energy

Note that our understanding of organic agriculture is that this strategic type is completely about the healthcare-related aspect, while the conservation of natural resources in agricultural production is the core of green agriculture.

The combination of all the strategic goals presented in Table 1 can be regarded as *ideal final result* [7, pp. 59–60] *for agriculture*, i.e. the latter is the agriculture that ensures the food security of large masses of people, maximum efficiency of agricultural production, full automation and intellectualization of agricultural production, and so on.

The contradictoriness of the ideal final result is shown in Table 2 by revealing contradictions between the strategic types of agriculture.

Table 2. Contradictions between the strategic types of agriculture and the corresponding contradictory nature of the ideal final result for agriculture.

Contradictory pair of strategic types of agriculture		Contradictions between the strategic goals of the pair in question
Classical agriculture	Organic agriculture	Providing food security of large masses of people by using mineral fertilizers, pesticides and other chemicals in classical agriculture deteriorates food safety for human health.
Classical agriculture	Green agriculture	The necessity of feeding a large number of people (classical agriculture) often leads to harmful effects of agriculture on the environment and makes impossible environmental sustainability of agricultural production.
Classical agriculture	Climate-smart agriculture	Ensuring food security of large masses of people is not climate-neutral and leads to climate change, which contradicts the strategic goal of climate-smart agriculture.
Organic agriculture	Classical agriculture	Achieving the strategic goals of organic agriculture, green agriculture, controlled-environment agriculture, and digital agriculture (i.e. full automation and intellectualization of agriculture) can cause a significant increase in agricultural prices and worsen the food security of large masses of people.
Green agriculture	Classical agriculture	
Controlled-environment agriculture	Classical agriculture	
Digital agriculture	Classical agriculture	
Biotechnology-based agriculture	Organic / green agriculture	By improving food security and creating better plant varieties and animal breeds, biotechnology can deteriorate the safety of agricultural products for human health and the environment (achieving the pair's goals at the same may become impossible).
Agricultural biofuel production as an alternative energy source	Classical agriculture	The production of agricultural biofuels can result in a deterioration in food security (the strategic goal of classical agriculture may not be achieved).

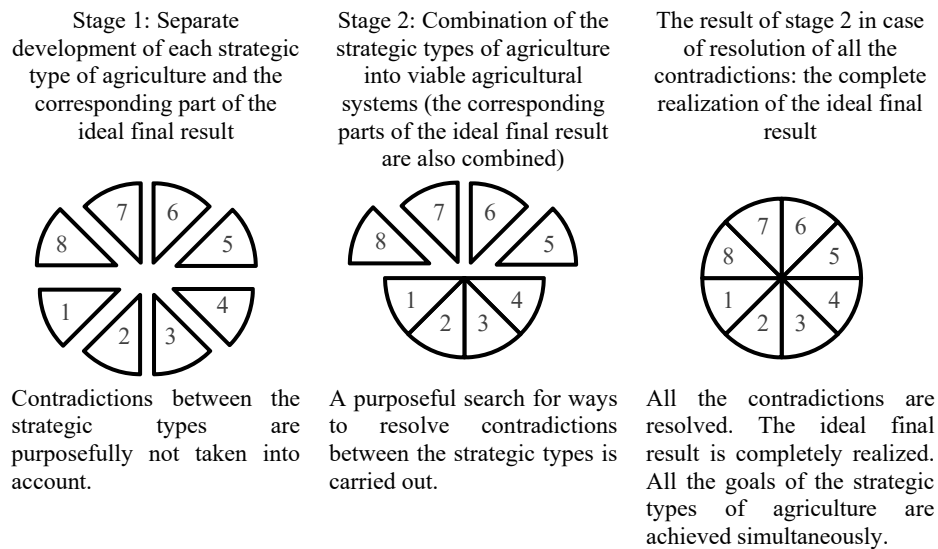
Analyzing the strategic types of agriculture and the corresponding ideal final result, we acknowledge the presence of serious contradictions in them—especially between

agriculture and the environment. Because of both the great importance and extreme difficulty of achieving this ideal final result in practice, we call this task a *grand challenge*. The striving to obtain a practical solution should be fulfilled as a *mission-oriented policy* of the world community [12].

As an attempt at finding this solution, we propose a *strategy for the balanced development of agricultural technologies*. It includes two stages: 1) developing each strategic type of agriculture separately to an advanced degree, thereby achieving separately the eight parts of the ideal final result for agriculture, which are represented by the eight strategic types of agriculture (Table 1; the third column); and 2) combining strategic types of agriculture into viable agricultural systems by resolving the corresponding contradictions (for example, combining classical agriculture, digital agriculture, organic agriculture, green agriculture, climate-smart agriculture, and biotechnology-based agriculture), which ideally would mean the complete realization of the ideal final result for agriculture, or, in other words, achieving all the goals of all the strategic types of agriculture at the same time.

The second stage is the most difficult, because no one has yet managed to find an optimal way of farming, which does not cause damage to the environment or humans. Therefore, this study is focused on identifying a large scientific and social problem and trying to offer its own solutions with the help of TRIZ.

Fig. 1 depicts the general idea of the proposed strategy.



Each segment represents one of the eight strategic types of agriculture.

Fig. 1. Strategy for the balanced development of agricultural technologies: a general idea.

In the next section of our paper, using the TRIZ methodology, we will present some ways how to resolve contradictions between ensuring the food security for large masses of people and the need to preserve the environment. How to make agriculture sustainable is our goal and challenge. Hence, we will make an effort to combine clas-

sical agriculture and green agriculture as part of stage 2 of our approach to the balanced development of agricultural technologies.

3 Striving for Sustainability of Agriculture

TRIZ [7, pp. 76–77] distinguishes three kinds of interrelated contradictions: administrative, technical, and physical. Let us reveal their essence in relation to providing the sustainability of agriculture and offer ways of resolving them.

With regard to making agriculture sustainable, *the administrative contradiction*, a contradiction between a certain need of a person or a group of people and the ability to satisfy it, can be formulated as follows: agriculture, while providing food for large masses of people, unintentionally harms the environment, and it is not known how to solve this ecological problem. Here, the indicated contradiction is expressed as opposition between the need to prevent an undesirable effect (harm to nature) and not knowing how to do it.

The technical contradictions (contradictions between the parameters of the technical system in question, when the improvement of some parameter(s) leads to the deterioration of (an)other parameter(s); they underlie the administrative contradiction) will be the following:

the need to feed the growing population of the planet causes an increase in agricultural land and a simultaneous reduction in the area of wildlife habitat with a tremendous loss of biodiversity¹;

ensuring food security for a large number of people gives rise to climate change (due to greenhouse gas emissions and the conversion of non-agricultural land such as forests to farmland²);

obtaining high yields through the use of mineral fertilizers and pesticides causes environmental pollution³;

intensive agriculture, in pursuit of high yields, degrades soil, reducing its fertility [4, 5]⁴.

We should note that as regards different ways of resolving technical contradictions in accordance with the contradiction matrix by Altshuller [13], we could not find any appropriate solutions. In our problem of making agriculture sustainable, we have the following two pairs of contradictory characteristics (the first characteristic improves,

¹ According to FAO data, the share of land used in agriculture in the total land area of all countries increased from 34.3% in 1961 to 36.7% in 2019 (the maximum of 37.6% was reached in 2001, and the minimum for this period was in 1961). Continued growth of the world's population will contribute to the expansion of farmland and will require a constant increase in agricultural productivity. Agriculture is considered one of the main causes of biodiversity loss [1, 2] and changes in terrestrial and freshwater natural ecosystems [1].

² About a quarter of the global greenhouse gas emissions come from land clearing and agriculture, with 75% of them coming from animal husbandry [1, p. XXXII].

³ In [3], it was found that 64% of the agricultural land in the world (about 24.5 million km²) is at risk of pesticide pollution, and 31% is at high risk.

⁴ According to experts [5, p. 52], globally, the loss of soil is 24 billion tons per year.

but the other deteriorates): area of a stationary object—harmful factors developed by an object; and capacity/productivity—harmful factors developed by an object.

The first contradictory pair represents extensive agricultural practices and covers the first two technical contradictions mentioned above. The characteristic “area of a stationary object” is the area of agricultural land, and its improvement means the increase in the farmland. Our purpose is to feed large masses of people. In order to achieve that we increase our agricultural land, which in turn creates more harmful impact on the environment. Hence, our agricultural practices become unsustainable.

On the other hand, the second contradictory pair represents intensive agricultural practices and concerns the last two technical contradictions mentioned above. Here, to feed people, we increase the productivity of agriculture, but intensive methods exacerbate environmental harm. Again, the problem of unsustainability arises.

In both of these situations, the ways of resolving technical contradictions that can be found in the contradiction matrix [13] are not appropriate. For example, it seems inconceivable to successfully apply the “Convert Harm into Benefit” principle in relation to the environmental damage of agriculture. Apparently, these contradictions are impossible to solve on the technical level. We should go deeper—down to the level of physical contradictions.

Finally, the following assertions constitute *the physical contradictions* (imposing diametrically opposing requirements to any property of some part of the technical system in question; they are the cause of technical contradictions):

1. in order to feed a large number of people, it is necessary to have a large area of agricultural land, but in order to preserve the wildlife habitat, the agricultural land area must be small; the same holds for the contradiction between food security and climate neutrality;
2. to increase crop yields, it is necessary to use mineral fertilizers and pesticides, but in order not to pollute the environment, mineral fertilizers and pesticides cannot be applied; the same holds for the contradiction between intensive agriculture and the need to preserve soil fertility (to increase crop yields, it is necessary to apply intensive technologies, but to preserve soil fertility, intensive technologies cannot be used).

These physical contradictions can be formulated even more succinctly: the current extensive and intensive agricultural practices, which are necessary to ensure food security, harm the environment.

As specified by TRIZ [7, p. 79], resolving a physical contradiction is done by separating the opposite properties in space, time, structure, or according to condition.

Now let us present some solutions to the physical contradictions in relation to agriculture and the environment, organizing them in accordance with the above two-element list of the physical contradictions, and separating the opposite properties:

1. **in space:** the creation of protected nature reserves helps to preserve natural ecosystems [14];

in space and structure: relocating cropland to a territory with the most favorable conditions for growing agricultural plants can significantly reduce the size of necessary cropland and environmental impact of agriculture, including carbon emissions [15];

according to condition: subject to compliance with the requirements of agricultural technology and post-harvest management, there is a decrease in crop losses [16, 17];

in structure and according to condition: promoting healthy lifestyles and sport activities can help tackle the problem of obesity, which in turn will lead to consuming less food [18];

according to condition: upon reaching the threshold values in the world population growth rate, humane mechanisms that mitigate the problem of overpopulation should be engaged (at the global level, this solution requires close international cooperation) [19];

in structure and space: the transition of humanity to a vegetarian lifestyle would reduce the amount of greenhouse gases emitted by agriculture [20];

2. **in space and structure:** variable rate fertilizer and pesticide application, a technique used in precision agriculture, reduces environmental pollution [21, 22];

in structure and space: zero and minimum tillage contribute to soil conservation and carbon sequestration, thus preventing respectively soil erosion and global warming [23–25];

in time and space: fallowing and crop rotation as farming techniques can be very helpful in restoring soil fertility and reducing the harm of intensive agriculture [26];

according to condition: in the event of overexploitation of agricultural land or damage to the environment, measures of government support for the restoration of ecosystems, as well as penalties, should be provided [27, 28];

according to condition: a significant contribution to resolving the contradiction between humans and nature can be made by purposeful improvement of agricultural technology, when there is high agricultural productivity without environmental degradation (for example, through digitalization / intellectualization [29]; substituting physical, biological and other eco-friendly weed control systems for herbicides [30]).

The list of solutions is far from exhaustive. Nevertheless, despite the fact that the majority of these solutions are well-known and represent only a mitigation of the anthropogenic impact of humanity on Mother Nature (with the exception of zero and minimum tillage, fallowing and crop rotation, and purposeful improvement of agricultural technology), in our opinion, the presented methods still provide understanding

and point the way to resolving the contradiction between agriculture and the environment. Let us demonstrate this in the context of our strategy for the balanced development of agricultural technologies, which was discussed in section 2. Our purpose is to combine classical agriculture and green agriculture by making agriculture sustainable.

First, agricultural technologies must be improved as much as possible so that they become truly sustainable, or green (*this is included in the first stage of our proposed strategy*). If it is difficult, impossible or too expensive to ensure the sustainability of certain aspects of agricultural technology, mitigation measures should be used, examples of which are given above. We do not consider perfecting classical agriculture here because this type of agriculture has been developing and improving for centuries.

Second, in order to ensure environmental sustainability and be able to feed large masses of people, our green technologies must be made highly productive, and we as a society should establish the humane control of the growth of the world's population (*these measures are part of the second stage of our strategy*). High productivity is achieved through the direct, purposeful improvement of green technologies.

As regards both the control of the growth of the global population and productivity of green agriculture, it is necessary to set up a long-term experiment on the application of sustainable agriculture in a relatively large area in order to test green technologies and experimentally determine the *agricultural carrying capacity of the environment* (similar to the human carrying capacity of the environment, or ecological footprint [31, 32]). By the agricultural carrying capacity of the environment, we mean the maximum number of people who can be fed from a given territory, and at the same time not permanently damage the environment. In the scientific literature, there are different estimates of the human carrying capacity of the entire planet (up to one trillion people or even more [32, p. 1; 33]). However, we believe that it is better to establish the agricultural carrying capacity *experimentally*, taking into account the productivity of the green technologies and the soil and climate conditions in the area in question.

Also, we should take into account an opportunity of relocating agricultural production to land more suited for agriculture, which will give us an advantage of reducing our farmland and environmental footprint [15].

It is necessary to achieve both the sustainability of agricultural technologies and a high level of agricultural carrying capacity, although the latter is more dependent on nature itself. The idea behind all this is very simple: the use of highly productive green technologies in agriculture and the humane control of the growth of the world's population is what we need to ensure long-term sustainability of our food systems, thereby resolving contradictions between agriculture and the environment. This is how, on a fundamental level, we combine classical agriculture and green agriculture, which is done in the second stage of our strategy.

Before we create efficient green technologies, it is advisable to use the mitigation measures listed above or similar to those.

At the end of this section, we want to emphasize that the approach proposed in this paper expands the application of TRIZ: the concept of ideal final result is applied not to a technical system, but to an entire industry. This macro approach and the micro

approach to the environmental problems of agriculture available in the literature, embodied, for example, in [10], can be used together.

4 Conclusion

The major conclusion of our paper is that TRIZ is a convenient, suitable tool for finding ways to resolve contradictions between strategic types of agriculture, when the solution found opens the way to a balanced development of agricultural technologies. The key category here is ideal final result, which is applied to agriculture as a whole.

Thus, after defining eight strategic types of agriculture, the application of TRIZ allowed us to state ideal final result for agriculture, identify the contradictions—administrative, technical, and physical—contained in it, and point the way to solving the fundamental contradiction between agriculture and the environment. It was found that making green technologies highly productive and humane control of the growth of the world's population are those factors that ensure sustainability of agriculture.

Such a process of resolving contradictions between all the strategic types of agriculture was called in the paper a strategy for the balanced development of agricultural technologies.

The limitation of our research is that we considered the resolution of contradictions only between two strategic types of agriculture—classical and green (though we indicated contradictions between all the types). The combination of all the eight strategic types into a viable agricultural system was not our task, but can be a purpose for future research. Due to the complexity of the issue, it is appropriate to perform this task sequentially, adding one strategic type at a time. In the case of successful resolution of all contradictions between all the strategic types, which is expressed in obtaining a viable, organically coherent system of agriculture, there is a complete realization of the ideal final result for agriculture. This is the most difficult part of a strategy for the balanced development of agricultural technologies presented in this paper.

But even the combination of conventional and green technologies presents a challenge. The current state of development of agricultural technologies is such that there is now an integration of classical agriculture and digital agriculture, which is in line with the economic-driven goal of maximizing the efficiency of agricultural production, while green technologies reflect an alternative paradigm that has not yet become mainstream. However, sooner or later humanity will come to the inevitability of sustainable agriculture on a large scale.

We hope that this work will make its contribution to the creation of a kind, harmonious world, where both humanity and Mother Earth would live a happier and more sustainable life.

References

1. IPBES: Global assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn (2019).

2. Kehoe, L., Romero-Muñoz, A., Polaina, E., Estes, L., Kreft, H., Kuemmerle, T.: Biodiversity at risk under future cropland expansion and intensification. *Nat. Ecol. Evol.* **1**, 1129–1135 (2017). <https://doi.org/10.1038/s41559-017-0234-3>
3. Tang, F.H.M., Lenzen, M., McBratney, A., Maggi, F.: Risk of pesticide pollution at the global scale. *Nat. Geosci.* **14**, 206–210 (2021). <https://doi.org/10.1038/s41561-021-00712-5>
4. Kopittke, P.M., Menzies, N.W., Wang, P., McKenna, B.A., Lombi, E.: Soil and the intensification of agriculture for global food security. *Environ Int* **132**, 105078 (2019). <https://doi.org/10.1016/j.envint.2019.105078>
5. United Nations Convention to Combat Desertification: Global land outlook. 1st edn. Secretariat of the United Nations Convention to Combat Desertification, Bonn (2017).
6. Altshuller, G.S.: Creativity as an exact science: the theory of the solution of inventive problems. Gordon and Breach Publishers, Amsterdam (1984).
7. Petrov, V.: TRIZ. Theory of inventive problem solving: level 1. Springer, Cham (2019). <https://doi.org/10.1007/978-3-030-04254-7>
8. Buzuku, S., Shnai, I.: A systematic literature review of TRIZ used in Eco-Design. *J. Eur. TRIZ Assoc.* **4**, 20–31 (2017).
9. Mishra, U.: Understanding secrets of sustainability through TRIZ philosophy (2014). <https://doi.org/10.2139/ssrn.2421392>. Accessed 19 June 2022
10. Bogatyrev, N., Bogatyreva, O.: BioTRIZ: a win-win methodology for eco-innovation. In: Azevedo, S.G., Brandenburg, M., Carvalho, H., Cruz-Machado, V. (eds.) *Eco-innovation and the development of business models: lessons from experience and new frontiers in theory and practice*, pp. 297–314. Springer, Cham (2014). https://doi.org/10.1007/978-3-319-05077-5_15
11. Sunding, D., Zilberman, D.: The agricultural innovation process: research and technology adoption in a changing agricultural sector. In: Gardner, B., Rausser, G. (eds.) *Handbook of agricultural economics*, volume 1, pp. 207–261. Elsevier, Amsterdam, New York (2001).
12. Mazzucato, M.: *Mission economy: a moonshot guide to changing capitalism*. Harper Business, New York (2021).
13. Altshuller, G.S.: *The innovation algorithm: TRIZ, systematic innovation and technical creativity*. 2nd edn. Technical Innovation Center, Inc., Worcester (2007).
14. Geldmann, J., Manica, A., Burgess, N.D., Coad, L., Balmford, A.: A global-level assessment of the effectiveness of protected areas at resisting anthropogenic pressures. *PNAS* **116**(46), 23209–23215 (2019). <https://doi.org/10.1073/pnas.1908221116>
15. Beyer, R.M., Hua, F., Martin, P.A., Manica, A., Rademacher, T.: Relocating croplands could drastically reduce the environmental impacts of global food production. *Commun Earth Environ* **3**, 49 (2022). <https://doi.org/10.1038/s43247-022-00360-6>
16. Chakraborty, I., Chattopadhyay, A.: Pre- and post-harvest losses in vegetables. In: Singh, B., Singh, S., Koley, T.K. (eds.) *Advances in postharvest technologies of vegetable crops*, pp. 25–87. Apple Academic Press, Waretown (2018). <https://doi.org/10.1201/9781315161020-2>
17. Sawicka, B.: Post-harvest losses of agricultural produce. In: Filho, W.L., Azul, A.M., Brandli, L., Özuyar, P.G., Wall, T. (eds.) *Zero hunger*, *Encyclopedia of the UN Sustainable Development Goals*, pp. 654–669. Springer, Cham (2020). https://doi.org/10.1007/978-3-319-95675-6_40
18. Frey, S., Barrett, J.: Our health, our environment: the ecological footprint of what we eat. In: *International Ecological Footprint Conference*. BRASS, Cardiff University, Cardiff (2007).

19. Lidicker, W.Z., Jr.: A scientist's warning to humanity on human population growth. *Glob Ecol Conserv.* **24**, e01232 (2020). <https://doi.org/10.1016/j.gecco.2020.e01232>
20. Xu, X., Sharma, P., Shu, S., Lin, T.-S., Ciaias, P., Tubiello, F.N., Smith, P., Campbell, N., Jain, A.K.: Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods. *Nat Food* **2**, 724–732 (2021). <https://doi.org/10.1038/s43016-021-00358-x>
21. Bongiovanni, R., Lowenberg-Deboer, J.: Precision agriculture and sustainability. *Precis. Agric.* **5**, 359–387 (2004). <https://doi.org/10.1023/B:PRAG.0000040806.39604.aa>
22. Majumder, D., Akhter, J., Mandal, A., Roy, R., Mondal, D., Bhatt, R., Hossain, A.: Precision input management for minimizing and recycling of agricultural waste. In: Bhatt, R., Meena, R.S., Hossain, A. (eds.) *Input use efficiency for food and environmental security*, pp. 567–603. Springer, Singapore (2021). https://doi.org/10.1007/978-981-16-5199-1_19
23. Komissarov, M.A., Klik, A.: The impact of no-till, conservation, and conventional tillage systems on erosion and soil properties in Lower Austria. *Eurasian Soil Sc.* **53**, 503–511 (2020). <https://doi.org/10.1134/S1064229320040079>
24. Ogle, S.M., Alsaker, C., Baldock, J., Bernoux, M., Breidt, F.J., McConkey, B., Regina, K., Vazquez-Amabile, G.G.: Climate and soil characteristics determine where no-till management can store carbon in soils and mitigate greenhouse gas emissions. *Sci Rep* **9**, 11665 (2019). <https://doi.org/10.1038/s41598-019-47861-7>
25. Krauss, M., Wiesmeier, M., Don, A., Cuperus, F., Gattinger, A., Gruber, S., Haagsma, W.K., Peigné, J., Chioldelli Palazzoli, M., Schulz, F., Heijden, M.G.A. van der, Vincent-Caboud, L., Wittwer, R.A., Zikeli, S., Steffens, M.: Reduced tillage in organic farming affects soil organic carbon stocks in temperate Europe. *Soil Tillage Res* **216**, 105262 (2022). <https://doi.org/10.1016/j.still.2021.105262>
26. Nadeem, F., Nawaz, A., Farooq, M.: Crop rotations, fallowing, and associated environmental benefits. In: *Oxford research encyclopedia of environmental science*. <https://doi.org/10.1093/acrefore/9780199389414.013.197>. Accessed 19 June 2022
27. Coria, J., Sterner, T.: Natural resource management: challenges and policy options. *Annu Rev Resour Economics* **3**, 203–230 (2011). <https://doi.org/10.1146/annurev-resource-083110-120131>
28. Peake, L., Robb, C.: Saving the ground beneath our feet: establishing priorities and criteria for governing soil use and protection. *R. Soc. Open Sci.* **8**, 201994 (2021). <https://doi.org/10.1098/rsos.201994>
29. Hrustek, L.: Sustainability driven by agriculture through digital transformation. *Sustainability* **12**, 8596 (2020). <https://doi.org/10.3390/su12208596>
30. Hasan, M., Ahmad-Hamdani, M.S., Rosli, A.M., Hamdan, H.: Bioherbicides: an eco-friendly tool for sustainable weed management. *Plants* **10**, 1212 (2021). <https://doi.org/10.3390/plants10061212>
31. Chakraborty, T., Thakur, B.K.: Ecological footprint and sustainable development: a two-way approach. In: Filho, W.L., Azul, A.M., Brandli, L., Salvia, A.L., Wall, T. (eds.) *Affordable and clean energy, Encyclopedia of the UN Sustainable Development Goals*, pp. 303–311. Springer, Cham (2021). https://doi.org/10.1007/978-3-319-95864-4_41
32. Siegel, F.R.: *The Earth's human carrying capacity: limitations assessed, solutions proposed*. Springer, Cham (2021). <https://doi.org/10.1007/978-3-030-73476-3>
33. Franck, S., Bloh, W. von, Müller, C., Bondeau, A., Sakschewski, B.: Harvesting the sun: new estimations of the maximum population of planet Earth. *Ecol Modell* **222**(12), 2019–2026 (2011). <https://doi.org/10.1016/j.ecolmodel.2011.03.030>