Kate Hildenbrand

Benefits and Barriers of Regenerative Agriculture in the Current Sociopolitical Context

Contact: katehildenbrand.com, kate@katehildenbrand.com

Master Thesis for the Master of Science in Landscape Ecology and Nature Conservation at the University of Greifswald, Germany

September 2025

Advisors: Dr. des. Felix Suckstorff, Dr. Jaap van Schaik

Table of Contents

Abstract

Humanity's agricultural and food systems are responsible for pushing the planetary boundaries in many regards: Agriculture is a major driver of the climate and biodiversity crises by causing high emissions, habitat fragmentation and loss, high freshwater consumption, nutrient and water-cycle disruptions, and severe soil degradation.

With most of the world already feeling the consequences of climate change, reducing emissions and preserving biodiversity have become essential to protecting humanity's future. The impacts of these crises are disproportionately felt by the less privileged: by the global South, indigenous peoples, but also the poorer parts of societies within developed countries.

Ironically, while a main driver of climate change, agriculture itself is projected to continue to be severely impacted by climate change. The rising temperatures and altered precipitation associated with anthropogenic climate change create tougher growing conditions for farmers and make fields more vulnerable to pests. Agrochemicals like pesticides and synthetic fertilizers threaten biodiversity, water and soil quality, and human health.

Regenerative agriculture is seen as a solution to the growing problem at the intersection of agriculture and climate change, and as such an alternative to the current capitalistic model with a focus on soil health, ecosystem thinking, and community rather than yields or profits. By minimizing impacts, regenerative agriculture focuses on regenerating ecosystems instead of using yield as the single metric for success. In the context of yield, it is further important to consider that a significant portion of agricultural land is used to provide feed for livestock and bio-fuels instead of going to human consumption, and that the food systems are still highly inefficient with large amounts of food wasted at every stage of the process. While it is true that yields can drop, especially in the early years of transition, yields tend to stabilize after a few years, and profits are often higher than in capitalistic farming systems. A lack of a clear definition makes it harder for researchers to verify claims of regenerative agriculture, a problem that is further complicated by the contextuality of regenerative agriculture: Regenerative methods need to be adjusted and evaluated based on the local, individual

context. Regenerative agriculture should be seen as a toolbox from which the right tools for each space are selected.

Holism and a stewardship mindset are common in regenerative agriculture but by no means prerequisite. While many regenerative farmers embrace holism and connect to the environment of their farm to work with nature rather than control nature, other practitioners choose regenerative methods for economic, pragmatic reasons. Nonetheless, the ethics surrounding humans and their environment are highly relevant. It is highly unethical to exploit nature and the living space of future generations to meet the needs of the current generation, and especially to further the gains of powerful stakeholders.

Perception of regenerative methods varies widely, and the narrative is influenced significantly by powerful stakeholders from the fossil-fuel, agrochemical, and other related industries that benefit from the status quo. While proponents promise huge advantages with little downside, valid concerns include the large investment of time and money necessary during the transition period. Other than a temporary reduction in yield, criticism remains largely ideological or based in fear rather than fact. There are many social and political barriers blocking the implementation of regenerative agricultural practices across the globe, such as lack of knowledge among farmers, active lobby work by those profiting from the capitalistic agricultural system, and slow-moving policy processes.

A literary analysis and interviews with stakeholders indicate that while regenerative agriculture does have the ability to feed a growing population of humanity without borrowing from future generations, a better question would be *how* regenerative agriculture can do so.

Chapter One: Introduction

Food systems are responsible for a third of our greenhouse-gas emissions globally with agriculture causing the bulk of those emissions (Crippa et al., 2021). In addition, cattle pasture and agriculture are a main driver of deforestation, especially in the global South (Chemnitz et al., 2022). More than half of the habitable land on Earth is used for agriculture (Ellis et al., 2010).

With most of the world already feeling the consequences of climate change (Callaghan et al., 2021), reducing emissions and preserving biodiversity have become essential to protecting humanity's future. Ironically, while a main driver of climate change, agriculture itself is projected to be severely impacted by climate change (Malhi et al., 2021). The rising temperature and altered precipitation associated with anthropogenic climate change create not only tougher growing conditions for farmers but also more horizons for pest infestations. Pesticide use is already threatening biodiversity, water and soil quality, as well as human health across the globe (Chemnitz et al., 2022). The global use of pesticides is as high as ever despite the known threat to health and environment (Chemnitz et al., 2022) .

Regenerative agriculture is considered as a solution to the growing problem at the intersection of agriculture and climate change, some even going as far as claiming that regenerative agricultural methods can reverse climate change impacts (Kastner, 2016) . Regenerative agricultural practices include reduced tilling, water management and retention practices, keeping the soil covered, pasture and crop rotation, as well as integrating life stock with crop cultivation (Malhi et al., 2021).

Perception of those methods differs widely with some studies pointing to little interest among conventional farmers (Alexanderson et al., 2023) and other even seeing the term used for green-washing (Wilson et al., 2024). Others see regenerative farming as the only ethical way to feed humanity (Seymour & Connelly, 2023), some studies even going as far as concluding that there is a link between human health and regenerative agricultural practices (Ramkumar et al., 2024). In a speech at the Center for Global Justice in San Miguel de Allende, Mexico, Rachel Kastner (2016) called regenerative agriculture a "game-changing solution for global climate change" and claimed its "potential to reverse climate change by drawing billions of tons of carbon out of the atmosphere, and locking it down to the soil, where it came from, where it belongs."

Proponents of regenerative agriculture promise huge advantages with little downside. Valid concerns include large investment of time and money necessary during the transition period (Petry et al., 2023), but other than that remain largely ideological or based in fear rather than fact. Studies found fewer pests on regenerative farms, and higher profits even if some did find lower yields (LaCanne & Lundgren, 2018).

Nonetheless, there are many social and political barriers blocking the implementation of regenerative agricultural practices across the globe, such as lack of knowledge among farmers, active lobby work by those profiting from the currently predominant (capitalistic) agricultural system, and slow-moving policy processes.

This work aims to provide an overview of the benefits and barriers of regenerative agricultural on the global food systems and the environment, as well as to show the role of stakeholders on their implementation. I aim to answer the following questions:

1. **Can regenerative agriculture feed the growing population on Earth without borrowing from future generations?**
2. **What are its benefits and barriers compared to capitalistic agriculture?**
3. **What obstacles stand in the way of transition from capitalistic agriculture to regenerative practices?**

To do so, I will first explore the connection between agriculture and the environment, give an overview of the practices and processes involved in growing food, and explain how regenerative agricultural practices influence this dynamic. I will then evaluate the perception of agriculture and regenerative agriculture by different stakeholders and the general public. The findings from a literary analysis will be combined with the knowledge acquired in semi-structured interviews with different agricultural practitioners. Finally, I will discuss the findings as they relate to the research questions and provide suggestions for communicating and implementing regenerative agricultural methods in our current sociopolitical context.

Chapter Two: Background

Humans first transitioned from mere foraging in Nomadic tribes to growing crops about 10,000 to 12,000 years ago (Naithani, 2021) but it was not until the so-called Green Revolution of the second half of the 20th century that high-yield varieties were planted, fertilizers and pesticides were applied, irrigation during dry summer months became commonplace, and the use of tractors and combine harvesters replaced animal power and human labor (Pimentel, 1996). Agriculture has increasingly gotten more intensive over the last decades (Fuglie et al., 2024).

With the human population expected to reach almost 10 billion by 2050 (United Nations, n.d.), food demand will continue to grow. Human population size is not thought to peak until the mid-2080s (at 10.4 billion) according to the United Nations. Commodity-driven deforestation, so the permanent (or long-term) conversion of forests to other land uses such as agriculture remains one of the key drivers of forest loss (Ritchie & Roser, 2023). Thus, feeding the growing population remains a key talking point in the conversation around agriculture. In 2019, the United Nations called for urgent action to feed the growing population in a healthy, equitable and sustainable way.

For clarity, the currently predominant intensive form of agriculture will be called capitalistic agriculture, as the main driver is profit (Gliessman, 2007, Gordon et al., 2022). Capitalistic agriculture is inherently productivist and, as defined by Lowe et al. (1993, as cited in Gordon et al., 2022, p.809), committed "to an intensive, industrially driven and expansionist agriculture with state support based primarily on output and increased productivity." This mode of agriculture is often termed as conventional due to the mere predominance but the use of agrochemicals like synthetic fertilizers and pesticides is a postwar phenomenon (Zimmer, 2000, as cited in Gordon et al., 2022). Compared to the time humans have cultivated food, these conventional practices are a rather new phenomenon (Gordon et al., 2022).

Table 1: An overview of terms used to describe agriculture. Various terms used for regenerative agriculture will be discussed in detail in section 2.5.

Term	Description
Conventional agriculture	Currently predominant system of agriculture with pesticide and fertilizer input, tilling, and a focus on yields.
Capitalistic agriculture	Term used in this paper to describe conventional agriculture to emphasize the focus on profits.
Organic (capitalistic) agriculture	A form of capitalistic agriculture with some limitations on the use of pesticides, fertilizers, and practices.
Sustainable agriculture	Agriculture that seeks to sustain the current state of the farm.
Regenerative agriculture	Agriculture that seeks to regenerate the farm.

Growing more food under the current capitalistic agricultural model, i.e. an agricultural model that seeks to maximize profits, would require increasing amounts of land and agrochemicals to feed an increasing number of people. According to an article in the Guardian (Harvey, 2019), a "wealth of scientific evidence [...] shows that continuing down the same path would risk runaway climate change, the extinction of species vital to human life, pollution of our water and air, and the death of our soils."

The following will evaluate the history of agricultural practices, the interplay of agriculture, the environment, and sociopolitical systems, as well as introduce the alternative model of regenerative agricultural practices.

2.1 The past and present of agriculture

While the Neolithic Revolution, i.e. the shift from hunter-gatherer tribes to settled farmers is often described as "one of the most rapid and significant transitions in human history," the transition period likely lasted thousands of years (University of Cambridge, 2012). Before the shift toward agricultural settlements, humans lived a nomadic lifestyle sustained by hunting and gathering. For 95 percent of human history, humans were hunters and gatherers (Naithani, 2021). For the past 10,000 to 12,000 years of human history, we have been at least growing some of our own food, cultivated crops, and lived a mostly settled lifestyle.

The drive to settle down is still being debated but a common conception is that the climate changed after the last ice age (ended about 13,000 years ago). Changing rainfall and droughts made it harder to sustain the population with hunting and gathering, which might have pushed the tribes to settle and grow food near water sources (Naithani, 2021).

Agriculture was mostly driven by human and animal labor until the Green Revolution in the 1950s and 1960s when farmers took advantage of modern machinery, synthetic fertilizers, and highly bred crop varieties (Breier et al., 2023). While this resulted in increased yields, the impact on our environment was immense. Soil health, water quality, emissions, and a loss of biodiversity were neglected while focusing on meeting the increasing demand for food (Breier et al., 2023).

The human population grew from three billion to almost eight billion between 1961 and 2020 (Fuglie et al., 2024). Crop yields first increased rapidly only in North America and Western Europe while remaining stagnant in developing countries until the establishment of the Consultative Group for International Agricultural Research (CGIAR) which created research centers in developing nations (Fuglie et al., 2024).

Over the past 25 years especially, the diet of most humans shifted away from staple foods like grains and root crops and instead relied more heavily on animal products. This in turn drove a shift in cereal production from directly feeding humans to feeding livestock (Fuglie et al., 2024). Since the mid-1990s, a lot of the grain production was shifted to genetically modified crop varieties, typically those with pesticide resistance and herbicide tolerance (Fuglie et al., 2024). While the proponents of genetically-modified crops often proclaim a reduction in pesticide and herbicide use with these crops, research shows a substantial increase in herbicide use that far outweighs the modest reduction in insecticides allowed by resistant crop varieties (Benbrook, 2012).

Since the Green Revolution, pesticide use and the use of synthetic fertilizers has increased significantly and remains on the rise (see Figure 2; Benbrook, 2012). Pesticides are agents applied to prevent or eliminate pest infestations (Freedman, 2018). It is a broad term that includes a wide range of products. In the agricultural context, herbicides, fungicides/bactericides, and insecticides are most common (see Figure 2). Pesticides are often used prophylactically, so without a present current infestation, sometimes even as coatings on every seed despite estimates that only one in ten fields would be infested without their use (Furlan et al., 2020). One issue of pesticides is their lack of specificity: Plants that were not harmful to the crop in question are affected alongside the pest the farmer wishes to eliminate (Koman et al., 2021). In addition to directly harming non-target species, pesticides can accumulate in organisms and move up the food chain to expose further non-target organisms (Freedman, 2018). Another issue is that these pesticides do not remain constrained to the fields where they are applied. Water flow after application and wind during application can carry these agents into nearby ecosystems, waterways, and even the groundwater (Koman et al., 2021).

Fertilizers are used to add nutrients to crops. While there are natural fertilization options, capitalistic agriculture commonly uses synthetic fertilizers with high concentrations of nitrogen, potassium, and phosphorus, the main plant nutrients (Lowenfels and Lewis, 2010). These compounds are, in and off themselves, not an issue, as the plants cannot distinguish between different sources of nutrients (Lowenfels and Lewis, 2010). The main issues with synthetic fertilizers are in their production process, in their overuse, and in their effect on the soil microbes (see section 2.2). Crops take up only about a third to half of the nutrients applied with the excess getting washed off as part of agricultural run-off. This runoff can cause eutrophication, an excess of nutrients, which can lead to low-oxygen conditions in waters and thus kill aquatic life (Tilman, 2002, as cited in Koman et al., 2021). Some further argue that synthetic fertilizers disrupt the way plants take up nutrients by affecting soil bacteria composition.

It is hard to deny the impact agriculture has on the planet. In addition to literally feeding the world, an estimated 4.5 billion people's livelihoods are directly connected to our food systems (United Nations, n.d.). By 2030, human population is expected to have reached 9 billion (Fuglie et al., 2024), and by mid-century, the UN expects there will be 9.7 million humans to feed (United Nations, n.d.). There are already more than 3 billion people worldwide who cannot afford to choose a healthy diet (United Nations, n.d.) further deepening the issue. At this point, food systems are already responsible for a third our our greenhouse-gas emissions (Crippa et al., 2021) and a major driver of deforestation (Chemnitz et al., 2022). Adding the negative impacts of agriculture on natural ecosystems and water quality, the question remains how we will meet a growing demand for food caused by a growing population without threatening the livability of Earth for future generations.

2.2 The effects of agriculture on the planet

Agricultural practices to meet the growing demand for food and the diets of especially the Global North have taken a toll on our planet: Agriculture occupies more than a third of Earth's land area, constitutes seventy percent of freshwater use, and causes roughly a quarter of greenhouse-gas emissions (Fuglie et al., 2024), a third of which are caused by land-use changes like deforestation (Crippa et al., 2021).

In recent years, the increasing demand for food has been met by expansion of agricultural land but also by intensification of existing operations (Yadav et al., 2023). As McLennon et al. (p. 4541) put it in a 2021 paper, the "rapid growth in food production through specialized operations such as monoculture cropping systems, so system where one single crop is grown over a large area, has aligned to satisfy increases in demand for food and fiber. However, its adverse impacts on natural resources pose huge challenges for the sustainability of food production." In developing countries and rural regions, the social issues are even direr because the farming communities in those areas tend to have fewer available resources (McLennon et al., 2021).

Humanity has reshaped the landscapes around it in the name of yields and profit (Gordon et al., 2023) by drawing unsustainably on "human, material and natural capital (Gordon et al., 2023, p. 1833)." To make matters worse, this expansive mode of agriculture continues to displace indigenous populations and ecosystems (Gordon et al., 2023). Gordon et al. (2023, p. 1833) see this expansion driven by "neoliberal economic story lines, which are staunchly committed to economic growth, leading to over-consumption and exploitation." In other words, humans have ignored the environmental and social impacts of agriculture while focusing on profit and yield.

Human agricultural activity is at least partially to blame for overstepping several planetary boundaries and contributing to all. In 2009, Rockström et al. suggested the concept of planetary boundaries as a "safe operating space for humanity (Steffen et al., 2015, p. 736)," and Steffen et al. (2015) later revised the concept. Two years later, Campbell et al. (2017) published a study that looked at the contribution of agriculture to these boundaries and found agriculture had not only contributed to most of them but been the major driver of the boundaries with increasing or already at high risk.

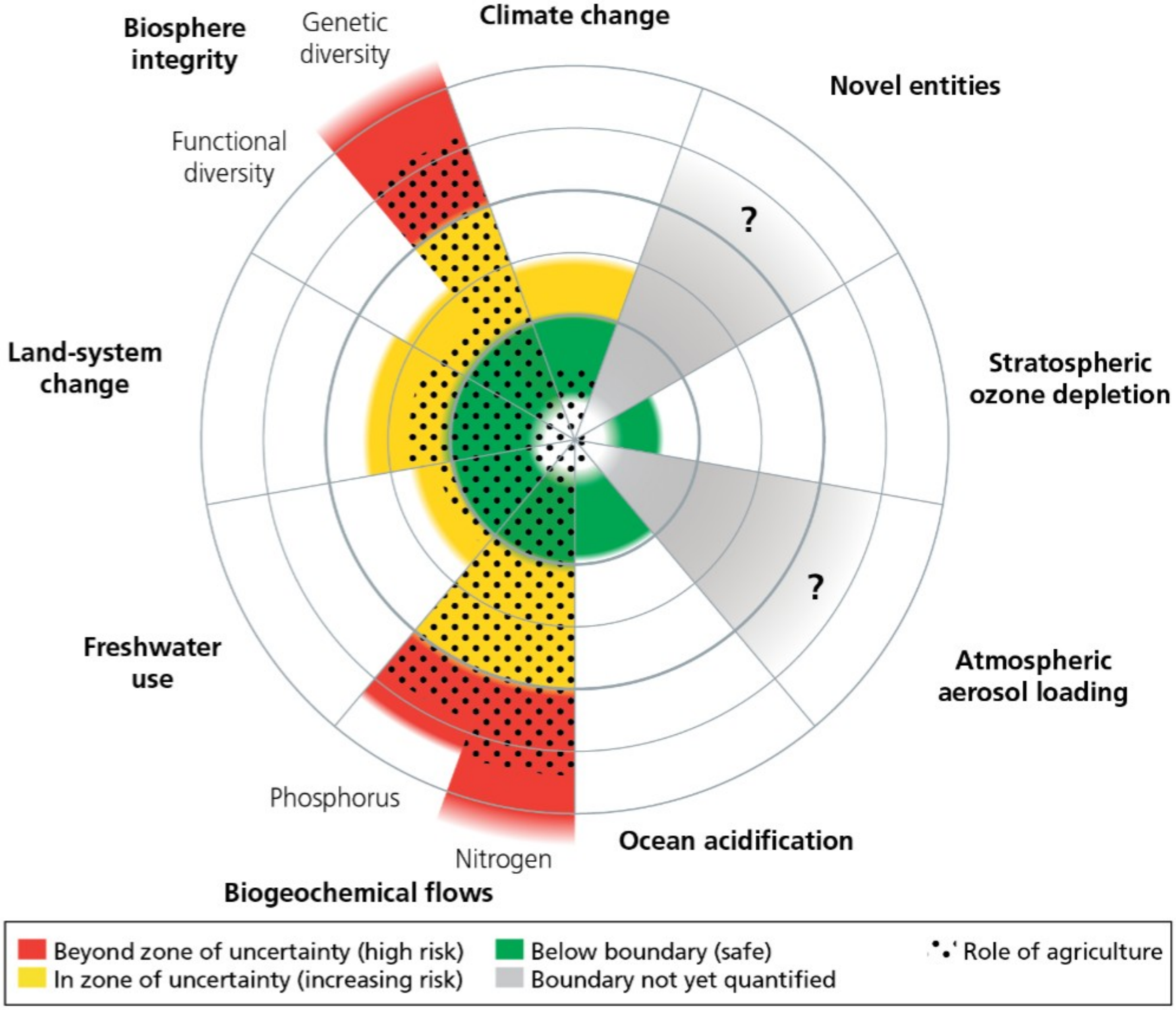

Figure 1: The status of the nine planetary boundaries with the role of agriculture overlaid (Campbell et al., 2017). Alt text in Appendix.

The effects of agriculture on the planet are many and varied. Habitat destruction, biodiversity loss, disturbances of the water and nutrient cycles, soil degradation, climate change, and social issues. Each of these will be discussed in more detail in the following subsections.

2.2.1 Habitat destruction and biodiversity loss

Most agricultural land is home to few species. Capitalistic agricultural fields are dominated by monocultures, so there is little diversity within the field. But even seen globally, agricultural fields are dominated by the same twelve species of grain crops, 23 species of vegetable crops, and about 35 species of fruit and nut crops (Altieri 1999, as cited in Koman et al., 2021). This means that the global food supply depends on the resilience of about seventy plant species and their ability to withstand wipe-outs by pests, diseases and extreme weather events (Koman et al., 2021).

Agriculture directly depends on biodiversity: 75 percent of globally important crops and 35 perrcent of our food relies on the pollination services of animals. Porto et al. (2020) estimates that these services provided by the ecosystem around fields are valued at 195-387 billion US dollars per year. Despite this reliance on biodiversity, agriculture is a significant threat to biodiversity. Even when considered, the economic value of ecosystem functions is often underestimated, as we know so little about the role of ecosystems and the ecological function of many species (Gorke, 2000).

Biodiversity is threatened in two ways by agriculture: by fragmenting or destroying biodiverse habitats to replace them with agricultural lands (Brawn, 2017) and by directly harming the organisms with farming practices such as the application of synthetic fertilizers and pesticides (Nicholson et al., 2024).

Agriculture is one of the main drivers of deforestation, as mentioned before. A total of six million hectares of forest is lost to deforestation each year, and 95 percent of that deforestation happens in the tropics (Ritchie, 2021) where some of the most diverse ecosystems can be found. There, agricultural land replaces biodiverse rain forests, savanna, and other vital ecosystems with more clearing expected in the future (Gibbs et al., 2010). As the tropics are home to 29 percent of the global vertebrate species and more than a fifth of those are at risk of extinction, protecting the tropical forests from destruction is paramount (Pillay et al., 2022). To make matters worse, habitat fragmentation makes it easier for invasive species to take over natural habitats, thus further threatening the remaining biodiversity (Campbell et al., 2017).

When reevaluating the planetary boundaries, Steffen et al. (2015) decided to change the evaluation criterion for land-system changes from cropland cover to remaining forest cover. Campbell et al. (2017) calculated that the current loss in forest cover represents 62 percent of the planetary boundary with agriculture responsible for most of this: 75 percent of the deforestation between 1990 and 2005 can be traced back to agriculture as the culprit, and the percentage climbs to eighty percent for the time period of 2000 through 2010. Over the last 300 years, between seven and eleven million square kilometers of forest were lost and converted to agricultural land—most of which (55%) replaced pristine forests rather than degraded forests (Foley et al., 2005, as cited in Campbell et al. 2017). The deforestation of tropical forests is seen as a leading factor in the destruction of biodiversity on Earth (Sodhi et al., 2010, as cited in Apriyani et al., 2021). Past trends imply that 48 percent of the ice-free surface of Earth will be covered by agricultural lands in 2050 (Campbell et al., 2017).

Forests are not only crucial for the global carbon cycles (see section 2.2.3 and 2.2.5) but also home to a wide variety of species. When these diverse forests are replaced by capitalistic agriculture dominated by mono-cultures and degraded soils, crucial habitat for wild species is lost to diversity deserts.

The threat of pesticides on biodiversity is more direct: one of the main issues with pesticides is their lack of specificity to the target organisms (Koman et al., 2021, Zahoor and Mushtaq, 2023). Pesticides not only make their way to nearby ecosystems and waterways (Yadav et al., 2023; Koman et al., 2021), they can also accumulate through the food web and affect even further organisms (Freedman, 2018). When pesticides mix in water systems, the combination can be even more detrimental and reach further ecosystems through the hydrological cycles (Freedman, 2018). Agricultural intensification leads to a contamination of broad areas around fields. This run-off has been linked to reductions in insect numbers which cascade through the food web impacting birds, bats, and amphibians who rely on the insects for food (Zahoor and Mushtaq, 2023).

There are various types of pesticides used in capitalistic agricultural systems depending on the type of pest in question. Herbicides are applied to keep competing plants from growing. Fungicides and bactericides are used to prevent fungal and bacterial infestations respectively. Insecticides are used to control insect pests, and rodenticides are used to control rodent populations around the fields and farms. In addition there are other, more specialized pesticides and plant-growth regulators, the latter of which are used to control germination and growth and ripening processes of the plants (VanDerZanden, 2018).

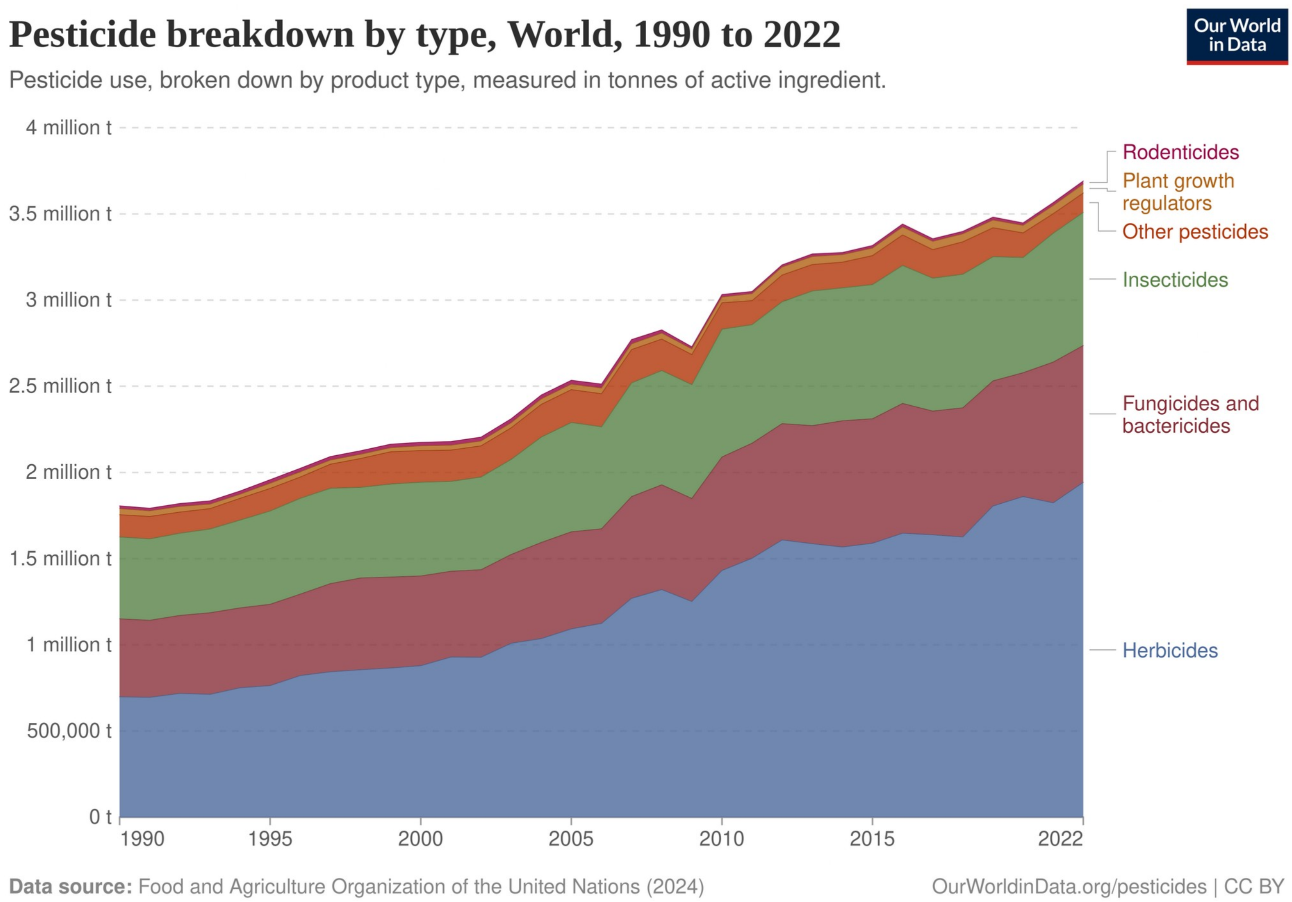

Figure 2: Pesticide breakdown by type between 1990 and 2022. Alt text in Appendix.

As established above, agrochemicals like pesticides and synthetic fertilizers are post-war phenomena despite their now almost universal prevalence. Since 1990, the world consumption of pesticides has more than doubled with now more than 3.5 million tons of pesticide applied each year (see Figure 2).

In addition to the effects on the field itself, pesticide use has severe impacts off the field. Insecticides like the high-impact neonicotinoids are often used prophylactically, so without a present infestation (Furlan et al., 2020). As Furlan explains in a documentary for Plan B, a production by the German public network ZDF, nine out of ten fields would never get infested (Gerhartz und Pecher, 2024). Furlan claims, the main reason for the over-application of pesticides is an unawareness of farmers of alternatives like integrated pest management (see section 2.5.3.6) and low-cost monitoring tools such as the indicator traps they have been developing for the past decades.

Pesticide use has been connected to detrimental health effects for people working on the fields or living nearby (Zahoor and Mushtaq, 2023; Campbell et al., 2017). For instance, there is a clear correlation between pesticide application and Parkinson's disease (Paul et al., 2023).

Both fertilizers and pesticides make their way from the field to adjacent ecosystems and waterways (see section 2.2.2), affecting not only the area of the field but organisms in other, sometimes far-off, ecosystems as well (Yadav et al., 2023). Pesticides have routinely been detected in 88 percent of streams and rivers (Covert et al., 2020) and inside the bodies of 90 percent of US residents (Chiu et al., 2018, as cited in Miller-Klugesherz and Sanderson, 2023). To make matters worse, rising temperatures and changing precipitation patterns associated with climate change will not only lead to crop losses and lost harvests but also increase the likelihood of flooding which in turn is expected to increase the run-off from agricultural fields into nearby water-based ecosystems (Zahoor and Mushtaq, 2023).

Synthetic fertilizers, too, affect the biodiversity of the soil. They disrupt the natural mechanisms of plant-bacteria and plant-fungi interactions, not only removing biodiversity in the soil community but also making plants dependent on these synthetic inputs (Yadav et al., 2023).

In simplifying the agricultural production systems, we have taken nature's ability to self-manage and self-heal, leading to less resilient ecosystems (Haggard and Mang, 2016; Provenca, 2008; both as cited in Gordon et al., 2022). Agriculture depends on the pollination, pest control, soil structure, hydrological, and fertility regulating services of many species (Apriyani et al., 2021). These services are directly associated with biodiversity (Apriyani et al., 2021).

2.2.2 Water-cycle disturbance

Crop production consumes immense amounts of water, both for supplying the plants with the water necessary for transpiration and via evaporation from soils and irrigation systems. Agriculture accounts for about 70 percent of global freshwater withdrawals (Campbell et al., 2017). In addition, agriculture is one of the major sources of water pollution with fertilizers, pesticides, and other chemicals leaching into not only nearby rivers and lakes but also into the groundwater, a critical source of drinking water for many, and even all the way into the ocean (Zahoor and Mushtaq, 2023).

The amount of water needed by agriculture varies with the production method and location. Growing livestock requires even more water than crop production, as both the crop grown for feed and the animals themselves need water. As human consumption shifts to more meat, more water will be required. Finally, an increase in bio-fuel production will put even more pressure on water resources by requiring more agriculture to grow the crops (Campbell et al., 2017).

The World Water Assessment Programme found in 2012 (as cited in Campbell et al., 2017) that the amount of water needed per unit of food has almost halved, so growing crops has become a lot more efficient in water use. Nonetheless, there is still huge potential for more efficient water use (Campbell et al., 2017). Water use can be improved in various ways by reforming policy and investing in infrastructure: conveyance efficiency, so the efficiency of transporting water from the source to the farm, distribution efficiency, so transporting water from the farm to the field, and application efficiency, so getting water to the crops themselves, can all be improved upon for increased efficiency and lowered consumption (Campbell et al., 2017). As Campbell et al. (2017, p. 4) put it: "Agriculture is, and will continue to be, the largest consumer of freshwater globally. In addition to the absolute amount, ground-water depletion in some regions is also a major concern."

Irrigation systems are often crucial to agriculture, especially when growing crops not suitable for the selected region. However, they often lack efficiency which leads to over-extraction of water from rivers and aquifers which in turn contaminates the ground water with elevated levels of salt (Zahoor and Mushtaq, 2023).

The sheer amount of water use of agriculture is not the only way agriculture affects the water cycle: In addition to extracting water for agricultural needs, agriculture has a major impact on water quality and conditions. Various contaminants from excess nitrogen, phosphorus, and pesticides to soil particles leave the fields and enter the water cycle. The effect of excess nutrients which can lead to algal blooms and low-oxygen conditions (Koman et al., 2021, Zahoor and Mushtaq, 2023) will be discussed in the following section. The WHO set the threshold for nitrates, one of the major nutrients in fertilizers, to 50 ppm, but Europe has the highest percentage of regions which surpass this threshold, followed by Asia and America (Zahoor and Mushtaq, 2023). This contamination of drinking water not only affects humans but also biodiversity. Animals drink the water and the pollutant makes it up the food chain. Entire ecosystems suffocate in the low-oxygen dead zones left by algal blooms (Zahoor and Mushtaq, 2023).

In addition to direct inputs, agriculture emits a large amount of greenhouse gases, contributing to the climate crisis and affecting the conditions of water-based ecosystems both on land and in the ocean (Campbell et al., 2017, Zahoor and Mushtaq, 2023). This will be discussed in more detail in 2.2.5.

2.2.3 Nutrient-cycle disturbances

Plants need nutrients to grow. Each nutrient plays a different role in the plant growth cycle. Nitrogen (N), potassium (P), and phosphorus (K) are three macro-nutrients essential for plant growth that are vigorously applied to capitalistic agricultural systems. Since 1961, global consumption of such fertilizers has grown from 50 million tonnes in 1961 to more than 200 million tonnes in 2019 (see Figure 3).

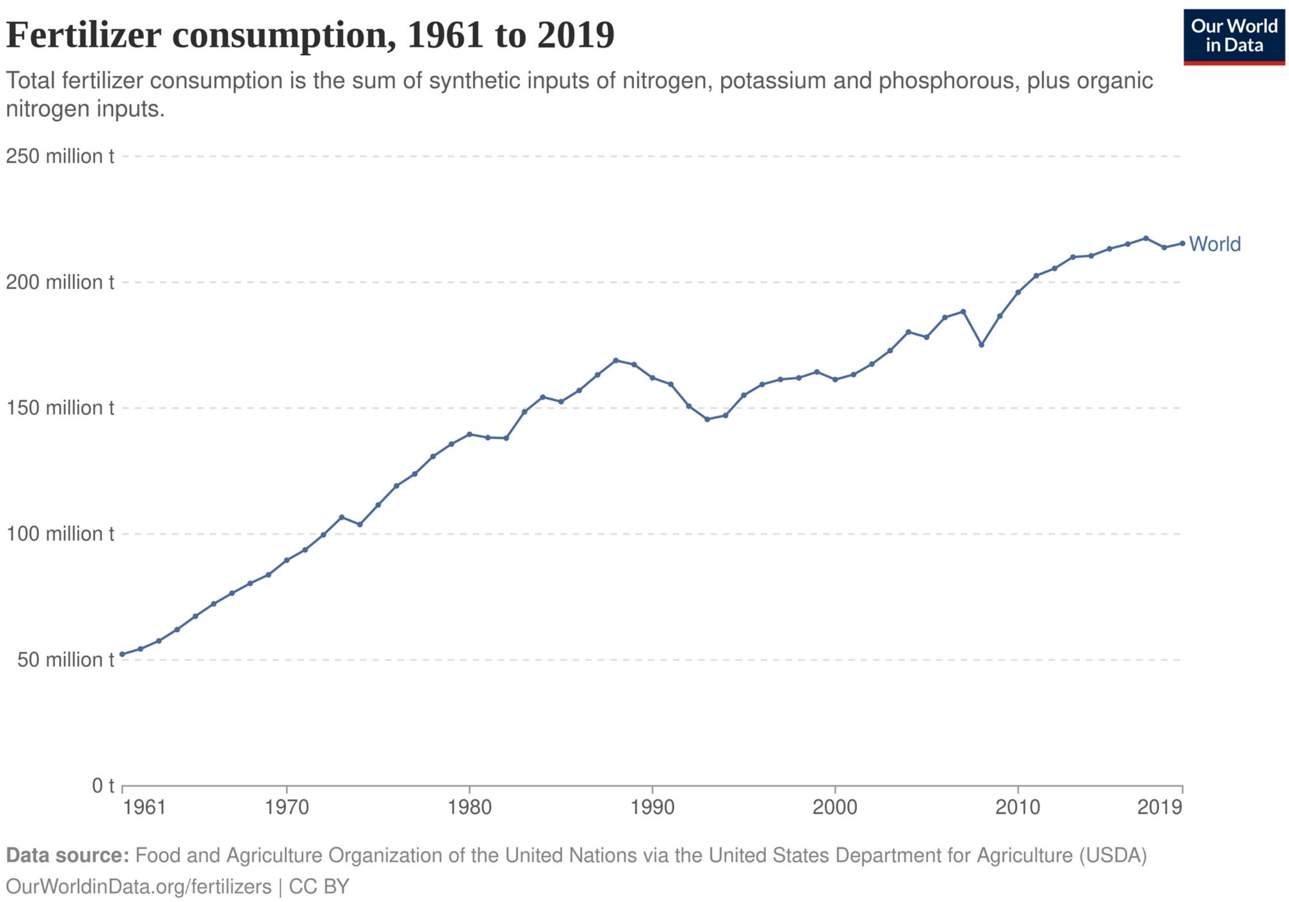

Figure 3: Fertilizer consumption between 1961 and 2019. Alt text in Appendix.

As Figure 1 shows, both the phosphorus cycle and the nitrogen cycle are at high risk of exceeding the planetary boundary of bio-geo-chemical flows with agriculture playing a major role in both.

Nitrogen is one of the essential macro-nutrients for plant growth. If a plant cannot get enough nitrogen, plant growth is limited (Campbell et al., 2017). Human activity has impacted the global nitrogen cycle significantly through increased fossil-fuel use, agriculture and industry demand for the nutrient (Swaney et al., 2012, as cited in Campbell et al., 2017). Rockström et al. (2009, as cited in Campbell et al., 2017) found that the anthropogenic, so human-caused, sources of nitrogen now out-compete all natural terrestrial processes combined.

Several studies have shown that the use of nitrogen in crops is rather inefficient: only about half of the nitrogen applied is incorporated into plant biomass (Liu et al., 2010; Bodirsky et al., 2012). The rest is lost through leaching (16%), soil erosion (15%), and gaseous emissions (14%) instead (Liu et al., 2010). When leached, the nitrogen is dissolved into water and carried away in the liquid. When eroded, the nitrogen is carried away with the solid soil particles, and when emitted as gas, the nitrogen escapes through the air into the atmosphere.

The excess of nitrogen affects water and soil quality, contributes directly to biodiversity loss (Zahoor & Mushtaq, 2023), and changes the composition of our troposphere, the lowest layer in our atmosphere (Bodirsky et al., 2012.; Campbell et al., 2017). When excess nitrogen reaches nearby rivers, lakes, or the coastal waters of the ocean, it can cause algal blooms:

Eutrophication increases the phytoplankton biomass, which in turn reduces the transparency of the water column (Scheffer et al., 1993, as cited in Ouaissa et al., 2023) and thus the availability of light for oxygen production. The added biomass also lowers the amount of oxygen dissolved in the water when it decomposes. Washed-off sediment from the field can lead to even more clouding and worsen this effect (Zahoor and Mushtaq, 2023). The rotting of decayed bacteria and plant material produces carbon dioxide which leads to a local effect of ocean acidification (Ekstrom et al., 2015, as cited in Campbell et al., 2017), as will be discussed more in 2.2.4.

Algal blooms have been observed in many regions by now. Coastal ecosystems around the world have been affected (Ouaissa et al., 2023) A well-studied site is the Mar Menor coastal lagoon in the Western Mediterranean Sea which experienced an intensive algal bloom of cyanobacteria in 2015 (Ouaissa et al., 2023). The area has received large amounts of nitrate pollution from agriculture in the region, and was even declared a "sensitive eutrophication area" in 2001 (Ouaissa et al., 2023, p. 6). The first catastrophic bloom event (a "so-called first dystrophic crisis") was caused by a heat wave which added a stressor to the high nitrogen load. Ouaissa et al. (2023, p. 1) describe it as an "almost total collapse of [non-microscopic plant] communities, which previously played a key role in maintaining the ecological balance."

Similarly, the Sea of Marama near Istanbul, was covered in "a thick, brown, bubbly foam dubbed 'sea snot'" in 2021 which threatened marine life (France Press, 2021). A biology professor from the Istanbul university, Muharrem Balci, explained that it was a combination of "a sort of nutrient overload for the algae, which feast on warm weather and water pollution," a phenomenon they have seen worsen in the 40 years prior. In this case, local intensive industry is seen as the likely source for eutrophication (France Press, 2021).

Even from a mere economic standpoint, preventing the destruction caused by excess nitrogen is vital: Sutton et al. (2011, as cited in Campbell et al., 2017) estimated that the environmental cost of this nitrogen excess caused by capitalistic agriculture outweighs the entire economic benefit of nitrogen used at all.

The IUCN Blue Carbon initiative has explained that coastal vegetation can play a major role in preventing run-off from harming the ocean (Campbell et al., 2017). Seaweed farming and restoration of mangrove forests are listed as a way to keep our impact on Earth within the planetary boundaries discussed above. Further up the line, the farmers themselves can also help lower the impact of their practices: learning when, where, and how much nitrogen needs to be applied would lower the input directly; buffer zones could stop the run-off from the field; crop rotation with nitrogen-fixing species could further lower the required input (Robertson and Vitousek, 2009, as cited in Campbell et al., 2017).

Phosphate is another major macro-nutrient applied as fertilizer in agricultural systems. Most agricultural production is dependent on some form of phosphate, be it from synthetic fertilizers or from manures (Cordell and White, 2013). Mining rock phosphate to produce phosphate fertilizers has changed the global phosphate cycle and accelerated it to two to three times the background rate (Smil, 2000, as cited in Campbell et al., 2017). According to Smil (2000, as cited in Campbell et al., 2017), agriculture is culpable of 90 percent of the global phosphate production, almost all of which is added to terrestrial soils. This leads to another eutrophication, i.e. over-saturation with a nutrient, in water-based ecosystems (Diaz and Rosenberg, 2008, as cited in Campbell et al., 2017). Again, reduction of phosphate input would be the ideal solution. However, even shifting from mined phosphates to manures, human excreta, and food residues would reduce the harm done by phosphate fertilizers. Here, too, buffer zones around the fields could reduce run-off (Campbell et al., 2017).

2.2.4 Climate change and greenhouse gases

Agricultural systems, both on the field and in the related food and industrial chains, emit huge amounts of greenhouse gases, even when excluding the effects of land-use change (Smith et al., 2014, as cited in Campbell et al., 2017).

Capitalistic agriculture is a large contributor to carbon-dioxide emissions, nitrogen-dioxide emissions, atmospheric aerosols (Campbell et al., 2017), and methane emissions (Smith et al., 2021). All combined, agricultural systems are one of the main contributors to greenhouse-gas emissions (Campbell et al., 2017). Globally, agriculture is responsible for about 11 percent of total anthropogenic greenhouse-gas emissions when excluding land-use change (Smith et al., 2014). Developing countries produce the majority of these agriculture-related emissions and there the impact is expected to increase (Smith et al., 2014; Campbell et al., 2017). In 2015, an estimated that 35 percent of the greenhouse-gas emissions of developing countries and 12 percent of greenhouse-gas emissions in developed countries could be led back to agricultural systems (Campbell et al., 2017). If the entire food system is included, from production to consumption, these values increase further to an average of about 19-29 percent globally (Vermeulen et al., 2012). The practice of tilling, so cutting and turning the top layers of soil, not only leads to soil erosion but also releases significant amounts of carbon dioxide to the atmosphere (Yadav et al., 2023).

The ocean buffers a significant amount of greenhouse-gas emissions. About a quarter of carbon dioxide emissions since 1800 have been absorbed by the ocean where carbon dioxide forms carbonic acid and leads to ocean acidification. Ocean acidity has already increased by 34 percent since 1800, and Hönisch et al., (2012, as cited in Campbell et al., 2017) estimate a further increase of 150 percent in ocean-surface acidity by 2100. Campbell et al. (2017) point out that this is the fastest rate of chemical change for millions of years. As a major source of carbon-dioxide emissions, agricultural systems directly contribute to ocean acidification. In addition, the run-off discussed in the previous sections can lead to more local acidification of seas and oceans (Campbell et al., 2017).

Methane is a second potent greenhouse gas, although the equivalent carbon-dioxide-emission calculation has led to some disagreement in the scientific community. While some use the GWP100 metric, the Global Warming Potential calculated over a 100-year period, others use the more recent GWP* metric. Proponents of the latter argue that GWP100 misrepresents the temporalities of warming potential of different greenhouse gases (Allen et al., 2018). They argue the GWP* metric better captures how certain greenhouse gases flux over the time frames relevant to anthropogenic warming (Cusworth et al., 2022). Independent of the metric used, agriculture is the largest source of anthropogenic methane. In 2017, agriculture emitted a total of 145 Tg of methane per year. The main sources are the fermentation inside ruminant stomachs, manure management, rice cultivation, and residue burning (Smith et al., 2021).

A diverse community of microbes called archaea live inside ruminant stomachs and play an integral role in the digestion of these animals. A byproduct of this enteric fermentation is methane. How much methane is produced during digestion of ruminants depends on the feed but also on the breed of ruminant (Smith et al., 2021). Enteric fermentation is source of about a third of anthropogenic methane emissions, of which cattle makes up 77 percent (Gerber et al., 2013).

Methane production from animal wastes is similar as it is an anaerobic microbial process. Depending on how the manure is stored, more or less methane escapes between excretion and absorbance by the soil in the field. For instance, wet manure emits more methane than dried manure. Other factors include the storage method and duration, the temperature during storage and application, and the chemical composition of the specific manure (Smith et al., 2021).

Methane escaping from rice fields, so called paddies, is another example of an anaerobic process where microbes produce methane as a byproduct of digestion. Tropical Asia is source of 90 percent of rice-growing emissions (Smith et al., 2021). South-East Asia exported almost 519 million tonnes of rice produced in its region between 2011 and 2020. In the same period, the region contributed 14.94 Pg (14.94 billion tonnes) of carbon, which corresponds to about four-fifth of the total terrestrial carbon emissions from all of Asia (Tan and Kuebbing, 2023).

Methane is produced in paddies when the soils are flooded. Flooding creates anaerobic conditions which is where the methane-generating microbes thrive. While there are some methane-digesting microbes that counter some of these emissions, there is still a large net emission from these paddies on balance (Smith et al., 2021).

And finally, residue burning releases methane when the crop is burnt. Methane and other aerosols are added to the atmosphere due to incomplete combustion. The reduction potential is low, though, as total emissions are low when compared to the other agricultural sources of methane emissions, responsible for just 1 Tg (1 million tonnes) of methane per year, which means the total reduction potential would make up only about 10 percent of the total reduction potential in rice paddies (Smith et al., 2021).

When looking at total methane emissions created by humanity, Smith et al. (2021), points out that agricultural processes and the waste sector are responsible for the majority.

To add to these emissions, agricultural land has a much lower sink capacity than the mineral soils found under forests and grasslands. The sink capacity is even lower in fields where nitrogen fertilizers are applied. As we'll see in the next section this is, again, linked to microbes (Smith et al., 2021). When fields are flooded, they turn from a net sink to a net source of methane due to the anaerobic microbes thriving in these low-oxygen conditions (Smith et al., 2021).

Even in capitalistic agricultural systems, some mitigation practices are applied more frequently now than in the past: mid-season drainage of the flooded fields along with a change in fertilizer and tilling practices, such as applying organic matter during the dry period rather than the flooded period or fermenting the organic matter in air before applying, can significantly lower methane emissions, as Smith et al., (2021) point out. They caution, however, that some of the effect might be offset by a higher nitrous-oxide emission.

A third greenhouse gas influenced greatly by agricultural systems are nitrous oxides, a known ozone-depleting substance and one of the main greenhouse gasses (Ravishankara et al., 2009, as cited in Campbell et al., 2017). Most ozone depletion to date can be lead back to chloroflurocarbons which were used in manufactured refrigerants, propellants, solvents, and other chemical agents until they were phased out globally after the *Montreal Protocol on Substances that Deplete the Ozone Layer,* adopted in September of 1987, one of few global treaties with universal ratification (UN Environment

Programme, 2018). The Protocol regulated the production and use of almost a hundred such synthetic chemicals. The fact that these substances have been banned for such a long time and still are responsible for the vast majority of ozone depletion to date shows how long-lasting the effects of greenhouse gases can be—and how effective mitigation methods. The ozone layer is projected to recover by 2050 instead of a tenfold depletion without the ban (UN Environment Programme, 2018).

Since the ban of the widespread production and use of chloroflurocarbons, they have lost in significance as ozone-depleting substances. Nitrous oxides are expected to grow in importance, as they are now "the single most important ozone-depleting emission and [are] expected to remain the largest throughout the 21^{st} century (Ravinshankara et al., 2009, p. 123, as cited in Campbell et al., 2017)."

66 to 90 percent of global human-emitted nitrous oxide stems from agricultural processes, most of which is associated with nitrogen fertilizers and manure applied to soils. These values are expected to grow by 35 to 60 percent by 2030 due to an increase in fertilizer and manure use (Smith et al., 2008, as cited in Campbell et al., 2017). The most effective way to lower these emissions is by reducing fertilizer use and manure application (Ravinshankara et al., 2009, as cited in Campbell et al., 2017).

For all of these substances, solutions to mitigate or reduce emissions exist, and are commonly applied in regenerative agriculture, as will be discussed in sections 2.5.3 and 3.1.2. As will be detailed in the following section, the practice of tilling the soil is a further significant source of carbon dioxide emissions in agriculture.

2.2.5 Soil degradation

"The nation that destroys its soil destroys itself," Franklin D. Roosevelt, US president from 1933 to 1945 once said in a letter (Roosevelt, 1937). Others have described soil as the "fragile, living skin of the Earth" but despite its importance, soil health has been neglected as agriculture expanded over the past decades (Rhodes, 2017, p. 80).

Soil degradation has already become a global issue with about a third of our soil severely degraded. The speed of further degradation is threatening not only the health of the planet but also the civilizations which depend on it (Whitmee et al., 2015).

The diverse community of organisms in and around soil is integral for the formation and maintenance of healthy soil (Rhodes, 2012): Larger organisms like worms, centipedes, or beetles mix the soil to allow air and water flow. Plants grow roots through the soil, creating more channels. Some roots penetrate deeply and draw nutrients and water to the surface. Organisms of all sizes add nutrients with their excrement but also when they die and get absorbed. Microorganisms facilitate chemical exchanges between the different participants in the soil food web, but also act as a reserve for nutrients.

This diverse community is being threatened by the methods common in capitalistic agriculture: fertilizer and pesticide use, as well as tilling, so turning and mixing of the top layer of soil. The interplay of agriculture and soil health will be explained in detail later in this section. To better understand the concept, an overview of soil ecosystems and the organisms involved in soils will be provided first.

2.2.5.1 A quick overview of soil ecosystems

Soils are made up of the organisms that live in them in addition to their abiotic environment. Soil is made up of minerals, organic matter (called humus in the soil context), water and air (Rhodes, 2012; Lowenfels & Lewis, 2010, p. 29-31). Technically, soil is "loose, unconsolidated, mineral and organic matter in the upper layer of Earth's crust (Lowenfels & Lewis, 2010, p. 28)." The solid parts of soil are the product of both weathering and decomposition (Lowenfels & Lewis, 2010, p. 29-31; Koman et al. 2021).

Soils are made up of layers, also called horizons, with different texture, structure, composition, and characteristics (Rhodes, 2012). In the agricultural context, the top-most layers are relevant: the surface layer or 0 horizon is made up of humus and partially decomposed plant debris while the topsoil, called the A horizon, is a mixture of sand, silt, clay, water and air (Koman et al., 2021). Below are a leaching zone, subsoil, parent material, and then finally bedrock (Koman et al., 2021).

Sand, silt, and clay differ in their size with sand being the largest and clay being the smallest (Koman et al., 2021; Lowenfels & Lewis, 2010, p. 34-36). Good agricultural and gardening soil is made up of about thirty to fifty percent sand, thirty to fifty percent silt, twenty to thirty percent clay, and three to ten percent organic matter (Lowenfels & Lewis, 2010, p. 36; Koman et al. 2021).

Between the solid soil particles are differently sized pores where water and air take up about equal portions in good soil (Lowenfels & Lewis, 2010, p. 32). In larger pores, gravitation pulls water through quickly, pushing out stale air, and pulling in fresh air (Lowenfels & Lewis, 2010, p. 32). Smaller pores can hold water inside due to capillary action, which means the water stays in the soil where plants can take it up (Lowenfels & Lewis, 2010, p. 32). In addition, a very thin film of water stays behind on soil particles; this water is not available for plants but important for microbial life (Lowenfels & Lewis, 2010, p. 32). Roots in the soil act as sponges and take up water (Lowenfels & Lewis, 2010, p. 32). In total, gases and liquids make up about a quarter each of the soil content (Koman et al., 2021). Most of the water eventually evaporates from the soil or is transpired by the plants (Rhodes, 2012).

The chemical properties of soil depend mostly on the pH level which affects the composition, abundance, and activity of micro-organisms in the soil (Koman et al., 2021) but also on the structures created by soil life (Lowenfels & Lewis, 2010, p. 23). Before I give an overview of the organisms that inhabit the ecosystem soil, an understanding of nutrients and root exudates is prerequisite:

A large part of the energy plants recover from the sun in photosynthesis is used to produce so-called root exudates, a mixture of carbohydrates (e.g. sugars) and proteins that attract beneficial bacteria, archaea, and fungi (Lowenfels & Lewis, 2010, p. 20-21). These signals are a form of communication where the plants signals what nutrients are required and the microbes respond and provide what is needed.

The primary nutrients for plants are nitrogen, phosphorus, and potassium (Koman et al., 2021). Further nutrients are important in differing amounts including secondary nutrients like calcium and sulfur and micro-nutrients like copper, iron and zinc (Koman et al., 2021). Different organisms in the soil food web make these nutrients available to plants:

Fungi trade water and nutrients, especially nitrogen, for root exudates, but also release them when they decompose (Lowenfels & Lewis, 2010, p. 66). In addition, some fungi can catch nematodes (see below; Lowenfels & Lewis, 2010, p. 67) in the shields they form around roots (Lowenfels & Lewis, 2010, p. 24). They also form symbiotic relationships with algae as lichen which break rocks down chemically and thus help in weathering (Lowenfels & Lewis, 2010, p. 68). Mycorrhizal fungi are important in making phosphorus, copper, calcium, and other nutrients available to plants (Lowenfels & Lewis, 2010, p. 69). Another form of fungi, endophyte fungi, live in plant tissues and offer various benefits to the host plant (Lowenfels & Lewis, 2010, p. 71ff.), such as producing toxins that kill aphids and other sucking pests, influencing seed germination, or inducing the plant to produce disease-preventing compounds. They are also essential first composers (Lowenfels & Lewis, 2010, p. 72). Endophyte fungi have been found in essentially all plants (Lowenfels & Lewis, 2010, p. 71) and mycorrhizal fungi are associated with 95 percent of all plant root systems (Rhodes, 2012).

Bacteria and archaea are major groups of decomposing organisms which decompose plant and animal matter and store it in their body. Alongside fungi (see below) are the primary decomposers. In the root tissues of legumes and other nitrogen-fixing plants, certain bacteria species take up nitrogen from the atmosphere and turn it into plant-available forms (Lowenfels & Lewis, 2010, p. 48). In addition, archaea form relationships with protozoans (see next paragraph) inside ruminant digestive system where the protozoa break cellulose down into hydrogen which then gets turned into methane and energy by the archaea (Lowenfels & Lewis, 2010, p. 60).

Protozoa, the third group of single-celled microbes, feed on bacteria and sometimes nematodes, and compete with nematodes for resources (Lowenfels & Lewis, 2010, p. 83). They play a vital role in mineralization of nutrients, and about 80 percent of plant nitrogen is supplied by protozoan waste (Lowenfels & Lewis, 2010, p. 84). All these microbes take up nutrients from their surroundings and/or food and store them in their bodies. These nutrients are then released as excrement or when the organism dies or gets eaten.

Some soils can be extremely diverse with up to a million species of microbes in a single gram but also very abundant with estimates of a billion organisms in a single teaspoon of soil (Rhodes, 2012). In a healthy soil ecosystem, no group can get too strong, as a balance is maintained (Lowenfels & Lewis, 2010, p. 24).

Nematodes, blind round-worms, feed on bacteria and fungi, and are major secondary consumers (Lowenfels & Lewis, 2010, p. 85), They need less nitrogen for their own processes than protozoa and can release more nitrogen to the plant for this reason (Lowenfels & Lewis, 2010, p. 87).

Arthropods, a diverse group of animals with chitin shells, segmented bodies, and jointed legs including, among many others, the spiders, centipedes, and insects, shred matter into smaller pieces (Lowenfels & Lewis, 2010, p. 92) and hereby increase fungal and microbial activity by creating fresh surfaces (Lowenfels & Lewis, 2010, p. 92). When they move around the soil, they not only turn over the soil but also move smaller organisms around on their bodies (Lowenfels & Lewis, 2010, p. 92).

Worms also shred matter and turn the soil (Lowenfels & Lewis, 2010, p. 99), but they also enrich soils with nutrients as they digest it: vermicasting, the term for worm excrements, are fifty percent higher in organic material after digestion, seven times richer in phosphate, five times richer in nitrogen, ten times richer in potassium, and one-and-a-half times richer in calcium due to the bacteria in the worms intestines (Lowenfels & Lewis, 2010, p. 98-100). Worm burrowing increases the water-holding capacity of soils (Lowenfels & Lewis, 2010, p. 100).

Slugs, like worms, decompose and shred while turning and aerating the soil when traveling underground (Lowenfels & Lewis, 2010, p. 104). Their slime binds to soil particles (Lowenfels & Lewis, 2010, p. 104). Slugs are a major food source, and in a healthy ecosystem, their numbers are controlled (Lowenfels & Lewis, 2010, p. 104).

Larger animals like birds, rodents, and larger mammals also all play roles in the ecosystem around the soil by e.g. feeding on slugs and worms (Lowenfels & Lewis, 2010, p. 104 ff).

As mentioned above, the pH of the soil determines the chemical properties and the soil microbe community. In turn, the pH of the soil is determined by the soil microbes: bacterial slime is alkaline (Lowenfels & Lewis, 2010, p. 49) while fungi produce acidic enzymes (Lowenfels & Lewis, 2010, p. 66). Certain plants prefer different ratios of bacteria and fungi which correlates to plant succession: annual species (so short-lived species that complete their life stages in a single year) and grasses prefer their nitrogen in nitrate form and thus bacterial-rich soils, while trees, shrubs, and other perennials prefer the ammonium form and thus fungally dominated soils (Lowenfels & Lewis, 2010, p. 111). In undisturbed forest soils, the ratio of fungi to bacteria can be ten to one while agricultural soil is typically one to one or less (Lowenfels & Lewis, 2010, p. 25).

The structure of soil is influenced by soil life of all sizes: bacteria produce a sticky slime that sticks them and soil particles together, and the hyphae of fungi are also sticky and aggregate soil. Meanwhile, larger organisms and roots break soil up into smaller pieces, mix the soil, and create channels for water to penetrate (Lowenfels & Lewis, 2010, p. 23).

2.2.5.2 The effects of agriculture on soil health

Agriculture affects soil health in a multitude of ways: disturbing and changing the soil community by tilling and applying agrochemicals, disturbing water-retention abilities, and compacting the soil with heavy machinery.

Tilling is a practice where the top layer of soil is turned or mixed. Tilling can reduce the labor needed to maintain a field, softens the soil for planting, and removes unwanted growth (Koman et al., 2021). This practice has its downsides, though:

The interplay of soil organisms in the different layers is disrupted when layers are mixed through tilling. For one, soil organisms that thrive in the darkness of the ground might not be able to cope with sunlight or even the warmer top layer of soil. In addition, more developed soils from further down the soil horizon are mixed into the top-most layer where they more easily get washed or blown off the field than their less-developed counterparts (Yadav et al., 2023; Rhodes, 2012).

In addition, tilling releases stored carbon dioxide and other greenhouse gases, including water which might then need to be replaced with irrigation (Prescott et al., 2021; Koman et al., 2012). As we saw in section 2.2.4, agricultural systems are one of the main contributors to greenhouse-gas emissions globally (Campbell et al., 2017).

The practice of tilling the soil is a rather modern phenomenon. Modern cultures support the use, even often think, "it's the only way to do this" (see Chapter 4), but indigenous cultures still understand the long-term benefits of refraining from tilling (Koman et al., 2021).

Soil degradation not only releases water during tilling but also diminishes the water infiltration and retention abilities of the soil (Prescott et al., 2021). Water acts as a solvent for nutrients and allows plants and microbes to utilize them. Water is a critical resource in all ecosystems and agriculture is impacting both the water quality and availability (Koman et al., 2021), as we saw in section 2.2.2.

Furthermore, the use of synthetic fertilizers and pesticides impacts soil ecosystems. In the case of pesticides, the toxins can directly impact soil life due to the non-specific nature, as explained in section 2.2.1. Synthetic fertilizers, too, impact the soil community, though, as they "disrupt the natural methods through which plants acquire nutrients (Yadav et al., 2023, p. 3)." In a system with synthetic fertilizers, the plants become dependent on the input as the composition of soil bacteria is altered resulting in vulnerable fertilizer-dependent plants (Yadav et al., 2023.)

And finally, the use of heavy machinery also compacts the soil on the field further degrading it and affecting soil organisms (Koman et al., 2012).

The Alps, for instance, have been stripped off almost all the soil formed since the glaciers retreated due to grazing livestock and farming. The rate of destruction is four to ten times as fast as the rate at which these top soils grew (Rapuc et al., 2025.) Soil formation is a slow process, and growing a single inch (2.5 cm) of fertile soil takes 800-1000 years (Rhodes, 2012). Protecting the soil is therefore crucial and urgent.

2.3 Social issues surrounding agriculture

An estimated 4.5 billion people globally depend on food systems for their livelihood (United Nations, n.d.). But even those who are not directly involved in our food systems are directly or indirectly affected by agriculture, be it through changes to the cost of food, air pollution around agricultural fields and industries producing agricultural products, or the more indirectly connected effects of biodiversity loss and climate change induced by agricultural practices.

Adaptations in agricultural practices will be direly needed but humanity will have to consider that even now more than a billion people do not have access to sufficient calories with even more lacking sufficient nutrients (WHO and FAO 2014; as cited in Campbell et al., 2017). Meanwhile, more than two billion people consume too many calories, though often without taking in sufficient nutrients. Campbell et al. (2017, p. 7) described this simultaneous over-consumption and under-nourishment as the "triple burden of malnutrition" and described addressing this discrepancy as a "major societal challenge."

As the human population on Earth is expected to exceed 9.7 billion by 2050 while income per capita rises (United Nations, n.d.), a substantial increase in agricultural production will likely be needed and put further pressure on agricultural processes (O'Donoghue et al., 2022). This demand can be met either by intensification of existing food systems or by further expanding the necessary space and resources needed to grow food for humanity.

Agricultural expansion already continues to cause the displacement of indigenous people and the "annihilation of ecosystems (Levers et al., 2021; Gordon et al., 2023, p. 1833)."

On the fields, exploitation of field workers is common-place. A report by the Initiative Faire Landarbeit (German: Initiative Fair Agricultural Work, Danilova, 2025) analyzed the conditions for field workers in European countries, focusing on Germany. They found issues with housing, irregular work hours and opaque payment structures, but also insufficient health insurance. When minimum wage in Germany was raised, seasonal workers often found the cost of housing rising to match. Instead of earning more, field workers paid more for the same housing—the burden of the cost was put onto the very field workers who were supposed to be protected by minimum wages. In June of 2025, the Deutscher Bauernverband (DBV, German: German Farmers' Association) even demanded that seasonal workers be excluded from minimum wage, supported by the agricultural minister Rainer. Others saw this as a clear case of discrimination (Tagesschau, 2025), as the minimum wage should be seen as the absolute minimum. The Initiative Faire Landarbeit (Danilova, 2025) explains that even basic worker protection often does not get followed for seasonal workers, that minimum requirements for housing is often not met despite the rising cost to seasonal workers, and that workers often do not feel like they have an option to report violations.

Not just Germany but the entire agricultural sector of the EU depends on migrant labor. An Oxfam study covering nine EU countries (Ruiz-Ramírez et al., 2024, p. 3) found a "broad range of problems:" migrant workers are paid low wages with inflated cost of living deducted, delayed payments, unpaid overtime, or even a full denial of payment. Housing tends to be basic in e.g. cramped containers without electricity, running water or even basic infrastructure. Out of fear, workers are unlikely to complain. Even when violence, abuse, and sexual assault have been found, any uprising from workers tends to lead to a full replacement of the work force in the following season, something Oxfam describes as "union busting" though there is no union involved (Ruiz-Ramírez et al., 2024, p. 4).

Questions of animal welfare are often raised when talking about livestock farming (e.g. Anomaly, 2015). Plenty of voices summarize animal suffering (e.g. Anomaly, 2015), the connection between factory farming and such pandemics as the bird flu which has by now affected many wild bird species (Giacinti et al., 2024), or the relationship, in general, between the needs of humanity as weighed against the needs of wild animals, as illustrated in the ongoing debate around wolves and other top predators that compete with human interests in hunting and animal rearing (e.g. Ordiz et al., 2024). All of these practices set the perceived needs of humanity above the needs of animals and nature, something that will be discussed more in chapter 3.3.

As established above, agriculture already degrades soils and emits vast amounts of greenhouse gases, uses up tremendous amounts of freshwater, and harms biodiversity with pesticides and synthetic fertilizers. A growing population of humans will only increase these issues under a business-as-usual approach. This is often defended as the only way to meet the growing demand for food. As the climate crisis progresses, extreme weather events will put further pressure on agricultural systems (Malhi et al., 2021).

The large questions remain: can the current level of planetary and human exploitation be excused with the need to feed humanity? Is it ethical to borrow from the future and to exploit nature to feed humanity? Are alternatives even possible?

2.4 Agriculture and governments

Governments have long subsidized farmers. A total of 842 billion USD was paid out in farm subsidies each year worldwide between 2021 and 2023 and across 54 countries (OECD, 2024). Almost four-fifth of the support went toward China (37%), the United States (15%), India (14%), and the EU (13%). In the early 2000s, the EU led the list with 26 percent, followed by the US (20%), and Japan (16%) while China and India did not even reach 15 percent jointly (OECD, 2024).

Subsidies do not necessarily link to agricultural production. Brazil, for example, accounts for five percent of agricultural production (value) but accounts for less than one percent of received subsidies (OECD, 2024).

While the recent rise in subsidies paid out to China and India clearly warrants a closer look, the EU GAP program and the US agricultural assistance programs will be used to illustrate the interplay between agriculture and subsidies in this work.

The EU's Common Agricultural Policy was first conceived in the early 1960s (Harvey, 2024). Initially, farmers were given quotas to meet with guaranteed pricing for these quotas. In the late 1980s, however, the market distortion was found to lead to a surplus of some products. Prominent examples include "Butter Mountain" and "Milk Lake" (Der Spiegel, 1979). A redesign of Common Agricultural Policy resulted in more direct payments to farmers. Between 2003 and 2012, farm payments were based on amount of land farmed rather than production with some additional rewards for adopting sustainable practices (Harvey, 2024). The largest farms gained the biggest rewards while smaller farms continue to struggle, a system so lopsided, Ariel Brunner (as cited in Harvey, 2024), the director of BirdLife Europe went as far as calling the Common Agricultural Policy "welfare for the rich." Faustine Bas-Defossez (as cited in Harvey, 2024), the director of Nature, Health and Environment at the European Environmental Bureau considers the Common Agricultural Policy a "monster" and claims the policy is not enticing farmers to adopt sustainable practices but instead "driving the intensification of farming."

By now, Common Agricultural Policy spending makes up a third of the EU budget at 55 billion Euros each year. While it has many flaws, much of the agricultural and food industries depends on the payments from farmers to suppliers of agrochemicals. With everyone taking their cut, farmers are left with very little, enticed to increase production to meet monetary minima (Harvey, 2024).

Despite the proportionally high impact of animal products on the climate, eighty percent of farm subsidies in the EU go toward animal products. Past efforts to curb this have been met with intensive protests by "cavalcades of tractors and burning haybales." In a Guardian article, Harvey (2024) even links the proposal to start limiting herds in the Netherlands to the rise of the far right in recent years. In Romania, most of the EU Common Agricultural Policy budget is paid out to a small amount of large land-owners (Dietrich and Dasgupta, 2023).

A similar story could be seen in the US: The first US agricultural assistance program was started in the 1920s after the first world war. Despite the lower demand after the end of the war, farmers continued to produce huge yields. As early as 1929, the government bought excess cotton and grains when production exceeded demand. This artificial yet guaranteed demand led farmers to further increase production. Later, the government shifted to paying farmers to refrain from growing crops that were overproduced (Fields et al., 2004).

In the US, the government subsidizes the major crops like corn, soybeans, wheat, cotton, and rice. These are typically grown in mono-cropping operations with large acreages (Koman et al., 2021; Fields et al., 2004). The 2014 Farm Bill shifted from a direct payment to farmers to insurance premium coverage that allows farmers to take out crop loans which enable the large, high-yield operations prevalent in US agriculture (Koman et al., 2021). But as Fields et al. (2004) argue, subsidizing only a small amount of crops has led to farmers focusing on large acreages of these subsidized crops while ignoring other crops like fruits, vegetables and less common grains. They link these subsidies to the rise of corn-based sweeteners and hydrogenated fats made from soy beans, as well as feed for cattle based on subsidized crops.

Similarly, the US started the Milk Price Support Program in 1949 (USDA, 2004, as cited in Climate Town, 2025): they purchase dairy products indirectly to ensure a minimum price for farmer's milk. A year after the introduction of the program, the US government created the school-lunch program to both find an outlet for excess products and help feed school children (Williams, 2025). The dairy lobby strongly influences policy (Williams, 2025). This has led to curiosities like the policy that prohibits schools from providing lunches that might lower the consumption of dairy products (7 CFR 210.10, as cited in Williams, 2025) or USDA recommendations to drink multiple glasses of milk every day (Williams, 2025).

Similar results and side-effects can be found for many kinds of subsidies, as I already found during the research for my bachelor thesis on marine-protected areas where a similar picture could be painted for fisheries subsidies (Hildenbrand, 2023).

A review by Laborde et al. in 2021 (p. 6) examined "the implications of current levels of agricultural support on global greenhouse-gas emissions from agricultural production." They found that while subsidies did increase global agricultural output by about one percent, they also increased emissions by 0.6 percent. Market-price support through trade barriers has almost no effect on global agricultural production. They do, however, reduce greenhouse-gas emissions by about two percent. Combined, subsidies and market-price support through trade barriers slightly increase yields (by about one percent) while reducing emissions by one to seven percent (Koman et al., 2021).

Even the upper range of these impacts is rather small compared to the potential. As Laborde et al. (2021) point out, they suggest an overhaul of current incentive structures will be needed. Subsidies, as they are done now, perpetuate a system that will not be able to meet humanity's need for food in coming years, is destructive to the environment, and benefits disproportionately those who already own more (Harvey, 2024).

2.5 Agroecology, permaculture and regenerative techniques

While the above focused on the issues surrounding the status quo of capitalistic agriculture, the following will present regenerative agriculture as an alternative. In this section, I'll explain what regenerative agriculture is, how it developed, and what the methods and techniques involved are, before we turn to an in-depth analysis of the validity of these methods in Chapter 3.

To date, there is no clear definition of regenerative agriculture (Newton et al., 2020)—much to the dismay of some and the joy of others. On the one hand, the openness of the term allows for diverse approaches (Cusworth and Garnett, 2023); on the other hand, the lack of a formal definition makes it hard to test specific claims (Newton et al., 2020) or regulate and enforce regulations. Cusworth and Garnett (2023, p. 16) see a risk that the lack of a definition could weaken the very heart of the regenerative idea and allow "unscrupulous actors to greenwash their unsustainable activities."

A study by Wilson et al. (2024) found that the term 'regenerative agriculture' carries both the positive and the negative characteristics of a buzzword, so a term "representing something trendy or in vogue that different people are talking about (Wilson et al., 2024, p. 1)". While the term is being used for green-washing, it is also used by a wide community of actors to connect and describe their approach. They further found that only about half of the papers written on regenerative methods even define their interpretation of what regenerative agriculture is. The wide-spread use of the term, to them, clearly signifies an "important area of public interest (Wilson et al., 2024, p. 2)."

A single definition for regenerative agriculture would make it easier for governments to create policies, for researchers to verify claims, and "de-confuse the market (Landers et al., 2021, p. 1)." But it would also limit options for those seeking to apply regenerative agriculture to their specific context. The current lack of a clear definition allows farmers to "try different things at different levels of ambition as they embark on their regenerative 'journey' (Cusworth and Garnett, 2023, p. 16)."

2.5.1 A brief history of regenerative agriculture

As established in 2.1, the currently prevalent, capitalistic mode of agriculture is a rather young phenomenon when considering human history. For 95 percent of our history, humans have been hunter-gatherers, and the intensification of agriculture did not take up speed until the Green Revolution of the 1950s and 1960s (Breier et al., 2023).

Despite the significant impacts on the environment, capitalistic agriculture is the norm nowadays. However, with sociopolitical pressure to offset carbon, improve biodiversity, and meet emission targets, while still mostly a farmer-led initiative, the idea has attracted powerful actors from retail, finance, and politics, but also from large corporations like General Mills, Danone, and Nestlé (Cusworth and Garnett, 2023). As mentioned, the risk for green-washing is large, and these corporations are likely to be involved out of a wish to green-wash their brand (Wilson et al., 2024). Regenerative agriculture has attracted stakeholders from conflicting sides of the food-system debate (Giller et al., 2021; Gordon et al., 2022). They support both regenerative practices and capitalistic agriculture (Gordon et al., 2022), because they believe regenerative practices can be layered onto current capitalistic methods (Fassler, 2021). Others argue that regenerative agriculture can only work when the society shifts to regenerative alternatives for other systems as well, i.e. a regenerative economic, political, and social system (Gordon et al., 2023).

Regenerative agriculture is not a new concept: the movement started in the 1980s, developed by farmers and research stations in an attempt to learn together and from each other. Regenerative agriculture has gained popularity with regular conferences, shows, but also research in, among others, the US, Europe, and Australia (Giller et al., 2021; Newton et al., 2020).

Cusworth and Garnett (2023, p. 8) see regenerative agriculture focused on "the importance of small-scale farming, the merits of removing chemical inputs from the farm, the shortening of supply chains, and the need to reconnect farmers with consumers. Among other things, this implies a redistribution of power in the food system." These ideas will be picked up in Chapter 3.

Regenerative agriculture has been developed over the past decades, mostly in grassroots-movements and farmer-led initiatives to go beyond sustainability: instead of merely reducing harm, it is intended to improve the health of the environment (Seymour and Connelly, 2023).

It is vital to keep in mind, though, that many of the techniques used in regenerative agriculture are a return to pre-industrial methods. Indigenous people have practiced regenerative methods for centuries in a form of land custodianship (Gordon et al., 2023). The connection between modern regenerative agriculture and the knowledge of indigenous people is often neglected due to an "ethnocentric bias, originating from the colonial global North (Gordon et al., 2023, p. 1842)." Indigenous voices urge to not merely repackage their ancient knowledge but also hope for a shift in consciousness from "a dominant culture of supremacy and domination to one founded on reciprocity, respect, and interrelations with all beings (Angarova et al., 2020; as cited in Gordon et al., 2023, p. 1842)."

Studying hunter-gatherer tribes can provide some insights into the long-distant past, as well: Sixty to eighty percent of the annual diet (by weight) of these tribes comes from plant foods. Meat is considered a "special treat" when available but was never depended upon as a staple (Lee, 1968, as cited in Naithani, 2021). Researchers observed that these hunter-gatherer tribes deeply cared for their environment: "They do not hunt without need, waste less, and play active roles in managing their resources." For instance, controlled forest fires were started at intervals to eliminate weeds and pests but also to help germinate hard-shelled seeds like chestnuts and walnuts. This, in turn, would lead to more seed-producing plants in their future. In addition, the fresh green after the fires attracted herbivores that were hunted more easily (Naithani, 2021). The tribes benefited but they cared about more than their own gains. But even in settled communities, many of the methods used in regenerative agriculture are still used in various parts of the world (Elevitch et al., 2018): for example, agroforestry and mixed-crop practices are still common in parts of India and Africa.

Despite the return-to-the-roots common in regenerative agricultural practices, some practitioners include cutting-edge modern technology to help quantify and analyze the system they steward. Digital regenerative agriculture combines the traditional approaches of regenerative agriculture with modern tools (O'Donoghue et al., 2024).

The multitude of methods and approaches makes it hard to define regenerative agriculture.

2.5.2 Outcome-based vs. process-based definitions

Definitions of regenerative agriculture typically fall into one of two categories: process-based or outcome-based (Newton et al., 2020): Process-based definitions explain which practices to include or exclude when growing regeneratively while outcome-based approaches evaluate soil health, sequestered carbon or biodiversity targets.

Process-based definitions often fail to consider the very different conditions farmers face: different climates, different crops, different abilities and resources. A review by Grelet et al. (2021, as cited in Gordon et al., 2023, p. 812) found that regenerative agriculture "does not preclude any particular practice if it is needed to facilitate the transition of the agroecosystem to a state of increased health." Regenerative agriculture typically is outcome-focused rather than process-focused (Gordon et al., 2023; Wilson et al., 2022).

O'Donoghue et al. (2022, p. 20) even described regenerative agriculture as a "state rather than a type of agriculture," Their definition of regenerative agriculture, consequently, is: "Any system of crop and/or livestock production that, through natural complexity and with respect to its contextual capacity, increases the quality of the product and the availability of the resources agriculture depends upon; soil, water, biota, renewable energy and human endeavor."

An outcome-based approach means being able to adapt to the specific context of growing or raising. Different contexts might be best approached with different techniques despite aiming for the same outcome. Which methods to apply depends on the specific context of the farm (Grelet et al., 2021; Scherr et al., 2012; both as cited in Gordon et al., 2023).

O'Donoghue et al. (2022) see an intention from both early and current supporters of regenerative agriculture to focus on regeneration and improving ecosystem function. Wilson et al. (2022) found three broad categories for intended outcomes: climate adaptation and mitigation, socioeconomic benefits, and integrated systems.

Many related but separate approaches have emerged over time, often because the founders clashed over details. Gordon et al. (2022) list the following extensive but still not exhaustive list: adaptive management, agroecology, biodynamic agriculture, carbon farming, climate smart agriculture, holistic management, Indigenous land stewardship, keyline farming, natural farming, organic agriculture, permaculture.

The definitions for each of these vary with the source and often overlap but also often differ in nuances. More terms exist for many of these practices, again with slightly differing definitions. By now, these different sub-groups often overlap, cooperate, and exchange ideas (Gordon et al., 2023). As one farmer described it in an interview with Gordon et al. (2023, p. 1836), "this new generation [of regenerative farmers] draw on the different threads that are going to work for them. No longer are you in this group or that group, it's not a club, there's no coercion. It's a movement of individuals."

Elevitch et al. (2018) tried to summarize the guiding principles of regenerative agriculture by focusing on soil, water, biodiversity, ecosystem health, and carbon sequestration. Though they treated these goals as separate, they are interwoven. Jaworski et al. (2024, p. 14) offer an alternative by providing more practical principles: "reduce soil disturbance, increase crop diversity, keep the soil covered, keep living roots all year round and increase soil organic matter using non-chemical fertilizers." Jayasinghe et al. (2023, p. 29) chose "understanding the farm-specfic context," "reducing synthetic inputs, integrating livestock, supporting soil fertility, and mimicking natural processes (Olsson et al., 2022, as cited in Jayasinghe et al., 2023, p. 29)."

Table 2: A selection of different definitions of regenerative agriculture from literature.

Definition	Source
Regenerative agriculture is a proposal about changing farming in order to undo the degradation of the farmed environment. It is a shift towards farming with the environment, rather than treating it as merely a platform. Such an approach recognises catchments, water flows though farm landscapes, erosion of soil and leaching of excessively added nutrients.	Burns, 2021
Extensive agriculture that: uses no-till farming; reduces or eliminates pesticide and herbicide use (e.g. spot spraying rather than broadacre spraying); reduces or eliminates fertiliser use; uses high intensity, short duration time-controlled grazing with frequent rotation of livestock between small paddocks with perennial native grasses (i.e. cell grazing) and long rest periods; increases and subsequently maintains the proportion of land with native vegetation; and reduces or eliminates the use of supplementary feeding by destocking during period of low vegetative primary productivity, rather than operating at a fixed stocking	Colley et al., 2020

Definition	Source
rate.	
Regenerative agriculture aims to maintain agricultural productivity, increase biodiversity, and in particular restore and maintain soil biodiversity, and enhance ecosystem services including carbon capture and storage. Regenerative agriculture is based on farming without tillage, and without the use of fertilizers and pesticides.	Dědina et al., 2024
Agricultural and transdisciplinary approach that integrates local and indigenous knowledge of landscapes, as well as their management, with established scientific knowledge. It combines a range of adoptable principles with context-specific practices, focusing on soil conservation as the initial step to restore soil health, enhance ecosystem functions, and promote improved socioeconomic outcomes.	Jayasinghe et al., 2023
The goal of regenerative farming systems is to increase soil quality and biodiversity in farmland while producing nourishing farm products profitably. Unifying principles consistent across regenerative farming systems include (1) abandoning tillage (or actively rebuilding soil communities following a tillage event), (2) eliminating spatiotemporal events of bare soil, (3) fostering plant diversity on the farm, and (4) integrating livestock and cropping operations on the land.	LaCanne and Lundgren, 2018
Regenerative agriculture is a set of approaches that emphasizes and make the most of naturally occurring beneficial soil–plant interactions, relying less on external inputs and taking advantage of ecological agricultural practices.	McLennon et al., 2021
Regenerative agriculture is a preservation and rehabilitation-oriented food and farming system. It concentrates on topsoil regeneration, biodiversity improvement, improved water cycle, ecosystem goods and services, bio-sequestration support, climate change resilience, and farm soil health and	Muhie et al., 2022

Definition	Source
vitality.	
Any system of crop and/or livestock production that, through natural complexity and with respect to its contextual capacity, increases the quality of the product and the availability of the resources agriculture depends upon; soil, water, biota, renewable energy and human endeavor.	O'Donoghue et al., 2022
Related to agroecological principles, regenerative agriculture is an outcome-based farming approach that generates agricultural products while improving soil health, biodiversity, climate, water resources, and supporting farming livelihoods. Regenerative agriculture is a holistic approach that aims to, simultaneously, promote above- and below-ground carbon sequestration, reduce greenhouse gas emissions, protect and enhance biodiversity in and around farms, improve water retention in the soil, reduce the use of pesticides, improve nutrient use efficiency, and support farming livelihoods.	Petry et al., 2023
Consciously designed landscapes which mimic the patterns and relationships found in nature, while yielding an abundance of food, fibre and energy for provision of local needs.	Rhodes, 2012
An approach to farming that uses soil health as the entry point to regenerate and contribute to multiple ecosystem services, with the aspiration that this will enhance not only the environmental, but also the social and economic dimensions of sustainable food production.	Schreefel et al., 2020
[A] place-based management philosophy whose adherents think about their land, their businesses, and their communities as dynamic ecosystems, contrary to today's dominant industrial agricultural model.	Sharma etal., 2022, as cited in Miller-Klugesherz and Sanderson, 2023
A system of farming principles and practices that increases biodiversity,	Terra Genesis International, 2020, as cited in Newton et

Definition	Source
enriches soils, improves watersheds, and enhances ecosystem services.	al., 2020
A long-term, holistic design that attempts to grow as much food using as few resources as possible in a way that revitalizes the soil rather than depleting it, while offering solutions to carbon sequestration.	The Rodale Institute, as cited in Rhodes, 2017
[A] system of principles and practices that generates agricultural products, sequesters carbon, and enhances biodiversity at the farm scale.	Yadav et al., 2023

Many more similar lists and definitions can be found. Currently, regenerative agriculture is an inclusive label, which means that not all who practice it share a common vision or agree on the exact methods and techniques (Beacham et al., 2023). There is no one shared goal nor one shared method that applies to all (Beacham et al., 2023). But at the core, the intention is typically to “improve soil health or to restore highly degraded soil, which symbiotically enhances the quality of water, vegetation and land-productivity (Rhodes, 2017, p. 80).”

This vagueity is further complicated by different stakeholders using the same term differently: permaculture, for instance, can mean a "forest garden in which plants and animals (including humans) live in harmony" on one end but might also refer to design permaculture which is "a kind of compromise between this holistic view and more structured cultivation (Rhodes, 2012. p. 52)." The concept of holism in connection with regenerative agriculture will be discussed more in sections 2.5 and 3.3.

Independent of the label applied and the wording chosen, this width allows recognizing the context of the farm in question instead of applying blueprint solutions (Lanford and Orr, 2022; Jayasinghe et al., 2023).

In essence, and for the sake of this paper, regenerative agriculture is any form of agricultural system, be it crop or livestock production, which seeks to limit disturbances to soil, water and nutrient cycles, and ecosystems with a focus on regenerating these systems taking into account the complexity and contextuality of the agricultural ecosystem of the farm and its surrounding community while maintaining the necessary yield.

2.5.3 Techniques and methods

Despite being mostly defined by outcome rather than process, most practitioners of regenerative agriculture select from the same methods and techniques and adapt these to their context.

Common practices in regenerative agriculture include minimized soil disturbance (i.e. tilling), keeping the ground covered and roots in the soil, rotating and integrating crops, reducing external inputs, increased use of perennials and agroforestry, integrated crop-livestock systems, and managed grazing (e.g. Jayasinghe et al., 2023; Khangura et al., 2023). This list, however, is not exhaustive, and many related methods and techniques exist.

From a mindset perspective, regenerative agriculture is committed to "restoring damaged landscapes and realising their innate potential (Massy, 2017; 2013; Francis and Hardwood, 1985; all as cited in Gordon et al., 2023, p. 812)."

The benefits and drawbacks of these methods will be described in Chapter 3. The following section will illustrate the methods and techniques used instead.

2.5.3.1 Minimizing soil disturbances

Regenerative agriculture is often seen as a movement concerned with soil health (O'Donoghue et al., 2022; Krzywoszynska, 2024; Sherwood and Uphoff, 2000) as their primary focus. While soil health is only one piece of the puzzle, the importance of regenerating soil, restoring the soil community, and adding topsoil, is clearly a major factor for most regenerative growers. Landers et al. (2021) calls “Zero tillage” the bedrock of regenerative agriculture, alongside crop-rotation and retention of crop residue.

While tilling is seen as necessary by modern farmers, indigenous groups and pre-industrial farmers understood the benefits of farming without tilling for centuries (Koman et al., 2021). As described in section 2.2.4, tilling means turning or mixing the top soil in an attempt to remove unwanted growth, soften the soil, and moving nutrients from lower layers to the surface (Koman et al., 2021). As established, the mixing of soil disrupts the soil ecosystem, releases greenhouse gases including water, furthers top-soil loss and erosion, and compacts the soil with the used heavy machinery (Nathan, 2017;

as cited in Koman et al., 2021). Minimizing or stopping tilling is often seen as an important first step in regenerative agriculture, as it removes the "disturbing effects of soil cultivation and reduces exposure to erosion (which represents a loss of soil depth) and atmospheric interaction (in which the nutrients in the soil are released as gases; Cusworth et al., 2024, p. 11)."

Minimizing soil-disturbance can be seen as a non-method rather than a method, as refraining from turning and cutting the soil can hardly be seen as a method. When refraining from tilling, the method has to be replaced with alternative methods such as cover cropping.

2.5.3.2 Retention of crop residue, cover cropping

The principal of never keeping exposed soil on any field is often considered an important alternative when not tilling (Koman et al., 2021; Cusworth et al., 2024). After harvest, crop residue is left on the field, and the roots stay in the ground. Instead of tilling or burning the residue, cover crops are added in between the main crops (Breier et al., 2023; Cusworth et al., 2024).

There are various options for keeping the ground covered: dead mulch, fresh mulch, and in-situ or living mulch, as well as artificial options like mulch mats and foils (Strüber, 2025). The exact terminology for the three types of mulch vary depending on the source. The chosen terminology is translated from Dieter Pansegrau who created a handbook on mulching in the agricultural context (Strüber, 2025). By this definition, both dead mulch and fresh mulch are grown on plots other than the field. There are "giver areas (Deutsch: Geberflächen)" and "taker areas (Deutsch: Nehmerflächen)." In the first case, the mulch material is dried first, then spread onto the taker field as dried "dead" mulch. In the latter case, the mulch material is applied shortly after harvesting the mulch material. These options allow working the soil prior to mulching. The third option is in-situ mulching, so mulching directly on the field, which is also called green manure or living mulch. The same area is giver area and taker area then. The mulch material is either left in between the crop (intercropping with green manure) or flattened prior to planting. The ground is not worked in fields where in-situ mulching is applied. In case of organic mulches (i.e. not plastic foils and other non-organic mulch alternatives), soil organisms digest the mulch and move nutrients from the mulch into the soil (Strüber, 2025).

The timing and type of mulch, as so often in regenerative agriculture, depends on the context: mulching affects soil temperature which, in turn, influences germination: Mulching dampens soil warming, which can be helpful or detrimental depending on the context: with early planting in spring, mulching too early might slow germination or kill sprouted plants while mulching in high heat might make growing possible where plants would otherwise wither (Strüber, 2025). Using fresh mulch material can further lower soil temperatures, so depending on the context, dried mulch or a later application might be preferable (Strüber, 2025). Some mulch materials are winter-hardy and need to be flattened or mowed, others die off in winter and rot on the field in time for spring planting. Different seed mixtures are available with varying number of species per mix. In their book *Dirt to Soil* (2018), Gabe Brown, a farmer in North Dakota who follows regenerative principles, describes that they use many species in a mix. They have run tests on different fields—though they should be regarded as anecdotal rather than scientific—and found that a larger variety of cover crops led to best results in their context.

Different mulch options have different ratios of carbon and nitrogen (by weight). Mixtures with legumes and other nitrogen-fixing plants (i.e. plants that take up nitrogen from the atmosphere and move it into their tissues and the soil) have lower C:N ratios, which leads to faster decomposition and release of nutrients, while straw, a popular mulch material, has a larger ratio. Dieter Pansegrau (Strüber, 2025) recommends a C:N ratio of under 25 for crop land. But, while straw has a high carbon content compared to its nitrogen content of about 100, this does not mean straw is not suitable for mulching. If the straw isn't worked into the soil by tilling but instead used as mulch, the straw's high carbon-content only affects the very top-most layers of the top soil, and, in effect, merely takes longer to decompose while positively affecting the oxygen content and water-retention properties of the soil (Dieter Pansegrau, as cited in Strüber, 2025). Soil organisms then mix the carbon into the other layers, as described in section 2.2.5.1. Pansegrau (Strüber, 2025) recommends manure with high nitrogen content for heavy feeders, so plants with an above-average demand for nutrients, like brassica (e.g. cauliflower, broccoli) and cucurbits (e.g. pumpkins, cucumbers) while straw is sufficient for medium feeders and light feeders. To him, keeping the ground covered is the main point. How much mulch is needed also depends on the context and crop. For most applications, a layer of five to ten centimeters is recommended (Strüber, 2025).

Another option for mulching is intercropping of green manure. A certain amount of time after planting the main crop, a green-manure species or mixture is planted around the main crop. An example would be to plant clover around cabbage (Strüber, 2025) or buckwheat around pumpkins/squashes (Strüber, 2025). Those intercropped green-manure plants can even be combined with dead manure by first bringing out the intercropping seeds, then adding mulch on top (Strüber, 2025).

Mulch material from animal sources can even out some of the high carbon content of straw manures: when straw is used as bedding and mixed with the excrement of e.g. horses, the spent bedding can be an excellent source of manure that most farmers can easily source from nearby stables. Integrating life stock into crop system will be discussed further in 2.5.3.7.

There is a wide selection of options for mulching, both on the farm and from external sources. Depending on the farm context, different applications are recommended. But all these methods share one guiding principle: keeping the soil covered.

2.5.3.3 Reducing external inputs

Synthetic fertilizers disrupt the natural methods which allow plants to communicate with the rest of the soil community. The same is true for pesticides and herbicides. Hence, these substances are not compatible with regenerative agriculture (Yadav et al., 2023).

Reducing external inputs, like minimizing soil disturbances is more a non-method that requires the use of alternative methods to realize. In the case of external inputs, this means sourcing mulch materials from the farm itself or from nearby sources, opting out of synthetic fertilizers, pesticides and herbicides in favor of integrated pest management (2.5.3.6), integrating livestock (2.5.3.7) and, in some cases, organic fertilizers like teas fermented from weeds or compost (Lowenfels & Lewis, 2010, p. 125) which are used to jump-start a neglected area when waiting for nature to run its course is not an option. Using crop residues and animal excrement to produce high-quality compost, then using this compost to inoculate the fields is one example of such integrated nutrient management (Muhie, 2022; Lowenfels & Lewis, 2010 p. 124-125).

While some regenerative growers are proponents of such additives to help regenerate the natural balance of the soil, others prefer to take the slower option of helping nature regenerate at its own pace.

2.5.3.4 Agroforestry

Agroforestry is the integration of trees and shrubs with crop and/or animal farming (Elevitch et al., 2018; Muhie, 2022). Many agroforestry practices can be integrated into current capitalistic agricultural practices: alley cropping, contour hedgerows, windbreaks, riparian buffer systems, and living fences are all options to surround or subdivide conventional fields or pastures with trees (Elevitch et al., 2018).

Forest farming, silvopasture, and food-forest systems are more complete transitions to agroforestry. Forest farming means combining shade-tolerant specialty crops like mushrooms or herbs with a managed forest while silvopasture means grazing livestock in a forest (Elevitch et al., 2018). Finally, food-forest systems are agroforestry systems which combine varying layers of plants: e.g. large trees, smaller trees, shrubs and bushes, as well as ground-cover (Albrecht and Wiek, 2021).

Forest farming is still common for specialty crops like black pepper (Piper nigra) and coffee (Coffea spp.) in parts of the world (Elevitch et al., 2018). Regional trees are used to shade shade-loving plants, sometimes intercropping various species (Elevitch et al., 2018). Coffee is undeniably an important and highly-valued crop (Wynter et al., 2025). While much of coffee production has been replaced with mono-culture cropping of sun-tolerant coffee varieties, even the shaded coffee is now often grown under non-native trees to gain extra income from the timber (Wynter et al., 2025).

Silvopasture has been done for centuries, especially in the middle ages and the early modern period before barns and stables became the norm in the 19th century, and most silvopasture system were transitioned to mere forestry (Hertel et al., 2017). Various types of ruminants are suitable for silvopasture with popular choices being pigs, cows, and goats, but also poultry. Forest-pasture systems can be established by planting trees on existing pasture or by thinning out forests to allow access to a forest by livestock (Elevitch et al., 2018).

Food forests tend to be multifunctional practices with varied income streams and targets (Albrecht and Wiek, 2021). In addition to multiple simultaneously cultivated crops from different layers of the system, food forests often offer sociocultural and environmental services (Albrecht and Wiek, 2021). This system has a large acceptance in the gardening community with forest gardens, as well as with smaller collectives but few large-scale practitioners to date (Albrecht and Wiek, 2021).

2.5.3.5 Layering of crops, intercropping, and crop rotation

While many agroforestry systems can be considered examples for layering of crops and intercropping, these methods can also be applied to more traditionally managed fields. Intercropping means combining multiple types of crops in one area (Stomph et al., 2020, as cited in Zhou et al., 2024). One form of intercropping, the intercropping of green manure, was discussed in section 2.5.3.2.

As an alternative that requires even fewer changes to the traditionally managed field, crop rotation can be used. In crop rotation, different crops are alternated in the same area. This can mean alternating between pasture and crop land (e.g. Strüber, 2025) or alternating through various crops (Choudhury et al., 2024, as cited in Zhou et al., 2024).

Dieter Pansegrau (Strüber, 2025), who was mentioned before in the section on manure, does a combination of many methods: intercropping of green manure, crop rotation of multiple crops, but also rotation with green-manure plants. Their crop rotation follows an eight-year plan with three years of a clover-grass mixture for nitrogen fixation, a year each of heavy-feeder crops and medium-feeder crops, then another year of green manure. Finally, another year of medium-feeder crops and a final year of light-feeder crops.

The basic principle of layering of crops, intercropping, and crop rotation is to vary what grows on the land, either by sharing or alternating, mimicking nature to a degree. Including green manure or nitrogen-fixing crops like legumes, can even add nutrients into the soil (see section 2.2.5.1).

Regenerative farmers also consider the depths the roots of different plants reach into: combining plants with different root depths in intercropping systems allows access to the nutrients in different layers without the plants competing for the same resources as much (Cusworth et al., 2024).

2.5.3.6 Integrated pest management

Integrated pest management seeks to replace the usage of pesticides (Muhie, 2022). Integrated pest management combines cultural, biological and chemical techniques to manage pests while minimizing the environmental and human-health impacts (Zhou et al., 2024).

Crop rotations is one part of integrated pest management, as rest periods where other crops grow mean specialized pests cannot survive until their food is back in the same field (Zhou et al., 2024; Strüber, 2025). Fields are monitored manually (Zhou et al., 2024), with traps (Furlan et al., 2020), or using digital technology (see section 2.5.3.8) to aid decision-making, and then a blend of biological, physical, and chemical controls are applied (Zhou et al., 2024).

Crop rotation and intercropping, as well as the use of pest-resistant crop varieties leads to less favorable habitats for pests (Zhou et al., 2024). Attracting predators or actively employing beneficial insects can further reduce pest pressure (Zhou et al., 2024). If all else fails, bio-pesticides, nano-technology, or even selective, targeted use of industrial pesticides is chosen (Zhou et al., 2024).

2.5.3.7 Integrating livestock

Integrating livestock can mean regenerative grazing systems with ruminant animals, the application of animals as pest control or the addition of non-ruminant livestock into the farm. They might combine livestock or fish with crop production (Muhie, 2022).

Regenerative grazing systems try to imitate the natural grazing habits of ruminants (Yadav et al., 2023). Pasture land is allowed to regenerate between grazing periods (Yadav et al., 2023). As described by Dieter Pansegrau (Strüber, 2025) and Gabe Brown (Brown, 2018), the rotation can alternate grazing with growing crops. It is even possible to graze until right before sowing, then planting straight into the graze stubble (Rhodes, 2012). Gabe Brown suggest adding chicken into the rotation. While large ruminants drop manure while grazing, chickens can further break up and spread this manure into the top layer of the soil while foraging for e.g. grubs in cow patties (Brown, 2018). Other ruminants like sheep are also possible in rotational grazing systems (Rhodes, 2012).

In systems that combine livestock with crop cultivation, ruminants fertilize the soil for the following crop (Cusworth et al., 2022). For most forms of animal farming, the excrement can be a valuable source of manure, composing material, or fertilizers. In these integrated systems, the waste from one part of the farm feeds another part of the farm (Muhie, 2022).

On the small scale, combining animal raising with gardening has gained popularity. Gardeners keep chickens not just for their eggs but also for the compost-making abilities of chickens. They scratch through composting material to search for grubs, worms, and insects. Manure-covered bedding material can be used as mulch or composted for later use. Pigs are used to clear forest underbrush as the animals dig through the ground in search for food. Geese are used as an alternative to guard dogs for chicken flocks. These same principles used to be common on farms but have been lost for large-scale operations.

As mentioned in section 2.2.4, rice production has a huge impact on the environment. Rearing ducks on rice fields can reduce labor-requirements for weeding and pest control without damaging the plants (Singh et al., 2021). When choosing native duck breeds, the additional cost for keeping ducks is negligible while saving on pesticides, tilling, and nutrients (Singh et al., 2021).

There is still debate within the regenerative agricultural groups if animals should be part of the design: some deliberately introduce them while others avoid them entirely. The reasons for this are largely ethical rather than scientific, another case of ideological differences within the regenerative movement.

2.5.3.8 Digital regenerative agriculture

Digital regenerative agriculture is farming based on measuring crop variability with high-tech sensors, decision-support systems, and analysis tools (Muhie, 2022). It "makes extensive use of data and information to increase the efficiency of agricultural resources, yields, and crop quality (Muhie, 2022, p. 6)."

Most of the methods of digital regenerative agriculture overlap with those used in capitalistic agriculture, making them more of a building block than a regenerative method. For instance, drone footage may be used to evaluate nutrient needs of plants or sensors may aid in manual weeding or pest monitoring (e.g. Tian et al., 2025; Subramanian et al., 2021). In animal raising, farmers use digital technology to aid their operations: for instance, spatial-analysis software is used to divide the land into smaller parcels based on their climate, soil, and vegetation data. This data is then used to plan rotational grazing. Gates can be controlled automatically or No-Fence systems with GPS-located electric pulse collars can be chosen (Cusworth et al., 2022).

Regenerative agriculture, while heavily relying on indigenous and pre-industrial knowledge is not at odds with the embrace of modern technology. Instead, machine-learning systems and other techniques of digital agriculture, are merely another set of tools to choose from depending on the farm's context. As Cusworth et al. (2022, p. 1016) explain, regenerative practitioners are “both modernising an ecologically sensitive agricultural epistemology, whilst ecologising modern agricultural technology." They repurpose their tools from capitalistic agricultural practices into a "holistic, remedial programme for regeneration (Cusworth et al., 2022, p. 1016)."

2.5.3.9 Urban farming

Urban farming has gained increasing attention with the rising population in cities (Chenarides et al., 2021). As a growing sector within the farming industry, urban agriculture increases food production in urban areas (Chenarides et al., 2021). Rhodes (2017, p. 80) urges that "urban food production should be seen as a significant potential contributor to regenerative agriculture in the future."

Farming for city populations used to be done close to the cities with short transport to ensure freshness of food with more perishable farming done closer to the city (Rashed, 2019). With urbanization, more people moved to the cities while food production and transportation became more energy intensive. Globalization further lengthened the distance traveled by food (Rashed, 2019).

In some areas, a minimum of urban farming is prescribed by policies, such as the Chinese policy that prescribes a cultivated belt around cities (Giradet, 2010; as cited in Rashed, 2019). In other places, urban farming developed in response to food shortages, such as in Havana, Cuba, where citizens encouraged each other to cultivate available surfaces within Cuban cities, in the end reaching government support in the form of providing land or subsidizing farm inputs (Rashed, 2019).

To increase food production within cities, urban agriculture has to adapt to available spaces and therefore takes many different forms from community gardens and backyards to roof-top farming, farming in abandoned factories, or even along roadsides (Chenarides et al., 2021).

2.5.3.10 Stewardship mindset

In essence, regenerative agriculture mimics functional relationships between different parts of their farm ecosystem: small adjustments lead to a slightly different composition of species with very similar ecological function but which are better suited to human purposes, e.g. cultivated fruit trees and domesticated animals in a temperate forest rather than wild fruit trees and game (Stojanovic, 2019; as cited in Gremmen, 2022).

The philosophy of regenerative agriculture is a "(re)turn to nature," a choice of words in reference to a 2022 paper by Sumberg: Nature is no longer exploited but rather the farmer works with and learns from nature to model nature (Gremmen, 2022). While not all farmers who follow regenerative practices also adopt this mindset, others see farming as a vocation of stewardship with a focus on the public good (Beachem et al., 2023). No matter the mindset, Seymour and Connelly (2023, p. 231) point out, drastically changing agricultural and food systems will "require a radical renegotiation of our relationship with the environment."

Chapter Three: Benefits and criticism of regenerative agriculture

Capitalistic agriculture has reshaped the planet we live on in the name of increased profits and yields while drawing on human, material, and natural capital at an unsustainable rate (Gordon et al., 2023). Over the past decades, agricultural practices have relied heavily on fossil-fuel inputs and an increasing amount of synthetic fertilizers, pesticides, and herbicides. These chemicals are supplied by large multi-national corporations (Gordon et al., 2023) with large influence on sociopolitical systems, as will be discussed in Chapter 4.

With the expected rise in demand, capitalistic farmers will be unable to meet demand. We then have two possible solutions: intensify the way we grow food with science and technology or "radically switch to nature-based solutions (Gremmen, 2022, p. 39)." These scenarios are often treated as exclusive. As will be discussed in the following chapters, stakeholders hold very different views on regenerative methods but also on technology-driven approaches.

The following sections will elaborate the benefits of regenerative agricultural practices on both an environmental and a social level, evaluate the criticism of these practices, and explore the ethical concepts surrounding the need to feed a growing population, before detailing the socioeconomic barriers slowing implementation of any change toward more sustainable agricultural practices.

3.1 Benefits of regenerative agriculture

With the undeniable impacts of agriculture on the planet, regenerative agriculture can be seen as an alternative that seeks to feed the world and regenerate landscapes while lowering the harm done.

Regenerative agriculture has the potential to regenerate soils (Frankel-Goldwater et al., 2024), improve nutrient cycling (Schreefel et al., 2020) and water quality and availability (Strüber, 2025; Schreefel et al., 2020; Burns, 2021), enhance biodiversity, and reduce or mitigate greenhouse-gas emissions (Burns, 2021; Schreefel et al., 2020). Some studies have shown regenerative agricultural methods also increase community well-being (Pearson, 2007; Schreefel et al., 2020) and the "social capital" of rural areas (Pearson, 2007, p. 409).

Thus, regenerative agriculture can be understood as a way to address many of the "prevailing environmental challenges, e.g. peak oil, climate change, carbon capture, unsustainable agriculture and food shortages, peak phosphorus (phosphate), water shortages, environmental pollution, desert reclamation, and soil degradation (Rhodes, 2012, p. 1)."

3.1.1 Regenerative agriculture and soil health

Capitalistic agriculture has already severely degraded our soils (e.g. Whitmee et al., 2015). Regenerative agriculture can reduce further harm and even regenerate soils: Regenerative agricultural practices have been linked to increased soil-carbon levels (Breier et al., 2023; Rehberger et al al., 2023), better soil-drainage and water-retention properties (Koman et al., 2021; Breier et al., 2023; Apriyani et al., 2021), increased diversity and numbers of soil organisms (Rhodes, 2012), changes to the ratio of soil bacteria and fungi groups (Li, 2020, as cited in Koman et al., 2021; Lowenfels and Lewis, 2010), and improvements to the fertility of the soil (Tan and Kuebbing, 2023; Breier et al., 2023; Koman et al., 2021).

Cusworth and Garnett, who reviewed the benefits of regenerative agricultural practices in a 2023 study found various improvements of soil health: "soil carbon levels, invertebrate numbers, soil drainage, friability [the ability to crumble into smaller pieces easily], moisture penetration, soil depth, soil nutrient content, fungal/bacteria ratios, greenhouse-gas emissions, pollinator abundance, antibiotic usage, and biodiversity measures (p. 8)."

Cover cropping, refraining from tilling, and leaving intact roots in the soil also protect the soil from erosion (Koman et al., 2021; Musto et al., 2023). The nutrients are added into the plant matter and the bodies of microbes instead of running off or breaking down (Cusworth et al., 2024). The roots of the cover crops essentially act as stabilizing anchors and keep the soil together (Tan and Kuebbing, 2023).

When crop residue and litter are left on the field, organic carbon in the soil accumulates, an effect that is especially pronounced in the tropics and fields transitioned from intensive capitalistic agriculture (Breier et al., 2023). Breier et al., 2023 estimate that the cumulative carbon sequestration from agricultural fields could reach 26 Gt of carbon equivalent if the transition were done in a "Giant Leap" scenario, so all at once and right now. Crop residues not only add more carbon to the soil but actually build new soil to counter the loss of top-soil around the world (Rhodes, 2017). Mulching with mulch grown elsewhere still gets digested by the soil organisms and adds to soil-organic carbon increases but without the added benefit of living roots (Strüber, 2025). In the long run, carbon content of the soil stabilizes (Prairie et al., 2023). In general, regenerative agriculture maintains the below-ground fluxes of carbon and other nutrients (Prescott et al., 2021).

As one farmer, Tim May, who combines livestock with growing crops on a 1,000-hectare farm, points out in an interview with Cusworth et al. (2024), fields that are left bare are a waste of solar energy: growing cover crops means "harvesting" more of the sunlight that reaches the soil. Instead of merely warming the soil or getting reflected, the plants use the sun energy for photosynthesis. Another mixed livestock-crop farmer, George Hosier, adds in the same interview series that grazing the cover crop is the logical next step, as it means cycling nutrients right on the field.

3.1.2 Regenerative agriculture and greenhouse-gas emissions

Capitalistic agriculture is responsible for a significant part of global greenhouse-gas emissions. Regenerative agriculture can help sequester carbon and other greenhouse gases, and thus mitigating the effects of the climate crisis directly, but also reduces the new emissions on the farms. Water, another potent greenhouse gas and limited resource, has been decimated by agriculture, as was discussed above. Regenerative agriculture can significantly lower freshwater use by farms, especially by reducing losses (Colley et al., 2020).

The potential to mitigate emissions, be it carbon dioxide, methane, or other greenhouse gases, is caused by refraining from the use of synthetic fertilizers (Rehberger et al., 2023, Dědina et al., 2024), no-till practices (Yadav et al., 2023), but also by cover cropping and leaving residue on the fields (Breier et al., 2023).

Schreefel et al. (2022) analyzed greenhouse-gas emissions for alternative farm systems and found a fifty-percent reduction (in carbon-dioxide equivalent) for crop farms, six percent reduction in dairy farms, and a 23 percent reduction in mixed-use farms, all while maintaining soil functionality and increasing profits.

The land used in regenerative agriculture has huge potential to sequester carbon (Miller-Klugesherz and Sanderson) but also other potent greenhouse gases like methane: Soil under natural vegetation, as found in e.g. forests, has the strongest ability to sequester methane, followed by grasslands (Smith et al., 2021). Cultivated land has a significantly lower sink capacity for methane (Smith et al., 2021). The sink strength is weakest in fields receiving nitrogen fertilizers (Smith et al., 2021).

A study of New Zealand agriculture (Burns, 2021) found that regenerative agriculture has the potential not only to sequester carbon but also to reverse the environmental degradation caused by capitalistic agriculture. Jordon et al. (2022a) estimate that crop land in Great Britain could mitigate 16 to 27 percent of their agricultural emissions by adopting regenerative practices. They conclude that adopting regenerative agriculture would be a "meaningful contribution" to net-zero in Great Britain's agricultural emissions. Within 30 years, a quarter of emissions could be mitigated (Jordon et al., 2022a). Their study was performed in temperate oceanic regions where cover cropping is likely to be less effective than in other regions.

Cover cropping reduces soil turnover and thus lowers the amount of soil exposed to the atmosphere, allowing less gas to be emitted (Breier et al., 2023). But even just leaving crop residues in the field as mulch would lower emissions of both greenhouse gases and water (Breier et al., 2023). Prairie et al. (2023) performed a meta analysis and found that no-till and keeping growing plants in the soil increases the organic carbon in the soil, and that any use of tilling moderates the effects. Their analysis showed that regenerative agriculture can be a key factor in long-term stabilization of the carbon cycle.

Rotational grazing and afforestation offer the highest potential for increasing soil carbon (Wiltshire and Beckage). After ten years, conventional agricultural land converted to a rotational grazing pattern would increase carbon stocks in the soil by 5.3 percent while converting the same land to forest would increase it by 6.5 percent. These soils would continue to sequester "at a high rate many decades into the future (Wiltshire and Beckage, 2022, p. 1)."

Similarly, the impacts on other nutrient cycles are significantly reduced in regenerative agriculture: it is unsurprising that refraining from synthetic fertilizers reduces the impact of agriculture on the related nutrient cycles described in section 2.2.

This is true even in cities where the ground soil is often hidden below hardened grounds: increased plants in the city both lower emissions by shortening transport routes but also with the added plant biomass that absorbs carbon emissions while producing oxygen and filtering out air pollutants (Rashed, 2019).

Some research has raised concerns that offsetting one greenhouse gas might happen at the cost of increasing other greenhouse gases. For instance, Tan and Kuebbing (2023) point to the importance of mitigating emissions caused by the addition of e.g. compost. They urge to take potential increases in methane emissions into account when evaluating the sequestration potential of farming system to avoid offsetting the benefits of one with the other.

Mitigating potential increases in greenhouse gases is as important on regenerative farms as it is in capitalistic agriculture. It is important to look at the full context, though. For instance, would the emission that now occurs at the regenerative field have just been outsourced to another site in capitalistic agriculture? Is it, in effect, only a shift of emissions from one place to another or an actual raise in emissions? Either way, offsetting these emissions needs to be taken into account. This, naturally, also holds true for capitalistic agricultural systems.

3.1.3 Regenerative agriculture and biodiversity

Agriculture in the currently prevalent form has caused biodiversity loss at a rapid pace. Regenerative agriculture reduces the harm done to the ecosystem while also increasing biodiversity on the farm. The benefits of regenerative agriculture on ecosystems are supported by a growing body of evidence: the more complex, diverse landscapes of regenerative agricultural systems can offer habitats for more biodiversity (Miller-Klugesherz and Sanderson, 2023).

Food forests offer particularly high benefits for biodiversity (Albrecht and Wiek, 2021) but even a less complete approach can be highly beneficial:

Alley cropping, so adding lines of trees around and in fields, has been shown to increase biodiversity (Elevitch et al., 2018). Windbreaks are similar but intentionally planted to protect against winds. They, too, create a different microclimate in addition to the intended protection against wind impacts (Elevitch et al., 2018). Riparian buffers, planted strips between the cultivated field and nearby river ecosystems that act as living buffers, protect water bodies from run-off from the farm, thus increasing biodiversity in affected waters (Elevitch et al., 2018). The shade coffee in food-forest systems mentioned in section 2.5.3.4 also demonstrates this: Wynter et al. (2025, p. 5) describe the regenerative shade coffee systems as "diverse agroecosystem[s] containing higher associated biodiversity than intensive agricultural systems."

Increasing species diversity by intercropping or adding green manure plants enhances the resilience of the ecosystem against environmental stresses (Musto et al., 2023). In general, a correlation between biodiversity and ecosystem strength has been found in various studies (Insurance Hypothesis, e.g. Yachi and Loreau, 1999).

Increased soil carbon sits at the intersection of soil health, water properties, and biodiversity: the increase in soil carbon resulting from regenerative methods affects biodiversity and soil properties. Root systems are better established and microbial activity is enhanced which in turn stabilizes the soil aggregates and protects the soil from degradation (Jordon et al., 2022a). At the same time, water properties are improved (Strüber, 2025; Schreefel et al., 2020; Burns, 2021). Ultimately, these characteristics lead to a biodiverse soil ecosystem.

But even where soil cannot be regenerated due to hardened grounds, as they are so often found in cities, regenerative agriculture can still increase biodiversity: regenerative urban agriculture adds diverse habitats back into cities (Rashed, 2025).

3.1.4 Regenerative agriculture and extreme-weather events and pests

Regenerative agricultural practices lead to farms that are better able to cope with the stresses added by climate change (Strüber, 2025; Zahoor and Mushtaq, 2023): droughts and heat waves, flooding, but also with pest infestations—which are incidentally likely to become more common with the changing global temperatures (Zahoor and Mushtaq, 2023) and the ongoing loss of biodiversity.

In general, biodiversity has been shown to increase resilience, to act as a buffer for ecosystems to deal with added stressors like extreme-weather events and pest infestations (Mohamed et al., 2023). As discussed above, regenerative farms tend to be more biodiverse than their capitalistic counterparts (e.g. Koman et al., 2021). In a study on corn fields, LaCanne and Lundgren (2018) found the fields in capitalistic agricultural were affected by ten times as many pests (by abundance). Anecdotal evidence further supports these claims:

When the Rhine, a major German river, overflowed in 2023, many farmers in the area found their fields soaked to the point where they could not be sowed in (Harvey, 2024). Regenerative farmer Thomas Bollig (Harvey, 2024) found that their fields were able to deal with the water: the improved soils held more water, then released the excess water gradually, a quality that also helps the farmer during droughts. Bollig has shifted large parts of their farm (about 10%) to wildflower meadows to increase biodiversity on their land. They have found that the attracted wildlife consumes their pests before they decimate their crops. For instance, when the bean field was infested, they considered spraying but decided to trust the process. Two weeks later, the field was full of ladybugs with the pest eliminated naturally.

In the Mediterranean, cool winters with a lot of rain and hot, dry summers are typical, and soils tend to be low in organic carbon and with bad water-flow attributes (Musto et al., 2023). Crops are often grown over winter with a summer fallow in capitalistic agricultural models there (Musto et al., 2023). While it is common to leave crop residue in the fields over summer, a "lack of anchored, living roots in the soil over the summer months renders these soils vulnerable to damage from torrential foods that are increasingly commonplace in these regions (Musto et al., 2023, p. 328)." Musto et al. (2023) found that cover cropping led to increased resilience of the land against environmental stresses—and thus to less risk of crop loss—while also lowering the need for agrochemical inputs.

3.1.5 Regenerative agriculture and human well-being

In addition to the more indirect benefits to human health from mitigating the impacts of the climate crisis (Rocque et al., 2021), and the detrimental health impacts of agrochemical on those who apply them (de-Assis et al., 2020), regenerative agriculture also affects the well-being of those who are involved in it:

When people get directly involved with the way their food is grown, benefits are even higher: growing food has positive effects on how produce is used (Chenarides et al., 2021), as well as the well-being of communities (Rashed, 2025). Rashed (2025, p. 96) describes urban agriculture as a "regenerative practice that works with rather than for the community," which they find encourages partnerships and creates opportunities to include "unprivileged inhabitants."

Urban agriculture reintegrates nature into the city which allows communities to work together, to be a community again (Rashed, 2019). Rashed (2019) found that producing food in cities improves both human and environmental health. Urban growing also increases plants in the city: As has been shown many times with street trees and urban green spaces, these do not just benefit human mental health, improve aesthetics, but also help mitigate some of the emissions of city life and create a healthier microclimate (McPherson et al., 1999). Trees and other plants lower the temperature of the air around them (McPherson et al., 1999), something that is particularly important in urban spaces where temperatures are already up to 15 degrees Celsius hotter than in surrounding rural areas (Mentaschi et al., 2021).

The same holds true for other systems that directly involve the consumer in some way: community-supported agriculture (CPA) in the US, Solidarische Landwirtschaft (SoLaWi) in Germany, and Cooperativa de Producción Agropecuaria (CPA) in Cuba, are only three examples of community-driven agriculture where consumers pay a certain amount for a share of the farm profits, and it is quite common for the end consumer to get involved in planting and harvesting. The well-being of the farmer, too, is improved by an increase in self-efficacy (Seymour & Connelly, 2023), not just by a reduced exposure to agrochemicals. In addition, the mindset and connection to their farm often changes for farmers who shift to more regenerative methods, as will be explored in Chapter 4. Beyond that are the mitigated impacts of local and global climates caused by capitalistic agriculture and other intensive industries. These mitigation effects will be felt by all of humanity, even in areas where the shift to regenerative methods is slowest.

3.2 Criticism of regenerative agriculture

While regenerative agriculture has the potential to be highly beneficial in many ways, it is crucial to not neglect the critical voices in the debate: farmers and other stakeholders need to be taken seriously when they raise concerns about yield, profit, labor input, or uncertainty.

Some farmers feel the practices of regenerative agriculture are already "Good Agricultural Practice" in capitalistic agriculture (Giller et al., 2021). While that is certainly true for many of the methods and techniques associated with regenerative agriculture, capitalistic agriculture has clearly neglected "Good Agricultural Practice" in the pursuit of yield and profit. Thus, the differences remain the same, independent of the reason for capitalistic agriculture's neglect of good practice.

In reality, the concerns are quite often idealistic or based on fear rather than facts. Nonetheless, there are valid concerns surrounding a full shift of agricultural practices.

3.2.1 Criticism 1: Regenerative agriculture and yields

A major concern raised against regenerative agriculture is the fear that regenerative methods will not be able to feed the growing human population. This was also one of the major questions I sought to answer with this thesis: will regenerative methods be able to feed humanity?

Rehberger et al. (2023) urges to not neglect the importance of maintaining yield. There is still no consensus if regenerative agriculture can maintain yield:

Ogle et al. (2012, 2005; both as cited in Tan and Kuebbing, 2023) found that reduced-till practices can lead to yield reductions, and Dědina et al. (2024) associates a reduction in fertilizer use with a reduction in yield, while Jordon et al. (2022a) said regenerative agriculture could bring benefits without crop-yield loss. LaCanne and Lundgren (2018), evaluated corn and concluded that regenerative fields had a reduced yield (29% lower) but much higher profits (78% higher). Concerns around profitability will be evaluated in the next section. Jordon et al. (2022b) found that reduced tilling and grass-based pasture/grass systems did not lower yield but they could not confirm claims that regenerative agriculture increased yields either.

Burns (2021, p. 59) evaluated the situation for New Zealand and sees the potential for regenerative agriculture to benefit not just New Zealand but the world while "maintaining food production by farmers." A meta analysis by Lechenet (2017, as cited in Koman et al., 2021) found that lowering pesticide use typically did not reduce productivity or profitability.

Rhodes (2017) even claimed regenerative agriculture could improve crop yields. Jordon et al. (2022b) found increased yields in certain climates where water is a limiting factor. In temperate oceanic regions and humid regions, they did not find a trade-off between regenerative methods and yield at all (Jordon et al., 2022b).

Schreefel et al. (2022) offer a more nuanced view: while crop yields drop for the first five years of transitioning to regenerative agriculture, yields are likely to stabilize over a longer time span. Initially, farmers have to expect yields to drop, as phasing out pesticides initially opens up opportunities for pest and disease (Schreefel et al., 2022). Similarly, Prairie et al. (2023) caution that practitioners might not see the benefits of increased soil carbon until their seventh year.

An important fact to keep in mind, as I'll discuss at more length in section 3.3 and the discussion section (Chapter 5), the current agricultural system, capitalistic agriculture, will not be able to maintain yield either. As Koman et al (2021) point out, long-term pesticide use not only depletes soils but also negatively affects yields.

Also, focusing on yield as a single metric for the success or failure of a farm does not reflect all that the farm does and has to offer, and thus "does not reflect performance of its collective intentions (O'Donoghue et al., 2022, p. 14)." Using yield alone is a "suboptimal indicator" of farm performance, as regenerative farms contribute to regenerative objectives in addition to cultivation (LaCanne and Lundgren, 2018, p. 13). Regenerative farms do much more than produce crops. As LaCanne and Lundgren (2018, p. 1) explain in their study on corn, regenerative farms provide many ecosystem functions. For example, fields without pesticide input showed only 1/10th of the pest pressure of conventional fields, as regenerative farms can be seen as a "pest-resilient food system that outperform farmers that react to pests chemically."

3.2.2 Criticism 2: Regenerative agriculture and profits

While yield and profit are integrally related, the effects of regenerative agriculture on yields and profits need to be decoupled for proper evaluation. Again, the consensus is not complete, and while most studies point to higher profitability (e.g. Strüber, 2025, Albus et al., 2023), some studies come to the opposite conclusion.

For instance, Schreefel et al. (2022, p. 13) points to higher environmental performance but lowered farm profitability which they associated with lowering the number of animals to "improve feed self-sufficiency," so how much of the animals feed comes from pasture instead of external feed sources, lower crop yields, and a higher labor input. Higher labor input is often raised as a related concern (Strüber, 2025). While there are many studies that find labor increases with a shift to regenerative systems (e.g. Pearson, 2007), others urge to consider longer timelines. For instance, while growing and applying green manure involves more work initially than tilling the field, the labor input decreases for weed management and other activities later in the process (Strüber, 2025).

While yield can be reduced, Albus et al. (2023) find that potato fields with regenerative cultivation are more profitable than capitalistic agricultural systems. LaCanne and Lundgren (2018) found corn production was 78 percent more profitable with regenerative agriculture.

Zhou et al. (2024) spoke with farmers about integrated pest management and found that farmers are often reluctant to adopt regenerative agricultural practices because of high initial costs but also a perceived risk that the shift will fail. With the advantages often not "immediately apparent" or not easily measurable, farmers hesitate to risk changing their practice.

Dieter Pansegrau's (Strüber, 2025) crop rotation even leads to a year without any income from crops for their fields. Pansegrau recommends the same treatment with green manure for any farm seeking to transition fields from capitalistic practices to more regenerative farming. This means, the first year of a field's transition would result in a full loss of profit for that plot while costs remain non-zero. Once capitalistic agricultural practices have seen widespread use on a farm, "it is very expensive to revert to sustainable practices (Wilson, 2001, as cited in Koman et al., 2021, p. 14)" Shifting to regenerative agriculture requires short-term investment of money and labor while benefits "may not be seen for years (Carlisle, 2019, p. 14)." Initial capital cost of switching to regenerative methods may be high (Muhie, 2022). Upfront costs include additional equipment—though some of the cost can be offset with no-longer needed equipment, cover crops, manures and composts, planting of trees and hedges, as well as increased labor cost (Carlisle, 2019). Muhie (2022) suggests seeing the shift to regenerative agriculture as a long-term investment.

Despite these concerns, the regenerative agricultural market was valued at almost one billion USD in 2022 with an expected annual growth of 15.9 percent between 2023 and 2030 (Jayasinghe et al., 2023). Jayasinghe et al. calculated, this would lead to a global market of 4.2 billion USD by 2032. Clearly, the economic impact of regenerative agriculture cannot be neglected.

The loss in profits often happens off the farm with the corporations that produce and supply the synthetic inputs used in capitalistic agriculture and with other large corporations further down the line in the food system (Cusworth and Garnett, 2023; Koman et al., 2021). These corporations have large lobbies that push their interests, as Chapter 4 will detail.

As LaCanne and Lundgren (2018, p. 1) explain, food production and conservation are "pitted against each other in simplified food production systems." They do not expect success if regenerative practices are applied individually in the current food system.

Many of the potential issues with profitability of regenerative farms could be overcome by compensating farmers for the ecosystem services their farms provide (Albrecht and Wiek, 2021). As Albrecht and Wiek (2021) point out, current compensation policies are mostly focused on agro-industrial sites instead of regenerative farms. Gordon et al. (2023, p. 1837) has termed compensation of farmers for their ecosystem services "restoration for profit" and sees huge potential as a "stepping-stone for conventional farmers" interested in regenerative agriculture. Enterprise stacking, as Cusworth et al. (2024) call it, can offer another solution: by combining various income streams on the same land, the farm becomes more profitable but also resilient.

3.2.3 Criticism 3: Uncertainty of Regenerative Methods

Another major theme of criticism of regenerative agriculture is the uncertainty of results:

Khangura et al. (2023, p. 1) point to a general "lack of empirical evidence" related to regenerative agriculture. This lack of certainty in scientific evidence is a common issue in regenerative agriculture due to the variability in context, chosen practices, and lack of a strict definition (Newton et al., 2020; Jayasinghe et al., 2023).

For every benefit, there are voices that raise concerns. Tan and Kuebbing (2023), for instance, confirmed the benefits for soil carbon in the upper layers but claims that carbon stocks decreased in deeper layers at the same time. Giller et al. (2021, p. 18) acknowledge the shift in soil food webs between cultivated and natural lands but point to "little evidence for any direct causal link between soil biodiversity and any loss in function." In other words, they see the change but question the benefit of a diverse soil ecosystem. Some argue that the ability of regenerative farms to sequester carbons "remains largely uncertain and overstated (Tan and Kuebbing, 2023, p. 3)."

However, it is important to realize that the same scrutiny is rarely applied to the status quo, so while regenerative agriculture is expected to prove its perfection, the currently predominant agricultural system of capitalistic agriculture is not scrutinized the same way.

Regenerative methods often face idealistic rather than fact-based criticism. Farmers might see a shift to regenerative agriculture as a threat to not only their economic gains but also, more idealistically, as a "threat to their identity, autonomy, or social status (Zhou et al., 2024, p. 41139)."

Further research and educational programs are needed to convince skeptics but a growing body of evidence points to the benefits of regenerative agriculture and its ability to maintain high enough yields to feed a growing population (see section 3.2.1).

3.3 Borrowing from the future, the poor, and the planet

There are two components to the social considerations around agriculture: the ethical issues involved in growing food in the present, and the ethical issues surrounding the future health of the planet—and thus the future living space of coming generations.

All of the previous section assumed that continuing down the path of capitalistic agriculture, i.e. sticking with the status quo, is an option. However, as Koman et al. (2021, p. 6) point out: failure to shift to more regenerative methods is "not a viable option for the future." Hultgren et al. (2025) estimate that with each degree of warming, crop yields will decline globally by 120 calories (kcal) per day and person without adaptations.

Current agricultural systems are not only putting severe strain on the planetary boundaries of the planet (Campbell et al., 2017) but are also riddled with ethical and sociopolitical issues, as the following sections will illustrate. But, to drastically change the current food systems, Seymour and Connelly (2023, p. 231) argue, will only be possible with a "radical renegotiation of our relationship with the environment."

Ethical considerations of the human role in their environments are more relevant than ever, as humans now have the ability to influence nature on a much larger scale than they used to: impacts can now be so severe that the effects are global and long-lasting (Gorke, 2000).

3.3.1 Holism in regenerative agriculture

A concept often encountered in the context of regenerative agriculture is that of holism (Gordon et al., 2022; Seymour and Connelly, 2023). Holism is a basic shift in perspective where humans are no longer seen as a closed community separate from nature or above nature but instead as a common community with animals and plants but also with non-living materials and systems (e.g. ecosystems, soil, water; Gorke, 2000).

In their conversations with farmers, Seymour and Connelly (2023) found that almost all participants referenced holism or its concepts as influencing their worldviews and the way they came to decisions. Holism isn't always prerequisite to regenerative agriculture: The same method can even be referred to by different terminology with the only difference being the inclusion of holistic thinking: Holistic grazing, for example, is also referred to as multi-paddock adaptive grazing or adaptive management (Gordon et al., 2022). In addition, the interpretations of the concept of holism might vary widely (Gordon et al., 2022).

Regenerative agriculture, more generally, is concerned with regeneration, as the term implies: regeneration, by definition, is not the same as sustainability. Sustainability aims to sustain, i.e. keep at the current state, while regeneration seeks to improve beyond the status quo (Leu, 2020; Gosnell et al., 2019). Regenerative agriculturists do not find it sufficient to "sustain dysfunctional approaches to landscape management (Gosnell et al., 2019, p. 812)"

At the core of what they call more-than-human ethics of care, Seymour and Connelly (2023) find, are social structures and relationships. Instead of viewing agricultural production as the only purpose of the farm system, and only valuing that which produces, they suggest a shift in perspective that replaces the "extractive mentalities" with a respect and care for the "more-than-human habitat." This shift in perspective lives on the idea that all life is interdependent (Seymour and Connelly, 2023, p. 237). Beachem (2018, as cited in Seymour and Conneły, 2023) counters that such a view would still place humanity above the natural world. Instead, they argue for a view with humans as part of a horizontal web rather than at the top or center of a hierarchy.

Gorke (2000) details four basic types of environmental ethics: anthropocentrism, pathocentrism, biocentrism, and holism. They differ in their inclusion or exclusion of different objects/organisms as worthy of their ethical consideration: At one extreme is Anthropocentrism which only sees a moral obligation toward humans. They often draw indirect arguments to answer questions of animal protection and nature conservation. Pathocentrism adds so-called higher animals into their consideration and biocentrism includes all beings independent of their organizational complexity.

Holism, at the other extreme, includes all these consideration but also considers all non-living things like materials and systems (e.g. ecosystems, biosphere), and argue that everything has an intrinsic value and nothing can only exist as a means for others. The concept of intrinsic value is by now part of various conservation policies such as the 1992 Earth Summit's agreement and multiple German state nature-conservation regulations (Gorke, 2000). And while Gorke argues that most conservationists agree that species conservation should not be limited to beneficial species, they often feel compelled to wrap their arguments into an anthropocentric context to reach more citizens. This detour furthers the thinking that humans are apart from nature.

The holistic mindset is common in indigenous populations which consider the universe at large as their "extended ecological family (Gordon et al., 2023, p. 1842)." Critics of holism argue that doing harm is natural, a fact of life, or unavoidable. Indeed, holism practitioners have to accept that "life has to live at the cost of other life" but assuming intrinsic value in their surroundings shifts the burden of proof of necessity to the impacter (Gorke, 2000, p. 96). It is now vital to consider everything affected, not just the human component, before making a decision to impact any part of our environment.

Similar to the fears of green-washing related to regenerative agriculture, holism has also suffered the same buzzword implications to the point where some actively avoid being associated with the term (Gordon et al., 2023). But, as so often, the abuse of a term does not invalidate the concepts the term refers to.

3.3.2 The need to feed humanity

Current food systems are surrounded by many ethical and sociopolitical issues: exploitation of workers, animals, nature, and poorer regions of the world are commonplace. The growing population on Earth, along with a shift in dietary preferences exacerbate these issues, with some regions being more affected than others (Mizik et al., 2025). Our food systems are "shaped by capitalistic values (Bakker and Gill, 2019; as cited in Suarez and Ume, 2024)."

The negative impacts of agriculture on the planet and societies disproportionally affects poorer populations and regions (Mizik et al., 2025; FSIN/GNAFC, 2025). Deforestation for agricultural expansion, as detailed in section 2.2, is especially fast in the Global South (Chemnitz et al., 2022). Biodiverse rainforests are destroyed to make room for mono-culture production of globally traded products like palm oil, coffee, grains, and fruit but also to meet local demand for food (Pendrill et al., 2022; Campbell et al., 2017).

Generally, there is a transfer of wealth from the Global South to the Global North: Since the 1960s, corporations have moved production to cheaper regions (Fischer, 2020). Higher valued tasks remain in the Global North while the majority of the world population has to accept a sinking share of global wealth (Fischer, 2020). The pressure for suppliers is high to perform flexibly and to keep cost low, the effects of which are felt by the workers at the very bottom of the hierarchy (Fischer, 2020).

Food crises are already a major cause for displacement: 95 percent of people internally displaced, so within their country, were due to food crises, and seventy percent of all refugees and asylum seekers were fleeing countries with food crises (FSIN/GNAFC, 2025). Global crises like the COVID-19 pandemic and wars have added pressure to agricultural systems, particularly in developing countries (Mizik et al., 2025). People in those regions are also more affected by the impacts of the climate crisis with some regions already seeing "climate-induced mass migration" with effects on agricultural labor markets (Mizik et al., 2025, p. 2). In other regions migration within the country toward urban areas is common, leaving the rural areas with labor shortages (Mizik et al., 2025). Mostly due to conflict, economic shock, and weather extremes, the percentage of the global population facing high levels of acute food insecurity has been rising for the past six years, as a report by the Global Network Against Food Crises and the Food Security Information Network (FSIN/GNAFC, 2025). Weather extremes were a primary driver in 18 of the analyzed countries which caused 96 million people to be faced with high levels of acute food insecurity (FSIN/GNAFC, 2025). Weather extremes are expected to rise in intensity and frequency in the near future, and with this, the number of people faced with their impacts (Ebi et al., 2021).

While initiatives like Consultative Group for International Agricultural Research mentioned above push capitalistic agricultural methods onto developing countries (Fuglie et al., 2024), these practices and technologies might not be ideal for these farms (Mizik et al., 2025). For one, the cost of importing agrochemicals and equipment leads to large-scale mining in e.g. West Africa (Pearson, 2007). Initiatives also need to consider the effect of introducing herbicides and pesticides: while the adoption of capitalistic agricultural methods can add jobs in adjacent sectors (e.g. sale of agrochemicals), they also "contribute to social differentiation, hunger, and the exacerbation of poverty in individuals (Bouwman et al., 2020, as cited in Mizik et al., 2025, p. 7)."

In addition, small family farms are well-suited to labor-intensive agriculture, and can often be more productive than larger capitalistic systems (Mizik et al., 2025). Shifting from mixed family farms to specialized farming can drive productivity in some areas, but also leads to "intensified competition for limited resources (Mizik et al., 2025)." Similarly, larger agricultural projects can generate employment in adjacent fields like selling agricultural products but can even displace family labor (Mizik et al., 2025, p. 4).

In addition to climate-induced migration, capable agricultural workers also migrate to developed countries for higher wages in the agricultural sector there but might find themselves vulnerable to exploitation instead (Mizik et al., 2025). With migration-related labor shortages, however, it should be mentioned that child labor frequently fills the gap in the labor market (Mizik et al., 2025).

The exploitation of agricultural workers is not limited to developing countries, though. Agricultural systems in developed countries heavily depend on migrant workers for labor. In the US, for instance, 61 percent of farm workers were born in Mexico and only 38 percent were US citizens (Fung et al., 2023). This was vivid recently when most agricultural workers in California were missing during harvest time of 2025 due to immigration-enforcement raids under the Trump administration and harvests rotted unpicked on the fields (Reid et al., 2025).

Factory farming, as common in capitalistic agriculture seeks to meet the minimum standards for maximized profits at the expense of animal welfare. Animals are exploited for human consumption without due consideration and treated as products instead of beings (e.g. Anomaly, 2015). Reports of animal cruelty in factory farming are common but those raising concerns place themselves at risk of prosecution (e.g. dpa, 2025).

Indigenous cultures have long practiced the methods of regenerative agriculture while considering themselves custodians of the land (Gordon et al., 2023). Some practitioners and proponents of regenerative agriculture fail to recognize the influence of indigenous communities on the practices of regenerative agriculture (Gordon et al., 2023). The collective knowledge of entire people is re-attributed to the Global North due to "ethnocentric bias, originating in the colonial global North

(Gordon et al., 2023, p. 1842)." Beyond the exploitation of people, animals, and planets, regenerative agriculture has been white-washed, neglecting the contributions of marginalized farmers and indigenous communities (Wilson et al., 2024). The first to benefit from regenerative agriculture, explains a participant in a conversation with Gordon et al. (2023, p. 1836), are "the whites and the able bodied."

A global holistic view on the matter of worker exploitation has to view the practices as unethical: The circle of consideration excludes indigenous peoples, developing countries, and underprivileged populations. As discussed in the previous section, this would be an egocentric view. The same holds true when excluding animals from consideration.

The working conditions in agricultural fields are already strenuous with extreme temperatures and exposure to the elements. This will only get more intense with the progression of the climate crisis and the rise in frequency and intensity of extreme-weather events expected (Ebi et al., 2021). Similarly, the climate crisis is expected to reduce yields (Huldgren et al., 2025) and put the resilience of agricultural production to the test (Gordon et al., 2022). Meanwhile, a growing population of humans frequently leads to the argument that agriculture needs to feed humanity. After all, the question if regenerative agriculture can feed humanity is one of the research questions of this work. Even a temporary loss in yields with regenerative agriculture could potentially place more humans at risk of facing food insecurities.

Reality, however, paints a less clear picture: In addition to the ethical concerns surrounding factory farming, animal farming requires more resources than crop farming: Only three percent of the protein fed to beef cattle gets taken up by humans, much less than pork (9%), dairy (14%), poultry (21%), and eggs (31%), but especially compared to direct consumption of the crops (Shepon et al., 2016). The EAT-Lancet Commission on Food, Planet, Health recommended in 2019 dramatically reducing products from ruminant systems (i.e. cows, sheep, an other ruminants) and replacing red meat with plant-based proteins. Shepon et al. (2016) estimate that even a shift from beef to poultry would allow feeding an additional 120-140 million people with the mean American diet, which is roughly forty percent of the US population. Both 'clean-cow' and 'no-cow' solutions would mean disrupting the way agriculture is currently working (Cusworth et al., 2022).

Similarly, large amounts of food and energy are wasted in the processing and packaging of industrial food stuffs (Corigliano, 2024). Thus, a shift to less processed, more plant-based foods with smaller percentages of animal foods would lower the amount of land, energy, and other resources needed to feed the planet. Around Vermont, for instance, most fields grow crops that won't be eaten by the local population, not even by people elsewhere, but rather converted to animal feed (Wiltshire and Beckage, 2022). Shifting from silos holding corn and soy for animal feed to pasture-based animal farming would not affect the availability of staple produce for the local residents, something Wiltshire and Beckage (2022, p. 18) claim would also lead to "better economic resilience" of the region.

Finally, bio-fuel production is responsible for about two to three percent of agricultural water and land use. Rulli et al. (2016) estimated that about a third of the malnourished population of Earth could be fed with the space used to grow crops for bio-fuels.

With copious amounts of food wasted during production and in the food supply chains and private house holds (United Nations Environment Programme, 2024; Corigliano, 2024), and large portions of agricultural production redirected to animal feed (Shepon et al., 2016) and bio-fuel production (Rulli et al., 2016), the argument that the intensity and extent of agricultural production has to be maintained to feed humanity falls short.

The exclusion of future generations from consideration cannot be justified ethically for the same reason as above: an exclusion would be drawing an arbitrary line, thus an egocentric view and immoral.

In the sociopolitical context, holistic ethics and regenerative practices are juxtaposed with "neoliberal economic storylines, which are staunchly committed to economic growth, leading to overconsumption and exploitation (Gordon et al., 2023, p. 1833)." The interests of large corporations are important drivers of discourse around changes to the capitalistic system of agriculture. Their influence will be further illuminated in Chapter 4.

In essence, the question of feeding humanity comes down to an ethical one: does humanity have the right to exploit nature, to push and exceed planetary boundaries, and to borrow from the future of humanity and the planet to feed the current population. This question will be explored further in the discussion (Chapter 5).

Chapter Four: Public perception and involvement

Agriculture concerns us all, as humans need food to survive and thrive. Agriculture is a giant industry: The world production of crop, livestock, and aquaculture combined grossed 1.1 trillion to 4.3 trillion USD since the early 1960s (Fuglie et al., 2024). The process from seed to food stuff involves many steps and thus many people, organizations, and companies.

Seed companies, growers, agricultural retailers, fertilizer and pesticide manufacturers, research facilities, agricultural credit institutions, consultants of many kinds, processors, distributors, and the farmers or ranchers themselves, as well as the public who eats the final product are only a few of the players involved. Many more industries are connected to agriculture such as those of the technical equipment and machinery involved in farming or the production of processed foods.

The following presents a closer look at the various stakeholders surrounding modern agriculture and their perception of capitalistic and regenerative agriculture.

4.1 Various stakeholders surrounding agriculture

With the focus on profit and yield maximization, capitalistic agriculture relies heavily on fossil-fuel inputs, agrochemicals like fertilizers, pesticides and herbicides which are supplied by multi-national corporations (Gordon et al., 2023). As Gordon et al. (2023, p. 1833) phrased it, "modern agriculture is underpinned by colonial, industrial and productivist discourse." Powerful stakeholders in fossil-fuel and agrochemical industries, as well as processed-food systems further down the chain have profited from capitalistic agriculture and seek to maintain their influence (Koman et al., 2021).

The industries of oil, fertilizer, and pesticides are deeply linked with capitalistic agriculture: agrochemicals like synthetic pesticides and fertilizers are derived from fossil fuels, and more fossil fuels are used directly on the farm (Koman et al., 2021). Regenerative practices would reduce the input of fossil fuels and agrochemicals significantly. Large corporations in the aforementioned industries green-wash the terms surrounding regenerative agriculture for their own gains (Koman et al., 2021). For instance, Bayer, which manufactures glyphosate-based pesticides, market their pesticide-coated, genetically modified seeds for no-till or reduced tilling practices (Koman et al., 2021). Similarly, Big

Food corporations are embracing the concepts with pledges to offset carbon emissions in their supply chains or by buying carbon offsets from farmers (Koman et al., 2021; Cusworth and Garnett, 2023).

Various lobby groups influence the discourse around food and agriculture by pushing against climate legislation and social change with huge amounts of money (Koman et al., 2021). Powerful actors, as Gordon et al. (2023, p. 1844) call these groups, "dilute the transformation potential of [regenerative agriculture] through co-optation and greenwashing." Government agencies are influenced by the political systems they are a part of: As such, the Trump Administration in the US has shifted many agencies to climate-change skepticism even during their first term (Koman et al., 2021). During their second term, Trump's administration even began to rewrite past publications of the National Climate Assessment (AFP, 2025).

In the EU, farmers protested heavily after the European Commission proposed changes to the requirements for subsidies and changes to import regulations: farmers with tractors blocked streets all over Europe (Henley, 2024). Politicians were "anxious not to further upset an already rebellious sector" and the European farmers drew further support from far-right parties after they made gains in the EU parliament (Harvey, 2024). This dynamic is still ongoing with protests happening at intervals all throughout Europe, and a report by CropLife Europe found that more than half of European farmers planned to protest in the future if their demands are not met (Ray et al., 2025).

Research struggles to evaluate claims and thus to impact policy with the results (Jayasinghe et al., 2023) due to the lack of a clear definition of regenerative agriculture. This opens the term up to green-washing, as we will again see in section 4.3. In a framework of "farming by numbers," regenerative agriculture struggles, as many of the outcomes cannot be put into metrics (Krzywoszynska, 2024, p. 1706). The interests of lobbies, large corporations, and large capitalistic agriculture influence the opinion of farmers, politicians, and the general public with smaller, often subdivided groups trying to shape the discourse on the other end. This will be discussed in more detail in section 4.3. More generally put, regenerative agriculture on the one side and economic interests on the other side compete in the agricultural and food systems (Jayasinghe et al., 2023).

4.2 Perception of regenerative methods

The perceptions of regenerative methods vary widely and are influenced by many factors (Frankel-Goldwater et al., 2022).

While most farmers agree that certain regenerative practices, e.g. using smaller amounts of fertilizers lowers the environmental impact of agriculture, conservative agriculturists tend to associate these practices with a certain reduction in yield and thus profit, a feeling that is even stronger when considering regenerative agriculture (Dědina et al., 2024).

Another factor that should not be discounted is the (mis)conception of conventional farmers that they are already practicing soil health. To them, many of the practices common in regenerative agriculture are seen as already "integral to conventional farming (Giller et al., 2021, p. 20)." Indeed, in a survey of UK farmers, Jaworski et al. (2024, p. 16) found that the farmers "judged the degradation of the land in the United Kingdom overall to be much worse than the degradation of their own land" and soils outside of the UK even more degraded. In 2010, Schneider et al. (as cited in Jaworski et al., 2024) already pointed out that farmers tended to fail to recognize soil health issues on their own farms.

Jaworski et al. (2024, p. 17) point to the "fragmented nature of knowledge exchange." Agricultural communities are also more likely to be skeptical of scientific research results and prone to dismiss anthropogenic climate change or the consequences of ignoring the climate crisis (Alexanderson et al., 2023). This skepticism of human influence on the climate may be a "barrier to investment (Alexanderson et al., 2023, p. 7)." Farmers might even be practicing multiple methods of regenerative agriculture without connecting the term or even while avoiding the connection (Alexanderson et al., 2023). Lankford and Orr (2022, p. 14) urge to "hear the voices of farmers" and to actively involve them when choosing site-specific solutions.

An example of such stakeholder consideration is the historic Hubbell Trading post in the Navajo Nation at Ganado, Arizona (Gordon et al., 2022): With the aim to make the post economically viable, the National Park Service wanted to lease it for alfalfa production. Locals, on the other hand, wanted more traditional crops. A local hospital was in the process of starting an anti-diabetes project and a local high-school was working to revive a threatened sheep species. In an example of cooperation and collaboration rather than competition, these groups came up with a joint concept that provided local crops for the diabetes program but also pasture for the sheep.

Another issue with the perception of regenerative agriculture is that there are no "blueprint solutions" that can be applied everywhere (Lankford and Orr, 2022, p. 14). The methods most successful for one farmer might fail completely just a few fields over due to the differences in context.

Farmers have very different reasons to adopt regenerative methods: to some, regenerative agriculture appeals for idealistic reasons, while others are drawn to it for economic reasons (Beacham et al., 2023). As pointed out in 2.5.3, the same practices are often described with very different terminology and vocabulary (Gordon et al., 2023).

Once farmers become involved in regenerative practices, their perspectives often change: they tend to become more aware of their environment (Seymour and Connelly, 2023). The reverse, however, is also common: farmers become more aware of their environment and turn to regenerative methods because of this (Seymour and Connelly, 2023). One farmer in the conversations with Seymour and Connelly (2023, p. 236) explained that they used to see themselves as separate from nature but later realized they are "at the mercy of things" but also how much they could affect the outcome.

The reasons for shifting from (or starting out in) regenerative agricultural practices vary but typically are either idealism or economic necessity (Frankel-Goldwater et al., 2024). "[I]mproving the health of people, soils, and ecosystems - through farming practices and related social configurations - was a primary driver for adoption (Frankel-Goldwater et al., 2024, p. 1)." But a lack of resources can also be a strong driver for reduced labor and agrochemical input, as in the case of Gabe Brown (Brown, 2018).

When farmers are not adequately educated to anticipate the transition period (or are forced into regenerative practices for economic reasons, e.g. no resources for pesticides or fertilizer), the initial years of transitioning to regenerative methods can feel like "the wheels fell off everything (Massy, 2017; as cited in Gordon et al., 2022, p. 815)." Lower yields have to be expected for the first few years but once the farm reaches stability again, farmers experience became more positive: The ability of the land to self-heal reduced input costs and the improved biodiversity and soil health results in better yields and water properties (Gordon et al., 2022).

Once regenerative methods have been adopted for a longer period of time, farmers begin to experience the benefits: They witness pest infestations getting exterminated by biodiversity without the use of pesticides, see their farms withstand extreme-weather events, and recognize the inter-connectivity of the system of their farm and the value of the entire farm, not just the parts that can be sold or eaten (Harvey, 2024; Seymour and Connelly, 2023).

Regenerative practices are performed by people who might have fully embraced regenerative ideas and see their farming as a "vocation" or "legacy" that aids the "public good" or they might take a more pragmatic view and reduce costs by reducing agrochemical inputs while continuing to use other methods of capitalistic agriculture (Beachem et al., 2023, p. 8).

While indigenous people urge to not merely "repackage" the methods they have used in their culture's histories but also to shift from a "culture of supremacy and domination to one funded on reciprocity, respect, and interrelations with all beings (Angarova et al., 2020, as cited in Gordon et al., 2023, p. 1842)," others see regenerative agricultural practice as nothing more than "common sense (Beachem et al., 2023, p. 8)."

With the large contextual component to regenerative agriculture, farmers learn to better understand their farms (Gordon et al., 2022). Haggard and Mang (2016, as cited in Gordon et al., 2022, p. 816) see a "coevolution [of] humans and natural systems [that] can only be undertaken in specific places, using approaches that are precisely fitted to them." As such, farmers are connected to their environment, in a sort of mutualism (Mang and Reed, 2012, as cited in Gordon et al., 2022).

The transitions to regenerative farming are often gradual and Miller-Klugesherz and Sanderson (2023, p. 31) see parallels to addiction: the farmers and farms were reliant on the "chemical-intensive and subsidy-fueled treadmill of production that characterizes industrial agriculture." Regenerative agriculture, then, is seen as a form of recovery (Miller-Klugesherz and Sanderson, 2023). Frankel-Goldwater et al. (2024) also describe the diversity of pathways into regenerative agriculture. Economic, social, and environmental factors contribute jointly or separately to the adoption of regenerative practices.

4.2.1 Interview spotlights

In preparation for this work, I reached out to various practitioners of both capitalistic and regenerative agriculture. While there were few responses, those that I received shed light on the perception and experiences with regenerative methods of very different people from a balcony gardener to large-acreage farmers.

Participant 6, a full-time produce farmer since 1986 works a 15-hectare farm in Germany where they've practiced no-till for 25 years to maintain the natural layers of their soil and the "potential for natural dynamic soil development, especially that of soil microbiology (German: "Potential für natürliche dynamische Bodenentwicklung, vor allem Bodenmikrobiologie")."

They describe soils that developed over millions of years as the most productive but only if they haven't been degraded, even better if they've been taken care of in a kind of symbiosis.

Their farm follows a 16-year crop rotation including feed, green manure, and mulch production. In addition, they grow produce on part of their land and in unheated poly-tunnels. Additional straw is bought from external sources for transfer mulching. Adapting to the natural soil system of soil and plants, developing their soils and growing humus is the "center of their efforts (German: "Mittelpunkt der Bemühungen")."

While they struggle with deer, rabbits, and pigeons, they mention the "increasingly extreme weather conditions" as a much bigger problem affecting their farm. They repeat the guiding principle "healthy soil, healthy plants, healthy animals, healthy people" which was also mentioned in some of the research sources as a guiding principle of regenerative practices.

As a main reason for not embracing regenerative practices, participant 6 cites the "short-term economic orientation" which often trumps over the guiding principle mentioned above.

One respondent (participant 3) is experimenting with minimal and no-till practices and other regenerative methods to provide guidance for small single-acre farms. They studied agricultral sciences, then worked at two community-supported farms (Solidarische Landwirtschaft; SoLaWi) before joining the current team. At their current work, they till occasionally but avoid it as much as possible and limit the depth. Depending on the crop, they use green manure or mulch but in some beds also plant-based pellet fertilizers for heavy feeders. As they choose not to (and are legally not allowed to) use pesticides, herbicides, or fungicides, they instead use diversity and natural predators to control pests. If infestations with e.g. aphids become too strong, they sometimes spray home remedies like a mixture of oil, dish detergent, and water.

Participant 3 understands that the plants interact with soil life for their nutrient supply, and thus prefer to support soil life rather than the plants directly. They also hope to extend their crop rotation from currently six years to a longer cycle. Participant 3 says, they do not yet use green manure and intercropping enough but they constantly experiment with more regenerative methods.

Another participant (4) grows vegetables and sells them through a community-supported agriculture program. In addition, they sell small amounts of wholesale seedlings. While they apply the term "ecological farm" to themselves, they see a lot of overlap with what others would refer to as regenerative methods.

Participant 4 points to context as an important factor in choosing the right methods. Their grandparent farmed in Hong Kong where humanure (human manure), was used as a fertilizer and tilling ensured sun exposure of soils that could otherwise contaminate crops with pathogens.

In their gardens, they do not till. They transitioned from tractor-driven tilling to no-dig to "preserve soil structure/health and to reduce triggering the germination of annual weeds." While all the work on the farm is now hand-labor, they found a reduction in total hours of labor at maintained yields.

Despite struggles with aphids and voles, the only pesticide used is *Bacillus thuringiensis kurstaki*, a biological pest control agent with very high target specificity, which they use to control tomato horn-worms in their poly-tunnels when signs of damage first become visible.

They pay attention to their crop needs to decide when and how much of pellet fertilizer made from chicken manure they apply. Effects of previous crop rotation, the season, and the needs of the next crop are taken into account.

They regret still relying on plastic-based materials for quite a few applications, e.g. their polytunnels, silage tarps, and row covers, but also the drip-tape used in irrigation, some of which can be reused, but nonetheless breaks down over time.

On a much larger scale, participant 1 applies what they call a till-once approach to break up their clay soils and the grasses which cover much of their land for initial planting. They'd originally hoped to use green manure for preparation but experiments with tillage radishes and oats did not succeed. They and their partner bought a 47-acre farm in New York (state) which used to be a potato farm, then a horse farm. They are in the economic position to choose values over economics. Participant 1 said, they believe "regenerative practices can increase soil health and fertility while reducing the amount of work o[f] the farmer" but at the cost of "predictability of yields" and "perceived control."

Instead of external inputs, they rely on their own animals for fertilization: "The fields get direct fertilizer from the horses and sheep, and anything they do not eat gets mowed down when they rotate out." They also use their animal's manure and bedding to fertilize their garden beds by mulching, further supplemented with composts, ground animal bones, and wood ash.

Most of their land is in a five-year rotation with both crop cultivation and animal grazing. Their garden beds are not part of this rotation but instead follow their own cycle: First, horse manure and bedding covers the bed over winter, then they inoculate with mushroom spores which digest the mulch before planting. To keep weeds down, they mulch with hay and chop-and-drop (i.e. remove weeds and leave them as fresh mulch where they were removed). As soon as crops are harvested, beds are covered with cover crops. They have successfully used this system with staple crops like tomatoes and potatoes, and will experiment with more produce as beds finish the mushroom cycle.

Participant 1 explains, they aim to "regenerate the land by increasing biodiversity, managing animal grazing, and encouraging deep-rooted native plants to break through the hard pan created by plowing." For them, regenerative methods bring many struggles (e.g. tillage radishes not germinating) but they also find that they do not need to water their crops and pests are kept in balance.

Participant 2's farm chose a minimum-tillage drill on a mixed farm with cattle, sheep, crops, and some produce in Scotland. They do this both for economic reasons and soil health. When invasive species overtake areas, they resort to plowing to avoid agrochemicals. While they apply many regenerative methods, they apply synthetic fertilizers as allowed in their area, a nitrate-vulnerable zone, as designated by the UK. To minimize agrochemical inputs, they do "regular field walking" and cost/benefit analysis to choose treatment options.

They have found that fields that were drilled directly (i.e. with minimal tilling) do better both in drought and wetter conditions. Participant 2 believes, the crops use the previous plants' roots to access more soil nutrients. They follow the regenerative principle of cover cropping, as they "want all [their] soils to have growing roots in them at all time[s]." If the next crop cannot yet be planted, cover crops are grown over winter.

They currently grow in a 5-year crop rotation but aim to introduce livestock into the rotation. They understand that farmers choose to "err on the side of caution" (by which they mean the use of pesticides) as "the devastation of these pest[s] can be brutal." They do, however, point out that agrochemicals are often used "routinely and not always when they are needed." They would like to reduce their agrochemical input but they fear a reduction in yield and thus for the viability of their farm.

Participant 5, a food-security student and gardener who also organizes mutual aid efforts in Toronto, sheds light on their experience with urban agriculture: They are connected to a "very urban, very patchwork" system of food cultivation: community gardens, balconies, back yards, fruit trees, but also micro-greens. They did not know they were learning regenerative agriculture when they first started gardening in the city but the gardens are centered around "native plants, pollinator habitat, and regenerative principles."

On their own balcony, they apply regenerative principles to container gardening: instead of discarding growing soil, they mulch and "work with that soil, build it up, treat it like a living ecology" both for regenerative and ecological reasons. They describe how mushrooms started to appear around the edges of some containers last year, a sign that the "soil was developing something of its own personality," in their mind.

Context matters a lot to them with very different growing spaces. They think "it's generally worthwhile [...] to be both specific to your place and observations and humble about techniques and failure. There's legitimately no reason why any technique is going to work as a general rule. I mean, why would it? Places and soils and weather and local crops and animal life and everything are different. So if that works for someone where they live, cool? I'm just critical about turning local practices too much into broad principles and losing the point of everything."

They raise concerns about the scalability of the principles they apply on the small scale but they keep trying to apply the methods to their urban agricultural systems. As a final remark, they said they are "probably an outlier and a bit experimental" with their downtown container gardening but then added they "have the sneaking suspicion it's not as outlier/experimental as [they] think."

Finally, participant 7 describes their 2-hectare farm where they are focusing on produce and herbs with the eventual goal of selling to restaurants. Their main crops are currently garlic, basil, and peppers.

They till new plots deep (15-20 centimeters) when they first break land to create raised beds with a walk-behind rotary tiller to incorporate amendments and organic materials like leaf mould. They point to their sandy-loam soils with a low pH and minimal organic content. Tilling once loosens the soil and facilitates shoveling the soil into the raised beds. They do, however, take extra care to stay above the mycorrhizal layer when working near forested parts of their land. When they are faced with persistent weeds or to incorporate organic matter, they till shallowly (5-10 centimeters) but their established older beds are no longer tilled. "The soil is happy, I don't want to disturb it," they described.

While they currently still apply industrial fertilizers in mid-season, because "the concentration, ease of application, and price is simply too good at this point," they hope to phase these agrochemicals out in the future.

Their partner grew up on a sustenance farm and their knowledge of plant health along with annual soil testing determine where soil needs to be amended or fertilized. With cover crops, surface mulching and lime, they hope to raise the pH of their soils over time.

In some areas of their farm, they rely on (organic) pesticides like a slug-repellent or a herbicide that kills the stumps of felled invasive trees but they limit the use of these agrochemicals and only apply treatment when issues have become apparent.

They shy away from terms like regenerative agriculture and permaculture, as they see the term green-washed or as they put it, "I want to sell you an expense course full of platitudes and basic good soil management" but they do practice many of the techniques "espoused by permaculture."

The experiences of these very different participants in their very different contexts echoed what the literary analysis had shown: Regenerative agriculture is not an all-or-nothing approach and results vary widely with context.

4.3 Influencing opinions

Environmental concerns are becoming more widespread which leads to a rising number of consumers interested in products indicating sustainable sources and processing (Nugraha et al., 2024).

The market for sustainable food is growing rapidly (Nugraha et al., 2024). According to the Ecolabel Index (2023, as cited in Nugraha et al., 2024), there are now 456 different eco-labels in 199 countries. Corporations have a large ability to promote sustainability but also to hinder sustainable development (Nugraha et al., 2024).

Because green-washing practices have risen significantly in the past decade (Nugraha et al., 2024) and due to the number of different labels, there is much consumer confusion about the trustworthiness of these eco-labels (Newton et al., 2020). As mentioned in section 2.5, there is no clear definition of regenerative agriculture, and as such, the term can be applied widely by various players. This "buzzword accusation" points to increasing public interest but it also has many negative effects (Wilson et al., 2024, p. 2). Consumers are misled with advertising, lack of transparency, and labeling to believe their products have been grown in a sustainable, regenerative way (Newton et al., 2020; Nugraha et al., 2024). The lack of a definition likely "open[s] the door for unscrupulous commercial interests to exploit the term and use it misleadingly in their marketing (Newton et al., 2020, p. 8)." Similarly, the sources trusted by farmers can shape opinion, especially when they are uncertain about policy changes (Beacham et al., 2023, p. 1). Stakeholders influence all parts of food systems from production to final consumer.

The modern farm typically has little in common with the picture of a little farm house surrounded by trees in the minds of many people (Küpper, 2024). The general public holds a lot of trust in farmers (Küpper, 2024). But with green-washing prevalent in the food industry (Nugraha et al., 2024), some of that trust is unearned. The public perception of the small family farm in lieu of big agricultural corporations is facilitating political pressure enough to allow even the reversal of EU resolutions (Küpper, 2024).

In addition, groups that have much in common are often divided by idealism or nuances. For example, there is still much debate if a regenerative food system should be low-cow or “no-cow”, as Cusworth et al. (2021) phrased it. Shifting from a meat-based diet to industrial meat-replacement products requires large amounts of crops like corn and soy which are predominantly grown in large mono-culture cropping and rely on agrochemical inputs (Cusworth et al., 2022). Often neglected is the fact that much of the soy and corn grown now is already grown this way and fed to animals for meat products instead—a much less efficient system (Shepon et al., 2016).

This division into smaller and smaller camps has been ongoing since the beginning of the regenerative movement (Gordon et al., 2023) and affects many environmental and social movements. Not only does this further complicate the discourse around regenerative methods for agriculture and food systems, it also taints the vocabulary used by regenerative agriculture. Beacham et al. (2023, p.8) describe that some farmers embrace the stewardship mindset and farm for the benefit of the "public good" or their "legacy," as mentioned above. Some see this as a "rational response to the current policy environment" while others point to idealism and use terms like "zealots" an "evangelicals" to describe practitioners of regenerative agriculture. With terms like "natural," "sustainable," and now "regenerative" and "holistic" used in green-washing (Gordon et al., 2023), the general public struggles to know which products are produced in ways they'd like to support.

In addition, humans have become distanced from their natural environment both literally and metaphorically (Cazalis et al., 2023). As Seymour and Connelly (2023, p. 231) point out, "a growing body of literature argues that achieving radical change in the agri-food system requires a radical renegotiation of our relationship with the environment."

According to Koman et al. (2023), consumers and farm laborers hold little influence on the discourse surrounding food and agricultural systems. As Landers et al. (2021, p. 1) points out: there is no "lobby for adequate payments for environmental services."

Put together, there are large corporations, powerful lobbies, and near endless resources fighting to maintain the status quo in agriculture and keep up their income streams without concern for the future of the planet, to shape the narrative, and shift the discourse. The interconnected industries of oil, agrochemicals, and large industrial farms have profited from the status quo and thus "have a strong desire and lobbying capacity to maintain their foothold in the industry (Koman et al., 2021, p. 14)." On the other side are subdivided groups and small collectives that often rely on grass-root efforts to fight the flood of misinformation around agriculture.

But even limited to a local scale conflicting interests and expectations often exist around the same space: a hunter might want to maintain certain populations of game in a forest while forester might want to prioritize wood production. Both those expectations could conflict with a use in agroforestry, as grazing forests changes the species composition (Hertel et al., 2017). Local residents might want the forest for recreation. Conservationists for certain species might fear an effect on the species of interest. Local developers might prefer more building grounds. All these different stakeholders need to be taken into account and weighed when making local decisions but also when making wider policy decisions.

To prevent the breakdown of our food systems, which have been made vulnerable by capitalistic agriculture, transformation will be needed (Gordon et al., 2023), and while all these different stakeholders need to be taken into account and weighed when making local and global decisions, the influence of powerful actors on the discourse cannot be dismissed.

Chapter Five: Discussion

A growing body of both scientific research and anecdotal evidence show that shifting our agricultural and food systems to more sustainable methods will be integral in halting the devastating impact agriculture continues to have on the planetary boundaries. Our agriculture-food systems are responsible for pushing many planetary boundaries: agriculture is a major driver of the climate and biodiversity crises with high emissions, habitat fragmentation and loss, high water use, disruptions to the nutrient and water cycles, as well as the severe degradation of the world's soils.

The effects of the climate and biodiversity crises are already increasingly affecting life on earth. These impacts are disproportionately felt by the less privileged, the global South, indigenous peoples, but also the poorer parts of societies, and this inequality will only increase with the continuing climate, biodiversity, and social crises.

The cost of inactivity is tremendous: with the expected rise in demand, capitalistic farming will be unable to meet it. Humanity will need to choose between expanding agriculture and intensifying production or a complete restructure of the agriculture-food system. Sustainability, concerned with maintaining the current health of the environment, will not be enough. It will not suffice to maintain a dysfunctional status quo. Current policy is unable to affect changes fast enough. For decades, governments and corporations have pledged change, but change is too slow, too incomplete, to solve the joint impacts of the climate, biodiversity, and social crises that affect the globe.

These threats have increasingly been recognized by both governments and the general public, and multiple waves of demonstrations have shown that there is public demand for action. Unfortunately, this rise in interest has led large corporations and lobbies taking up terminology surrounding regenerative agriculture in an attempt to boost their sales rather than actual conservation. The powerful stakeholders in the fossil-fuel, agrochemical, and related industries shift the narrative in the discourse around agriculture.

Government subsidies can be seen as "welfare for the rich" rather than a tool to drive more sustainable agricultural practices: Subsidies go to those who cultivate large areas and a few selected crops, something that furthers the overproduction of few crops in mono-culture cropping on large acreages, and can even be linked to human health issues like obesity and malnutrition (Fields, 2004; Liu et al., 2010).

Regenerative agriculture is seen as an alternative to the current capitalistic model of agriculture. With a focus on soil health, ecosystem thinking, and community, regenerative agriculture is a stark contrast to the predominant model of capitalistic agriculture. By minimizing soil disturbances and external, especially synthetic inputs like pesticides and fertilizers, by keeping the ground covered and roots in the soil, by layering and rotating crops, but also by integrating forests, livestock, and pest management, regenerative agriculture focuses on regenerating ecosystems instead of using yield as the single metric for success. In the context of yield, it is further important to recall that a significant portion of agricultural land is used to provide animal feed and bio-fuels instead of going to human consumption, and that the food systems are still highly inefficient with large amounts of food wastes at every stage of the process.

While it is true that yields can drop, especially in the early years of transition, yields tend to stabilize after a few years, and profits are often higher than in capitalistic farming systems. A lack of a clear definition makes it harder for researchers to verify claims of regenerative agriculture, a problem that is further complicated by the contextuality of regenerative agriculture. Regenerative methods need to be adjusted and evaluated based on the local, individual context. Regenerative agriculture should be seen as a toolbox from which the right tools for each space are selected.

Regenerative agriculture is not in juxtaposition with modern methods. While agrochemical inputs and heavy machinery are often excluded to avoid disruptions of natural systems, some regenerative practitioners embrace digital agriculture and its cutting-edge technology.

Holism and a stewardship mindset are common in regenerative agriculture but by no mean prerequisite. While many regenerative farmers embrace holism and connect to the environment of their farm to work with nature rather than control nature, other practitioners choose regenerative methods for economic, pragmatic reasons. Nonetheless, the ethics surrounding humans and their environment are highly relevant. It is highly unethical to exploit nature and the living space of future generations to meet the needs of the current generation, and especially to further the gains of powerful stakeholders.

Instead of borrowing from the future in the sense of exploiting resources that cannot be regenerated in time for the next generations' need, we should borrow knowledge from the past while embracing modern technology and options. Instead of asking "Can regenerative agriculture feed the growing population of Earth without borrowing from future generations?," a better question would be *how* regenerative agriculture can feed the growing population of Earth without borrowing from future generations. This shifts the burden of proof which currently unfairly favors the status quo and demands certain proof of the validity of regenerative agriculture while dismissing the same concerns when considering capitalistic agriculture.

It will be important to listen to the voices of farmers, but it is important to consider that their views are often tainted by neoliberal story-lines or a short-sighted need to meet economic minima. Nonetheless, farmers and their local communities need to be involved in shifting the agricultural system to a more regenerative model based on ecosystem thinking, community thinking, and knowledge sharing rather than a system where farmers compete for limited resources and government funding. The joint knowledge of indigenous people, non-profit organizations, and grass-root movements can aid in the shift to regenerative methods, and should be embraced rather than exploited.

Safeguarding against the nefarious influence of powerful stakeholders through green-washing and the exploitation of consumer trust and confusion will be important to not water down the effects of regenerative agricultural methods.

The following are my personal recommendations for a complete restructuring of the agricultural system, and while they are based on the research discussed in this thesis, they are nonetheless opinion and should be evaluated as such. Agriculture needs to change drastically, urgently, and globally. A focus on soil health, ecosystem thinking, community, and knowledge sharing will benefit everyone (except maybe the large corporations in the fossil-fuel, agrochemical, and related industries), and thus should be the focus replacing yield and profit as the metrics. The choice for better food should no longer be pushed onto the consumer but instead regenerative systems should become the default through policy. Harmful subsidies need to be phased out, even if this means some agricultural production is no longer profitable—after all their profitability and yield are used as an excuse to halt a shift to regenerative methods.

Similarly, animal farming should be done in pasture systems were the animals feed themselves instead of large factory-farming complexes that put an intensive strain on food systems. Land currently used for growing animal feed should be transformed to rotational grazing systems, even if this means a lower number of animals and thus a shift in diets toward more plant-based food. No agricultural land should be used to grow bio-fuels, as renewable energies are better equipped to replace fossil fuels.

Table 3: Comparison of capitalistic and regenerative agricultural methods as they relate to the different spheres of impact discussed in 2.2

Impact sphere	Impacts of capital agriculture	Recommendations from regenerative agriculture
Habitat destruction	Deforestation, mono-culture cropping	Deforestation stop, crop rotation, intercropping, layering (see 2.5.3.5)
Biodiversity loss	Agrochemical inputs, mono-culture cropping	Reduction of external inputs (see 2.5.3.3), crop rotation, intercropping, layering (see 2.5.3.5), diversification of crop choice
Water-cycle disturbances	Irrigation, agrochemical inputs (run-off)	Mulching, cover cropping (see 2.5.3.2), intercropping, layering (see 2.5.3.5), reduction of external inputs (see 2.5.3.3)
Nutrient-cycle disturbances	Agricultural inputs, tilling	Reduction of external inputs (see 2.5.3.3), minimizing soil disturbances (see 2.5.3.1), buffer zones around fields
Climate change	Agricultural inputs, fossil-fuel use, soil disturbances, animal factory farming	Reduction of external inputs (see 2.5.3.3), minimizing soil disturbances (see 2.5.3.1), integrating livestock (see 2.5.3.7)
Soil degradation	Agricultural inputs, soil disturbances, heavy machinery use	Reduction of external inputs (see 2.5.3.3), minimizing soil disturbances (see 2.5.3.1), mulching, cover cropping (see 2.5.3.2), limit to heavy machinery use
Social issues	Exploitation of farm workers, indirect impacts of climate change and biodiversity loss, depletion of limited resources	Involvement of farmers, local communities, and indigenous peoples, stewardship mindset (see 2.5.3.10), adoption of regenerative methods (see 2.5.3), limiting influence of powerful stakeholders (see 4.3)

As regenerative methods are highly contextual, local communities, especially indigenous people who have experience in stewarding the land in question, need to be involved in the selection of methods appropriate for the region. Old knowledge like herding sheep (a form of predator protection more effective than fencing), reading the natural surroundings, and preserving food without energy-intensive industrial processes should be revived and embraced.

Further research should be done on each of the regenerative methods to study their impact on the environment and the ability to meet the nutritional needs of the global community in various contexts. In addition, a clear but inclusive definition would help to verify claims of regenerative agriculture and hinder green-washing efforts. As mentioned above, I would define regenerative agriculture as any form of agricultural system, be it crop or livestock production, which seeks to limit disturbances to soil, water and nutrient cycles, and ecosystems with a focus on regenerating these systems taking into account the complexity and contextuality of the agricultural ecosystem of the farm and its surrounding community while maintaining the necessary yield.

While I would like to see a full shift to regenerative methods, this is not an all-or-nothing debate. A mixed approach that adopts some practices while disregarding others is less effective than a full shift, but any step toward regenerative agriculture needs to be seen as progress in the right direction rather than failure. To ease transition, I suggest starting with the low-hanging fruit: choose the most degraded land first, the hardest plots to farm, and the spaces that cannot be farmed conventionally at all like many urban spaces. Slowly, all agricultural land should be transitioned to regenerative methods or returned to their natural state. At the very least (and most urgently), further expansion of agricultural systems needs to be halted: no further deforestation or conversion of biodiverse lands to agriculture.

Most of this change will only be possible with drastic changes to policy: harmful subsidies need to be phased out, and practices that are detrimental to the planet's future need to be discouraged or banned while the incorporation of regenerative practices should be encouraged, either through subsidies or restoration-for-profit schemes if a total ban of harmful alternatives is not immediately feasible.

The benefits of regenerative agriculture compared to capitalistic agriculture are numerous and a growing body of evidence supports the claims while the barriers remain largely ideological or based in fear rather than fact. These fears are furthered by the powerful stakeholders who seek to continue to gain from the status quo of fossil-fuel based exploitation. While wide-ranging changes to the social system away from capitalism are direly needed and would benefit a shift to a more sustainable agriculture-food system, many of the benefits of regenerative agriculture could be gained even within the framework of capitalism by paying farmers for the ecosystem services and changing policies like minimum wage to apply to the entire supply chain.

The most important change is a shift from the question *if* regenerative agriculture can feed a growing population without borrowing from future generations and the planet to *how* it can do so.

Chapter Six: Methods and motivations

The basis for this report was a semi-structured literature analysis and my personal experience from multiple years of interested research into alternative methods of agriculture and the climate and social crises. Expert interviews and book sources were added to aid some sections of this work.

During my bachelor thesis, I first started exploring the intersection of environmental protection (specifically marine-protected areas) and sociopolitical systems. I found then that protection on paper was often the choice rather than true protection (Hildenbrand, 2020). This sparked a deeper interest in real alternatives to the way societies in much of the developed world function and ultimately led to this deep look into regenerative agriculture as an alternative to the prevalent capitalistic agricultural systems.

Adopting two neglected gardens and regenerating them into productive garden plots gave me some first-hand experience with regenerative growing methods, albeit on a much smaller scale (about 1/10th of a hectare in total). This journey was followed in video format and written articles (rootsandcalluses.com) and I was able to teach others as I learned. More generally, I have been educating both myself and the public on topics surrounding the climate crisis, biodiversity crisis, and various social crises connected to these. A lot of that information was reviewed prior to writing this thesis.

Even before starting my master's degree, I knew I wanted to eventually write about regenerative agriculture in the current sociopolitical context. Through the past few years, I paid attention to the news and various online sources to keep informed on current developments in agriculture and related policy. Nonetheless, the literature analysis builds the foundation of this work.

6.1 Literature analysis

The basis of this report is a semi-structured literature analysis. The initial research was done using Google Scholar on September 18, 2024. The keyword "regenerative agriculture" resulted in 193,000 results which were filtered by publication date to exclude papers older than 2020. In addition, citations were excluded. After sorting by relevance (and thus trusting Google with some of the selection process), the first 150 citations were added to Zotero for manual sorting. Papers in languages I do not understand were excluded, as well as duplicates.

The procedure was repeated with the German keyword "Regenerative Landwirtschaft" to take advantage of my second language. The first 50 of 6,480 papers were added to Zotero for manual sorting.

In total, 179 papers were added to Zotero prior to manual sorting. After reading the abstracts, I excluded papers that seemed of low quality (potentially due to bad translations or AI use), irrelevant for the topic, as well as sources that turned out to be books. In addition, papers that were not available to the public were excluded to allow people of all social standings to check the integrity of the thesis.

During the writing of the individual sections, sections with little support from the original papers were further researched. For example, the section on agricultural effects required further backing from sources on pesticide use and water pollution, among others. As before, the paper search was limited to papers newer than 2020. In some cases, a first overview of concepts was achieved by consulting wikipedia.com, though information found there was consequently verified.

If a topic lacked context, both Google Scholar and Kagi.com where used to look for scientific sources.

Prior to starting the thesis, I had read the two books *Dirt to Soil* by Gabe Brown and *Teaming with Microbes* by Jeff Lowenfels. I referred back to these during the writing of the thesis. I also gained some early insights while watching the documentary "Ohne Pestizide" by Plan B which portrayed the traps by the Italian scientist Furlan. A well-researched video by Climate Town (2025) was included for some of the information about dairy-farming in the US. As Rollie Williams and their team provide citations for all their claims, the video was included despite technically being gray literature. Some newspaper articles were also included when they referred to current events where no suitable scientific source could be found.

Further articles, papers, and leaflets were added while stumbling upon them during my regular activities or because they were referenced by papers found in the above-mentioned research. Some papers were also suggested in discussions on social media, then evaluated before including a selection of them.

6.2 Expert interviews

In addition to the literature analysis, I conducted semi-structured interviews with agricultural practitioners. While I had originally reached out to various stakeholders, it was mostly the smaller agricultural practitioners that responded to my query. Quite a few were found after posting on Mastodon, a federated open-source social media platform. This might bias the selection. All answers were received via email. None of the queried practitioners chose the option of phone or video call interviews. Most did not respond at all or promised to get back to me at a later point but then never did.

To maintain privacy, the interviewees were numbered arbitrarily.

Interview questions:

1. Please introduce yourself briefly. Who are you? How are you connected to agriculture? What kind of agriculture are you in touch with?
2. Do you till your land? Why? Why not?
3. Do you use any fertilizers? What kind? How do you decide how much to apply and where?
4. Do you use any pesticides/herbicides/fungicides? Always or just when you see a pest? What kind?
5. An Italian scientist has created a trap that can detect the common pests on fields reliably. He claims using the traps can reduce pesticide use by 90%. What are your thoughts?
6. The last generations have been taught to till the land twice (double-tilling). This is supposed to get more moisture and nutrients into the top soil. What are your thoughts?
7. Do you use regenerative methods (crop rotation, water management, surface mulching, cover cropping, no-dig/no-till, mixed-crop beds, permaculture, etc.) on your farm or the farms you work with?
8. What methods do you use that you'd like to stop but feel there is no good alternative for?
9. What pests and diseases do you struggle with on your farm or the farms you work with?
10. Anything else you'd like me to know? Any open questions?

6.3 General notes

All translations (marked by the language followed with a colon and the original text) were translated by me. I am proficient in German and English but have no training in translations. I have translated to the best of my ability and done my due diligence to translate not merely the word but the meaning of the statements, the intent.

Differences between versions of English or style preferences were ignored in direct citations unless understanding was limited, e.g. a quote from a British report might use ploughing while a quote from a US report might use plowing. Stylistic choices like the use of the Oxford comma or hyphenation were not changed in direct quotes.

All of this work was written by me personally, and all references were cited both in-text and in the reference list with all due diligence and care. No generative AI was involved in any part of writing this thesis. It should be noted that large parts of this thesis's ideas were and are being published as social media posts and articles to make the findings accessible to a large audience. In addition, the thesis is getting turned into a book or PDF guide to regenerative cultivation in the near future. All versions of these works were created by me and are the result of my own research.

To keep the thesis easy to read, I have chosen to allow some use of first-person pronouns. References to "we" and "our" refer to humanity or the collective of me and you, the reader. References to "me" or "I" refer to my personal opinion or experience. I have attempted to keep this thesis gender-neutral. As such, the singular they/them is used in some cases. Terms like “animal husbandry” were avoided.

No funding was received that might create a conflict of interest. It should, however, be noted that I have been active as an educator in the fields of regenerative gardening, and more generally the climate, biodiversity, and connected social crises. I have taken all due diligence to reduce any influence of my perceptions on this work.

References

AFP. (2025, August 7). *US to rewrite its past national climate reports*. France 24. https://www.france24.com/en/live-news/20250807-us-to-rewrite-its-past-national-climate-reports

Albrecht, S., & Wiek, A. (2021). (PDF) Food forests: Their services and sustainability. *ResearchGate*. https://doi.org/10.5304/jafscd.2021.103.014

Albus, J., Möller, D., Finckh, M. R., & Junge, S. M. (2023, May 19). Ökonomische Bewertung und Optimierung eines regenerativen Speisekartoffelanbaus unter Transfermulch. *One Step Ahead - einen Schritt voraus! Beiträge zur 16. Wissenschaftstagung Ökologischer Landbau, Frick (CH), 7. bis 10. März 2023*. https://orgprints.org/id/eprint/50564/

Alexanderson, M. S., Luke, H., & Lloyd, D. J. (2023). Regenerative farming as climate action. *Journal of Environmental Management*, *347*, 119063. https://doi.org/10.1016/j.jenvman.2023.119063

Alles in Butter. (1979, September 9). *Der Spiegel*. https://www.spiegel.de/wirtschaft/alles-in-butter-a-01743ebf-0002-0001-0000-000039909457

Anomaly, J. (2015). What's Wrong With Factory Farming? *Public Health Ethics*, *8*(3), 246–254. https://doi.org/10.1093/phe/phu001

Beacham, J. D., Jackson, P., Jaworski, C. C., Krzywoszynska, A., & Dicks, L. V. (2023). Contextualising farmer perspectives on regenerative agriculture: A post-productivist future? *Journal of Rural Studies*, *102*, 103100. https://doi.org/10.1016/j.jrurstud.2023.103100

Benbrook, C. M. (2012). Impacts of genetically engineered crops on pesticide use in the U.S. —The first sixteen years. *Environmental Sciences Europe*, *24*(1), Article 1. https://doi.org/10.1186/2190-4715-24-24

Bodirsky, B. L., Popp, A., Weindl, I., Dietrich, J. P., Rolinski, S., Scheiffele, L., Schmitz, C., & Lotze-Campen, H. (2012). N_2O emissions from the global agricultural nitrogen cycle – current state and future scenarios. *Biogeosciences*, *9*(10), 4169–4197. https://doi.org/10.5194/bg-9-4169-2012

Brawn, J. D. (2017). Implications of Agricultural Development for Tropical Biodiversity. *Tropical Conservation Science*, *10*, 1940082917720668. https://doi.org/10.1177/1940082917720668

Breier, J., Schwarz, L., Donges, J. F., Gerten, D., & Rockström, J. (2023). *Regenerative agriculture for food security and ecological resilience: Illustrating global biophysical and social spreading potentials* (p. 16 pages, 3 MB). Potsdam Institute for Climate Impact Research. https://doi.org/10.48485/PIK.2023.001

Brown, G. (2018). *Dirt to soil: One family's journey into regenerative agriculture*. Chelsea Green Publishing.

Burns, E. A. (2021). Regenerative Agriculture: Farmer motivation, environment and climate improvement. *Policy Quarterly*, *17*(3). https://doi.org/10.26686/pq.v17i3.7133

Callaghan, M., Schleussner, C.-F., Nath, S., Lejeune, Q., Knutson, T. R., Reichstein, M., Hansen, G., Theokritoff, E., Andrijevic, M., Brecha, R. J., Hegarty, M., Jones, C., Lee, K., Lucas, A., van Maanen, N., Menke, I., Pfleiderer, P., Yesil, B., & Minx, J. C. (2021). Machine-learning-based evidence and attribution mapping of 100,000 climate impact studies. *Nature Climate Change*, *11*(11), 966–972. https://doi.org/10.1038/s41558-021-01168-6

Campbell, B. M., Beare, D. J., Bennett, E. M., Hall-Spencer, J. M., Ingram, J. S. I., Jaramillo, F., Ortiz, R., Ramankutty, N., Sayer, J. A., & Shindell, D. (2017). Agriculture production as a major driver of the Earth system exceeding planetary boundaries. *Ecology and Society*, *22*(4). https://www.jstor.org/stable/26798991

Carlisle, L., Montenegro de Wit, M., DeLonge, M. S., Iles, A., Calo, A., Getz, C., Ory, J., Munden-Dixon, K., Galt, R., Melone, B., Knox, R., & Press, D. (2019). Transitioning to Sustainable Agriculture Requires Growing and Sustaining an Ecologically Skilled Workforce. *Frontiers in Sustainable Food Systems*, *3*. https://doi.org/10.3389/fsufs.2019.00096

Cazalis, V., Loreau, M., & Barragan-Jason, G. (2023). A global synthesis of trends in human experience of nature. *Frontiers in Ecology and the Environment*, *21*(2), 85–93. https://doi.org/10.1002/fee.2540

Chemnitz, C., Heinrich-Böll-Stiftung, & Bund für Umwelt und Naturschutz Deutschland (Eds.). (2022). *Pestizidatlas: Daten und Fakten zu Giften in der Landwirtschaft* (1. Auflage). Heinrich-Böll-Stiftung.

Chenarides, L., Grebitus, C., Lusk, J. L., & Printezis, I. (2021). Who practices urban agriculture? An empirical analysis of participation before and during the COVID-19 pandemic. *Agribusiness*, *37*(1), 142–159. https://doi.org/10.1002/agr.21675

Colley, T. A., Olsen, S. I., Birkved, M., & Hauschild, M. Z. (2020). Delta Life Cycle Assessment of Regenerative Agriculture in a Sheep Farming System. *Integrated Environmental Assessment and Management*, *16*(2), 282–290. https://doi.org/10.1002/ieam.4238

Cordell, D., & White, S. (2013). Sustainable Phosphorus Measures: Strategies and Technologies for Achieving Phosphorus Security. *Agronomy*, *3*(1), 86–116. https://doi.org/10.3390/agronomy3010086

Corigliano, O., & Algieri, A. (2024). A comprehensive investigation on energy consumptions, impacts, and challenges of the food industry. *Energy Conversion* *and Management: X*, *23*, 100661. https://doi.org/10.1016/j.ecmx.2024.100661

Covert, S. Alex., Shoda, M. E., Stackpoole, S. M., & Stone, W. W. (2020). Pesticide mixtures show potential toxicity to aquatic life in U.S. streams, water years 2013–2017. *Science of The Total Environment*, *745*, 141285. https://doi.org/10.1016/j.scitotenv.2020.141285

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N., & Leip, A. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food*, *2*(3), 198–209. https://doi.org/10.1038/s43016-021-00225-9

Cusworth, G., & Garnett, T. (2023). *What is regenerative agriculture?* TABLE. https://doi.org/10.56661/2d7b8d1c

Cusworth, G., Lorimer, J., Brice, J., & Garnett, T. (2022). Green rebranding: Regenerative agriculture, future-pasts, and the naturalisation of livestock. *Transactions of the Institute of British Geographers*, *47*(4), 1009–1027. https://doi.org/10.1111/tran.12555

Cusworth, G., Lorimer, J., & Welden, E. A. (2024). Farming for the patchy Anthropocene: The spatial imaginaries of regenerative agriculture. *The Geographical Journal*, *190*(3), e12558. https://doi.org/10.1111/geoj.12558

Danilova, K. (2025). *Saisonbericht 2024*. Initiative Faire Landarbeit. https://igbau.de/Binaries/Binary21683/InitiativeFaireLandarbeit-Saisonbericht2024.pdf

de-Assis, M. P., Barcella, R. C., Padilha, J. C., Pohl, H. H., & Krug, S. B. F. (n.d.). Health problems in agricultural workers occupationally exposed to pesticides. *Revista Brasileira de Medicina Do Trabalho*, *18*(3), 352–363. https://doi.org/10.47626/1679-4435-2020-532

Dědina, M., Jevič, P., Čermák, P., Moudrý, J., Mukosha, C. E., Lošák, T., Hrušovský, T., & Watzlová, E. (2024). Environmental Life Cycle Assessment of Silage Maize in Relation to Regenerative Agriculture. *Sustainability*, *16*(2), Article 2. https://doi.org/10.3390/su16020481

Dietrich, E., & Dasgupta, V. (2023, 2024). *Geheime Weltmächte*. ZDF. https://www.zdf.de/dokus/geheime-weltmaechte-wer-bestimmt-die-zukunft-der-globalisierten-maerkte-100

dpa. (2025, June 11). Landgericht Oldenburg: Schlachthof verklagt Aktivisten auf Schadenersatz. *Die Zeit*. https://www.zeit.de/news/2025-06/11/tierschuetzer-wegen-schadenersatz-angeklagt

Ebi, K. L., Vanos, J., Baldwin, J. W., Bell, J. E., Hondula, D. M., Errett, N. A., Hayes, K., Reid, C. E., Saha, S., Spector, J., & Berry, P. (2021). Extreme Weather and

Climate Change: Population Health and Health System Implications. *Annual Review of Public Health*, *42*, 293–315. https://doi.org/10.1146/annurev-publhealth-012420-105026

Elevitch, C. R., Mazaroli, D. N., & Ragone, D. (2018). Agroforestry Standards for Regenerative Agriculture. *Sustainability*, *10*(9), Article 9. https://doi.org/10.3390/su10093337

Ellis, E. C., Klein Goldewijk, K., Siebert, S., Lightman, D., & Ramankutty, N. (2010). Anthropogenic transformation of the biomes, 1700 to 2000. *Global Ecology and Biogeography*, *19*(5), 589–606. https://doi.org/10.1111/j.1466-8238.2010.00540.x

Fields, S. (2004). The Fat of the Land: Do Agricultural Subsidies Foster Poor Health? *Environmental Health Perspectives*, *112*(14), A820–A823. https://doi.org/10.1289/ehp.112-a820

Fischer, K. (2020). Dependenz trifft Warenketten: Zur Überausbeutung von Arbeit im globalen Süden. *PROKLA. Zeitschrift für kritische Sozialwissenschaft*, *50*(198), 33–51. https://doi.org/10.32387/prokla.v50i198.1860

Food Security Information Network (FSIN) & Global Network Against Food Crises (GNAFC). (2025). *Global Report on Food Crisis 2025* (p. 34.1 MB, 254 p.) [Pdf]. FSIN/GNAC,. https://doi.org/10.71958/WFP130664

France-Presse, A. (2021, June 5). 'Sea snot' covers Turkish coast, threatening fishing industry. *The Guardian*. https://www.theguardian.com/world/2021/jun/05/sea-snot-covers-turkish-coast-threatening-fishing-industry

Frankel-Goldwater, L., Wojtynia, N., & Dueñas-Ocampo, S. (2024). Healthy people, soils, and ecosystems: Uncovering primary drivers in the adoption of regenerative agriculture by US farmers and ranchers. *Frontiers in Sustainable Food Systems*, *7*. https://doi.org/10.3389/fsufs.2023.1070518

Freedman, B. (2018). *Chapter 22 ~ Pesticides*. https://ecampusontario.pressbooks.pub/environmentalscience/chapter/chapter-22-pesticides/

Fuglie, K. O., Morgan, S., Jelliffe, J., & United States. Department of Agriculture. Economic Research Service,. (2024). *World agricultural production, resource use, and productivity, 1961-2020*. Economic Reserach Service,. https://doi.org/10.32747/2024.8327789.ers

Fung, W., Padovani, A., Prado, K., Gold, A., Carroll, D., & Finchum-Mason, E. (2023). *Findings from the National Agricultural Workers Survey (NAWS) 2021–2022: A Demographic and Employment Profile of*

United States Crop Workers (No. 17). U.S. Department of Labor.

Furlan, L., Contiero, B., Chiarini, F., Benvegnù, I., & Tóth, M. (2020). The use of click beetle pheromone traps to optimize the risk assessment of wireworm (Coleoptera: Elateridae) maize damage. *Scientific Reports*, *10*. https://doi.org/10.1038/s41598-020-64347-z

Gerber, P. J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., & FAO (Eds.). (2013). *Tackling climate change through livestock: A global assessment of emissions and mitigation opportunities*. FAO.

Giacinti, J. A., Jarvis-Cross, M., Lewis, H., Provencher, J. F., Berhane, Y., Kuchinski, K., Jardine, C. M., Signore, A., Mansour, S. C., Sadler, D. E., Stevens, B., Prystajecky, N. A., Sarma, S. N., Ojkic, D., Cortez, G. A. P., Kalhor, M., Kenmuir, E., & Sharp, C. M. (2024). Transmission dynamics of highly pathogenic avian influenza virus at the wildlife-poultry-environmental interface: A case study. *One Health*, *19*, 100932. https://doi.org/10.1016/j.onehlt.2024.100932

Gibbs, H. K., Ruesch, A. S., Achard, F., Clayton, M. K., Holmgren, P., Ramankutty, N., & Foley, J. A. (2010). Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. *Proceedings of the National Academy of Sciences*, *107*(38), 16732–16737. https://doi.org/10.1073/pnas.0910275107

Giller, K. E., Hijbeek, R., Andersson, J. A., & Sumberg, J. (2021). Regenerative Agriculture: An agronomic perspective. *Outlook on Agriculture*, *50*(1), 13–25. https://doi.org/10.1177/0030727021998063

Gordon, E., Davila, F., & Riedy, C. (2022). Transforming landscapes and mindscapes through regenerative agriculture. *Agriculture and Human Values*, *39*(2), 809–826. https://doi.org/10.1007/s10460-021-10276-0

Gordon, E., Davila, F., & Riedy, C. (2023). Regenerative agriculture: A potentially transformative storyline shared by nine discourses. *Sustainability Science*, *18*(4), 1833–1849. https://doi.org/10.1007/s11625-022-01281-1

Gorke, M. (2000). *WAS SPRICHT FÜR EINE HOLISTISCHE UMWELTETHIK?*

Gosnell, H., Gill, N., & Voyer, M. (2019). Transformational adaptation on the farm: Processes of change and persistence in transitions to ‘climate-smart’ regenerative agriculture. *Global Environmental Change*, *59*, 101965. https://doi.org/10.1016/j.gloenvcha.2019.101965

Gremmen, B. (2022). Regenerative agriculture as a biomimetic technology. *Outlook on Agriculture*, *51*(1), 39–45. https://doi.org/10.1177/00307270211070317

Harvey, F. (2019, January 28). Can we ditch intensive farming—And still feed the world? *The Guardian*. https://www.theguardian.com/news/2019/jan/28/can-we-ditch-intensive-farming-and-still-feed-the-world

Harvey, F. (2024, November 2). 'Welfare for the rich': How farm subsidies wrecked Europe's landscapes. *The Guardian*. https://www.theguardian.com/environment/2024/nov/02/farm-subsidies-wrecked-europe-environments-common-agricultural-policy

Hertel, C., Kremmler, P., Rupp, M., & Schaber-Schoor, G. (2017). *Merkblatt Waldweide*. ForstBW. https://www.fva-bw.de/fileadmin/user_upload/Abteilungen/Waldnaturschutz/ForstBW_Merkblatt_Waldweide_WEB.pdf

Hildenbrand, K. (2023). *Marine Protected Areas in reality and public perception* [Bachelor thesis]. University of Hamburg.

Hultgren, A., Carleton, T., Delgado, M., Gergel, D. R., Greenstone, M., Houser, T., Hsiang, S., Jina, A., Kopp, R. E., Malevich, S. B., McCusker, K. E., Mayer, T., Nath, I., Rising, J., Rode, A., & Yuan, J. (2025). Impacts of climate change on global agriculture accounting for adaptation. *Nature, 642*(8068), 644–652. https://doi.org/10.1038/s41586-025-09085-w

Jaworski, C. C., Krzywoszynska, A., Leake, J. R., & Dicks, L. V. (2024). Sustainable soil management in the United Kingdom: A survey of current practices and how they relate to the principles of regenerative agriculture. *Soil Use and Management*, *40*(1), e12908. https://doi.org/10.1111/sum.12908

Jayasinghe, S. L., Thomas, D. T., Anderson, J. P., Chen, C., & Macdonald, B. C. T. (2023). Global Application of Regenerative Agriculture: A Review of Definitions and Assessment Approaches. *Sustainability, 15*(22), Article 22. https://doi.org/10.3390/su152215941

Jordon, M. W., Smith, P., Long, P. R., Bürkner, P.-C., Petrokofsky, G., & Willis, K. J. (2022). Can Regenerative Agriculture increase national soil carbon stocks? Simulated country-scale adoption of reduced tillage, cover cropping, and ley-arable integration using RothC. *Science of The Total Environment*, *825*, 153955. https://doi.org/10.1016/j.scitotenv.2022.153955

Jordon, M. W., Willis, K. J., Bürkner, P.-C., Haddaway, N. R., Smith, P., & Petrokofsky, G. (2022). Temperate Regenerative Agriculture practices increase soil carbon but not crop yield—A meta-analysis.

Environmental Research Letters, *17*(9), 093001. https://doi.org/10.1088/1748-9326/ac8609

Kastner, R. (2016). Hope for the Future: How Farmers Can Reverse Climate Change1. *Socialism and Democracy*, *30*(2), 154–170. https://doi.org/10.1080/08854300.2016.1195610

Khangura, R., Ferris, D., Wagg, C., & Bowyer, J. (2023). Regenerative Agriculture—A Literature Review on the Practices and Mechanisms Used to Improve Soil Health. *Sustainability*, *15*(3), Article 3. https://doi.org/10.3390/su15032338

Koman, E., Laurilliard, E., Moore, A., & Ruiz-Uribe, N. (2021). Restoration Through Regeneration: A Scientific and Political Lens into Regenerative Agriculture in the United States. *Journal of Science Policy & Governance*. https://doi.org/10.38126/JSPG190106

Krzywoszynska, A. (2024). “You can’t manage what you can’t measure”: Regenerative agriculture, farming by numbers, and calculability in soil microbiopolitics. *Environment and Planning E: Nature and Space*, *7*(4), 1691–1710. https://doi.org/10.1177/25148486241246498

Küpper, S. (2024, January 30). Romantisierung des bäuerlichen Lebens ist keine gute Antwort. *Augsburger Allgemeine*. https://www.augsburger-allgemeine.de/wirtschaft/interview-romantisierung-des-baeuerlichen-lebens-ist-keine-gute-antwort-id69206426.html

Laborde, D., Mamun, A., Martin, W., Piñeiro, V., & Vos, R. (2021). Agricultural subsidies and global greenhouse gas emissions. *Nature Communications*, *12*(1), 2601. https://doi.org/10.1038/s41467-021-22703-1

LaCanne, C. E., & Lundgren, J. G. (2018). Regenerative agriculture: Merging farming and natural resource conservation profitably. *PeerJ*, *6*, e4428. https://doi.org/10.7717/peerj.4428

Lal, R. (2020). Regenerative agriculture for food and climate. *Journal of Soil and Water Conservation*, *75*(5), 123A-124A. https://doi.org/10.2489/jswc.2020.0620A

Landers, J. N., de Freitas, P. L., de Oliveira, M. C., da Silva Neto, S. P., Ralisch, R., & Kueneman, E. A. (2021). Next Steps for Conservation Agriculture. *Agronomy*, *11*(12), Article 12. https://doi.org/10.3390/agronomy11122496

Lankford, B., & Orr, S. (2022). Exploring the Critical Role of Water in Regenerative Agriculture; Building Promises and Avoiding Pitfalls. *Frontiers in Sustainable Food Systems*, *6*. https://doi.org/10.3389/fsufs.2022.891709

Leu, A. (2020). An overview of global organic and regenerative agriculture movements. *Organic Food Systems: Meeting the Needs of Southern Africa*, 21–31. https://doi.org/10.1079/9781786399601.0021

Levers, C., Romero-Muñoz, A., Baumann, M., De Marzo, T., Fernández, P. D., Gasparri, N. I., Gavier-Pizarro, G. I., Waroux, Y. le P. de, Piquer-Rodríguez, M., Semper-Pascual, A., & Kuemmerle, T. (2021). Agricultural expansion and the ecological marginalization of forest-dependent people. *Proceedings of the National Academy of Sciences*, *118*(44), e2100436118. https://doi.org/10.1073/pnas.2100436118

Liu, J., You, L., Amini, M., Obersteiner, M., Herrero, M., Zehnder, A. J. B., & Yang, H. (2010). A high-resolution assessment on global nitrogen flows in cropland. *Proceedings of the National Academy of Sciences*, *107*(17), 8035–8040. https://doi.org/10.1073/pnas.0913658107

Lowenfels, J., & Lewis, W. (2010). *Teaming with microbes: The organic gardener's guide to the soil food web* (Rev. ed). Timber Press.

Luján Soto, R., Martínez-Mena, M., Cuéllar Padilla, M., & de Vente, J. (2021). Restoring soil quality of woody agroecosystems in Mediterranean drylands through regenerative agriculture. *Agriculture, Ecosystems & Environment*, *306*, 107191. https://doi.org/10.1016/j.agee.2020.107191

Malhi, G. S., Kaur, M., & Kaushik, P. (2021). Impact of Climate Change on Agriculture and Its Mitigation Strategies: A Review. *Sustainability*, *13*(3), Article 3. https://doi.org/10.3390/su13031318

McLennon, E., Dari, B., Jha, G., Sihi, D., & Kankarla, V. (2021). Regenerative agriculture and integrative permaculture for sustainable and technology driven global food production and security. *Agronomy Journal*, *113*(6), 4541–4559. https://doi.org/10.1002/agj2.20814

McPherson, E. G., Simpson, J. R., Peper, P. J., & Xiao, Q. (1999). Benefit-Cost Analysis of Modesto's Municipal Urban Forest. *Arboriculture & Urban Forestry (AUF)*, *25*(5), 235–248. https://doi.org/10.48044/jauf.1999.033

Mentaschi, L., Duveiller, G., Zulian, G., Corbane, C., Pesaresi, M., Maes, J., Stocchino, A., & Feyen, L. (2022). Global long-term mapping of surface temperature shows intensified intra-city urban heat island extremes. *Global Environmental Change*, *72*, 102441. https://doi.org/10.1016/j.gloenvcha.2021.102441

Miller-Klugesherz, J. A., & Sanderson, M. R. (2023). Good for the soil, but good for the farmer? Addiction and recovery in transitions to regenerative agriculture.

Journal of Rural Studies, *103*, 103123. https://doi.org/10.1016/j.jrurstud.2023.103123

Mizik, T., Nagy, J., Molnár, E. M., & Maró, Z. M. (2025). Challenges of employment in the agrifood sector of developing countries—A systematic literature review. *Humanities and Social Sciences Communications*, *12*(1), 62. https://doi.org/10.1057/s41599-024-04308-3

Mohamed, A., DeClerck, F., Verburg, P. H., Obura, D., Abrams, J. F., Zafra-Calvo, N., Rocha, J., Estrada-Carmona, N., Fremier, A., Jones, S. K., Meier, I. C., & Stewart-Koster, B. (2024). Securing Nature's Contributions to People requires at least 20%–25% (semi-)natural habitat in human-modified landscapes. *One Earth*, *7*(1), 59–71. https://doi.org/10.1016/j.oneear.2023.12.008

Muhie, S. H. (2022). Novel approaches and practices to sustainable agriculture. *Journal of Agriculture and Food Research*, *10*, 100446. https://doi.org/10.1016/j.jafr.2022.100446

Musto, G. A., Swanepoel, P. A., & Strauss, J. A. (2023). Regenerative agriculture v. conservation agriculture: Potential effects on soil quality, crop productivity and whole-farm economics in Mediterranean-climate regions. *The Journal of Agricultural Science*, *161*(3), 328–338. https://doi.org/10.1017/S0021859623000242

Naithani, S. (2021). *The Origins of Agriculture*. https://open.oregonstate.education/cultivatedplants/chapter/agriculture/

Newton, P., Civita, N., Frankel-Goldwater, L., Bartel, K., & Johns, C. (2020). What Is Regenerative Agriculture? A Review of Scholar and Practitioner Definitions Based on Processes and Outcomes. *Frontiers in Sustainable Food Systems*, *4*. https://doi.org/10.3389/fsufs.2020.577723

Nicholson, C. C., Knapp, J., Kiljanek, T., Albrecht, M., Chauzat, M.-P., Costa, C., De la Rúa, P., Klein, A.-M., Mänd, M., Potts, S. G., Schweiger, O., Bottero, I., Cini, E., de Miranda, J. R., Di Prisco, G., Dominik, C., Hodge, S., Kaunath, V., Knauer, A., … Rundlöf, M. (2024). Pesticide use negatively affects bumble bees across European landscapes. *Nature*, *628*(8007), 355–358. https://doi.org/10.1038/s41586-023-06773-3

Nugraha, W. S., Szakos, D., Süth, M., & Kasza, G. (2024). Greenwashing in the food industry: A systematic review exploring the current situation and possible countermeasures. *Cleaner and Responsible Consumption*, *15*, 100227. https://doi.org/10.1016/j.clrc.2024.100227

O'Donoghue, T., Minasny, B., & McBratney, A. (2022). Regenerative Agriculture and Its Potential to Improve

Farmscape Function. *Sustainability, 14*(10), Article 10. https://doi.org/10.3390/su14105815

OECD. (2024). *Agricultural Policy Monitoring and Evaluation 2024: Innovation for Sustainable Productivity Growth*. OECD. https://doi.org/10.1787/74da57ed-en

Ordiz, A., Canestrari, D., & Echegaray, J. (2024). Large carnivore management at odds: Science or prejudice? *Global Ecology and Conservation*, *54*, e03202. https://doi.org/10.1016/j.gecco.2024.e03202

Ouaissa, S., Gómez-Jakobsen, F., Yebra, L., Ferrera, I., Moreno-Ostos, E., Belando, M. D., Ruiz, J. M., & Mercado, J. M. (2023). Phytoplankton dynamics in the Mar Menor, a Mediterranean coastal lagoon strongly impacted by eutrophication. *Marine Pollution Bulletin*, *192*, 115074. https://doi.org/10.1016/j.marpolbul.2023.115074

Paul, K. C., Krolewski, R. C., Lucumi Moreno, E., Blank, J., Holton, K. M., Ahfeldt, T., Furlong, M., Yu, Y., Cockburn, M., Thompson, L. K., Kreymerman, A., Ricci-Blair, E. M., Li, Y. J., Patel, H. B., Lee, R. T., Bronstein, J., Rubin, L. L., Khurana, V., & Ritz, B. (2023). A pesticide and iPSC dopaminergic neuron screen identifies and classifies Parkinson-relevant pesticides. *Nature Communications*, *14*(1), 2803. https://doi.org/10.1038/s41467-023-38215-z

Pearson, C. J. (2007). Regenerative, Semiclosed Systems: A Priority for Twenty-First-Century Agriculture. *BioScience*, *57*(5), 409–418. https://doi.org/10.1641/B570506

Pendrill, F., Gardner, T. A., Meyfroidt, P., Persson, U. M., Adams, J., Azevedo, T., Bastos Lima, M. G., Baumann, M., Curtis, P. G., De Sy, V., Garrett, R., Godar, J., Goldman, E. D., Hansen, M. C., Heilmayr, R., Herold, M., Kuemmerle, T., Lathuillière, M. J., Ribeiro, V., … West, C. (2022). Disentangling the numbers behind agriculture-driven tropical deforestation. *Science*, *377*(6611), eabm9267. https://doi.org/10.1126/science.abm9267

Petry, D., Avanzini, S., Vidal, A., Bellino, F., Bugas, J., Conant, H., Hoo, S., Unnikrishnan, S., & Westerlund, M. (2023, May). *Cultivating-farmer-prosperity_Investing-in-regenerative-agriculture*. Boston Consulting Group, OP2B. https://www.wbcsd.org/wp-content/uploads/2023/09/Cultivating-farmer-prosperity_Investing-in-regenerative-agriculture.pdf

Pillay, R., Venter, M., Aragon-Osejo, J., González-del-Pliego, P., Hansen, A. J., Watson, J. E., & Venter, O. (2022). Tropical forests are home to over half of the world’s vertebrate species. *Frontiers in Ecology and the Environment*, *20*(1), 10–15. https://doi.org/10.1002/fee.2420

Pimentel, D. (1996). Green revolution agriculture and chemical hazards. *Science of The Total Environment*, *188*, S86–S98. https://doi.org/10.1016/0048-9697(96)05280-1

Porto, R. G., De Almeida, R. F., Cruz-Neto, O., Tabarelli, M., Viana, B. F., Peres, C. A., & Lopes, A. V. (2020). Pollination ecosystem services: A comprehensive review of economic values, research funding and policy actions. *Food Security*, *12*(6), 1425–1442. https://doi.org/10.1007/s12571-020-01043-w

Prairie, A. M., King, A. E., & Cotrufo, M. F. (2023). Restoring particulate and mineral-associated organic carbon through regenerative agriculture. *Proceedings of the National Academy of Sciences*, *120*(21), e2217481120. https://doi.org/10.1073/pnas.2217481120

Prescott, C. E., Rui, Y., Cotrufo, M. F., & Grayston, S. J. (2021). Managing plant surplus carbon to generate soil organic matter in regenerative agriculture. *Journal of Soil and Water Conservation*, *76*(6), 99A-104A. https://doi.org/10.2489/jswc.2021.0920A

Ramkumar, D., Marty, A., Ramkumar, J., Rosencranz, H., Vedantham, R., Goldman, M., Meyer, E., Steinmetz, J., Weckle, A., Bloedorn, K., & Rosier, C. (2024). Food for thought: Making the case for food produced via regenerative agriculture in the battle against non-communicable chronic diseases (NCDs). *One Health*, *18*, 100734. https://doi.org/10.1016/j.onehlt.2024.100734

Rapuc, W., Guinoiseau, D., Arnaud, F., Dellinger, M., Sabatier, P., Gaillardet, J., Poulenard, J., & Bouchez, J. (2025). Human and climate impacts on the alpine Critical Zone over the past 10,000 y. *Proceedings of the National Academy of Sciences*, *122*(29), e2506030122. https://doi.org/10.1073/pnas.2506030122

Rashed, R. (2019). (PDF) Urban Agriculture: A Regenerative Urban Development Practice to Decrease the Ecological Footprints of CitiesUntitled. *ResearchGate*. https://doi.org/10.21625/essd.v2i2.170

Ray, O., Vogel, N., & Barnier, D. (2025). *Farmer's Horizon: 1 year after farmers' protests*. CropLife Europe.

Regenerative agriculture needs a reckoning. (2021, May 3). *The Counter*. https://thecounter.org/regenerative-agriculture-racial-equity-climate-change-carbon-farming-environmental-issues/

Rehberger, E., West, P. C., Spillane, C., & McKeown, P. C. (2023). What climate and environmental benefits of regenerative agriculture practices? An evidence review. *Environmental Research Communications*, *5*(5), 052001. https://doi.org/10.1088/2515-7620/acd6dc

Rhodes, C. J. (2012). Feeding and Healing the World: Through Regenerative Agriculture and Permaculture. *Science Progress*, *95*(4), 345–446. https://doi.org/10.3184/003685012X13504990668392

Rhodes, C. J. (2017). The Imperative for Regenerative Agriculture. *Science Progress*, *100*(1), 80–129. https://doi.org/10.3184/003685017X14876775256165

Ritchie, H. (2021). Deforestation and Forest Loss. *Our World in Data*. https://ourworldindata.org/deforestation

Rocque, R. J., Beaudoin, C., Ndjaboue, R., Cameron, L., Poirier-Bergeron, L., Poulin-Rheault, R.-A., Fallon, C., Tricco, A. C., & Witteman, H. O. (2021). Health effects of climate change: An overview of systematic reviews. *BMJ Open*, *11*(6), e046333. https://doi.org/10.1136/bmjopen-2020-046333

Roosevelt, F. D. (1937, February 26). *Letter to all State Governors on a Uniform Soil Conservation Law.* https://www.presidency.ucsb.edu/documents/letter-all-state-governors-uniform-soil-conservation-law

Ruiz-Ramírez, C., Castillo-Rojas-Marcos, Juan, & Molinero-Gerbeau, Yoan. (2024). *Essential but Invisible and Exploited: A literature review of migrant workers' experiences in European agriculture*. Oxfam International. https://policy-practice.oxfam.org/resources/essential-but-invisible-and-exploited-a-literature-review-of-migrant-workers-ex-621604/

Rulli, M. C., Bellomi, D., Cazzoli, A., De Carolis, G., & D'Odorico, P. (2016). The water-land-food nexus of first-generation biofuels. *Scientific Reports*, *6*(1), 22521. https://doi.org/10.1038/srep22521

Schreefel, L., Schulte, R. P. O., de Boer, I. J. M., Schrijver, A. P., & van Zanten, H. H. E. (2020). Regenerative agriculture – the soil is the base. *Global Food Security*, *26*, 100404. https://doi.org/10.1016/j.gfs.2020.100404

Schreefel, L., van Zanten, H. H. E., Groot, J. C. J., Timler, C. J., Zwetsloot, M. J., Schrijver, A. P., Creamer, R. E., Schulte, R. P. O., & de Boer, I. J. M. (2022). Tailor-made solutions for regenerative agriculture in the Netherlands. *Agricultural Systems*, *203*, 103518. https://doi.org/10.1016/j.agsy.2022.103518

Seymour, M., & Connelly, S. (2023). Regenerative agriculture and a more-than-human ethic of care: A relational approach to understanding transformation. *Agriculture and Human Values*, *40*(1), 231–244. https://doi.org/10.1007/s10460-022-10350-1

Shepon, A., Eshel, G., Noor, E., & Milo, R. (2016). Energy and protein feed-to-food conversion efficiencies in the US and potential food security gains from dietary changes. *Environmental Research Letters*, *11*(10), 105002. https://doi.org/10.1088/1748-9326/11/10/105002

Sherwood, S., & Uphoff, N. (2000). Soil health: Research, practice and policy for a more regenerative agriculture. *Applied Soil Ecology*, *15*(1), 85–97. https://doi.org/10.1016/S0929-1393(00)00074-3

Singh, I., Hussain, M., Manjunath, G., Chandra, N., & Ravikanth, G. (2023). Regenerative agriculture augments bacterial community structure for a healthier soil and agriculture. *Frontiers in Agronomy*, *5*. https://doi.org/10.3389/fagro.2023.1134514

Smith, P., Bustamante, M., Ahammad, H., Clark, H., Haberl, H., Harper, R., House, J., Jafari, M., Masera, O., Mbow, C., Ravindranath, N. H., Rice, W., Abad, C. R., Romanovskaya, A., Sperling, F., Tubiello, F. N., Berndes, G., Bolwig, S., Böttcher, H., … Molodovskaya, M. (2014). *11 Agriculture, Forestry and Other Land Use (AFOLU)*.

Smith, P., Reay, D., & Smith, J. (2021). Agricultural methane emissions and the potential formitigation. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *379*(2210), 20200451. https://doi.org/10.1098/rsta.2020.0451

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries, W., de Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, *347*(6223), 1259855. https://doi.org/10.1126/science.1259855

Strüber, K. (2025). *Mulch im Gemüsebau*. ÖKORING. https://www.solidarische-landwirtschaft.org/aktuelles/news/news-detail/mulch-im-gemuesebau-broschuere-filme-und-podcasts-veroeffentlicht/

Subramanian, K. S., Pazhanivelan, S., Srinivasan, G., Santhi, R., & Sathiah, N. (2021). Drones in Insect Pest Management. *Frontiers in Agronomy*, *3*. https://doi.org/10.3389/fagro.2021.640885

Sumberg, J. (2022). Future agricultures: The promise and pitfalls of a (re)turn to nature. *Outlook on Agriculture*, *51*(1), 3–10. https://doi.org/10.1177/00307270221078027

Tagesschau. (2025, June 25). *Arbeitsministerin gegen Mindestlohn-Ausnahmen für Saisonarbeiter.* tagesschau.de. https://www.tagesschau.de/inland/debatte-mindestlohn-saisonkraefte-102.html

Tan, S. S. X., & Kuebbing, S. E. (2023). A synthesis of the effect of regenerative agriculture on soil carbon sequestration in Southeast Asian croplands. *Agriculture, Ecosystems & Environment*, *349*, 108450. https://doi.org/10.1016/j.agee.2023.108450

The EAT-Lancet Commission on Food, Planet, Health. (n.d.). *The Planetary Health Diet*. EAT. Retrieved September 5, 2025, from https://eatforum.org/eat-lancet-commission/the-planetary-health-diet-and-you/

Tian, F., Zhou, J., Ransom, C. J., Aloysius, N., & Sudduth, K. A. (2025). Estimating corn leaf chlorophyll content using airborne multispectral imagery and machine learning. *Smart Agricultural Technology, 10*, 100719. https://doi.org/10.1016/j.atech.2024.100719

United Nations. (n.d.). *UN calls for urgent action to feed the world's growing population healthily, equitably and sustainably*. United Nations; United Nations. Retrieved April 4, 2025, from https://www.un.org/en/desa/un-calls-urgent-action-feed-world%E2%80%99s-growing-population-healthily-equitably-and-sustainably

University of Cambridge. (2012, March 23). *From foraging to farming: The 10,000-year revolution | University of Cambridge*. https://www.cam.ac.uk/research/news/from-foraging-to-farming-the-10000-year-revolution

VanDerZanden, A. M. (2018). How hormones and growth regulators affect your plants. *Ag - Community Horticulture/Landscape*. https://extension.oregonstate.edu/gardening/techniques/how-hormones-growth-regulators-affect-your-plants

Whitmee, S., Haines, A., Beyrer, C., Boltz, F., Capon, A. G., De Souza Dias, B. F., Ezeh, A., Frumkin, H., Gong, P., Head, P., Horton, R., Mace, G. M., Marten, R., Myers, S. S., Nishtar, S., Osofsky, S. A., Pattanayak, S. K., Pongsiri, M. J., Romanelli, C., … Yach, D. (2015). Safeguarding human health in the Anthropocene epoch: Report of The Rockefeller Foundation–Lancet Commission on planetary health. *The Lancet*, *386*(10007), 1973–2028. https://doi.org/10.1016/S0140-6736(15)60901-1

Williams, R. (Director). (2025, May 28). *Dairy Is Milking America Dry | Climate Town* [Video recording]. Climate Town Productions. https://www.youtube.com/watch?v=NQiLly6Z1xs

Wilson, K. R., Hendrickson, M. K., & Myers, R. L. (2024). A buzzword, a "win-win", or a signal towards the future of agriculture? A critical analysis of regenerative agriculture. *Agriculture and Human Values*. https://doi.org/10.1007/s10460-024-10603-1

Wilson, K. R., Myers, R. L., Hendrickson, M. K., & Heaton, E. A. (2022). Different Stakeholders' Conceptualizations and Perspectives of Regenerative Agriculture Reveals More Consensus Than Discord. *Sustainability*, *14*(22), Article 22. https://doi.org/10.3390/su142215261

Wiltshire, S., & Beckage, B. (2022). Soil carbon sequestration through regenerative agriculture in the U.S. state of Vermont. *PLOS Climate*, *1*(4), e0000021. https://doi.org/10.1371/journal.pclm.0000021

WWF. (2024). *Living Planet Report 2024 – A System in Peril. WWF, Gland, Switzerland*. World Wildlife Foundation. https://wwflpr.awsassets.panda.org/downloads/2024-living-planet-report-a-system-in-peril.pdf

Wynter, V., Milner-Gulland, E. J., & Poore, J. (2025). A global comparison of the biodiversity impacts of coffee agricultural systems—From monoculture to diverse agroforestry. *Agricultural Systems*, *229*, 104449. https://doi.org/10.1016/j.agsy.2025.104449

Yachi, S., & Loreau, M. (1999). Biodiversity and ecosystem productivity in a fluctuating environment: The insurance hypothesis. *Proceedings of the National Academy of Sciences*, *96*(4), 1463–1468. https://doi.org/10.1073/pnas.96.4.1463

Yadav, A., Prajapati, J., Kumar, R., & Upadhyay, A. (2023). *Regenerative Agriculture-A Review*. *4*(1).

Zahoor, I., & Mushtaq, A. (2023). Water Pollution from Agricultural Activities: A Critical Global Review. *International Journal of Chemical and Biochemical Sciences*, *23*(1), 164–176.

Zhou, W., Arcot, Y., Medina, R. F., Bernal, J., Cisneros-Zevallos, L., & Akbulut, M. E. S. (2024). Integrated Pest Management: An Update on the Sustainability Approach to Crop Protection. *ACS Omega*, *9*(40), 41130–41147. https://doi.org/10.1021/acsomega.4c06628

Appendix

Acknowledgements

I'm grateful to my two advisors, Felix and Jaap, who have supported my choice of topic, but also agreed to a very dense schedule for completion that left them with little time for feedback and grading. I'm glad I chose you two to be my advisors. I couldn't have done this without you.

I'd also like to thank my interview respondents. Your timely and detailed responses helped tremendously in the creation of this work.

I'd like to thank my family and friends who kept me accountable, supported me in the research and writing of this thesis, especially my partner who let me take over the living room for weeks on end and listened to all my ramblings, and Sarah who never got tired debating the smallest nuances even after hundreds of messages related to the topic. Thank you for your help and unwavering support.

The writing of this thesis would not have been possible without the ongoing support of the Fediverse community which was always available to discuss gardening and agriculture, to calm my nerves, or help track down a lost reference, but also for proof-reading.

Glossary and abbreviations

The glossary describes the terms as they apply to this thesis. Keep in mind that some definitions will not necessarily apply in different contexts. For instance, an aerosol is technically solid or liquid particles in any gas, not just air. But for the sake of this thesis, only aerosols in air are relevant. I have done my best to keep this glossary easy to read which means simplifying some conceps.

Abiotic: non-living

Aerosol: solid or liquid particles in air

Anthropogenic: human-made, human-caused

Arthropod: animal belonging to the group Arthropoda; they have exoskeletons, segmented bodies, and paired limbs; examples: spiders, insects, centipedes, springtails

Archaea: microbial organisms similar to bacteria in shape and size that belong to the domain Archaea

Bio-fuel: fuel produced from biomass through industrial processes

Capillary force: the force that allows water to flow against gravity in very narrow spaces; wicking

Diversity desert: areas with little biodiversity

Domain: all life on Earth is split into three major groups: Bacteria, Archaea, Eukaryotes; humans, plants, animals, all belong to the third group

Enteric fermentation: digestive processes inside animals during which microbial organisms like archaea break down food

Green-washing: advertising that seeks to mislead customers into assuming a product is sustainable or regenerative

Heavy feeders: plants that require an above-average amount of nutrients

Horizon (soil horizon): layers in the soil with different characteristics

Humus: organic matter in soil

Light feeders: plants that require a below-average amount of nutrients

Medium feeders: plants that require an average amount of nutrients

Methanogenic: producing methane

Mono-culture: a single variety of crop is grown in an area

Nematode: roundworms

Paddies: rice fields

Pasture: land used to graze animals, especially ruminant animals

Protozoa: single-celled eukaryotes, so members of the domain humans belong to but much closer in shape and size to bacteria and archaea

Ruminant: herbivorous animals with three to four stomach divisions specialized for feeding on fibrous food like grass

Sink capacity: ability to sequester carbon from the atmosphere into the ground

Tables and Figures

Table of Figures

Alt texts for figures

Figure 1: A graph that separates a circle into slices for the nine planetary boundaries (1. Land-system change; 2. Freshwater use; 3. Biogeochemical flows - nitrogen and phosphorus cycles; 4. Biosphere integrity; 5. Climate change; 6. Ocean acidification; 7. Stratospheric ozone depletion; 8. Atmospheric aerosol loading; and 9. Introduction of novel entities.") The impact of agriculture is overlaid with dots. A green-yellow-red code shows the state of the planetary boundary (safe, increasing risk, high risk). Two boundaries (novel entities, atmospheric aerosol loading) are grayed out and show a question mark to indicate that the boundaries are not yet quantified. For the impact numbers, please refer to Campbell et al., 2017.

Figure 2: A graph showing the use of pesticides over time. Above the graph, the heading "Pesticide breakdown by type, World, 1990 to 2022" with the subheading "Pesticide use, broken down by product type, measured in tonnes of active ingredient." At the top right is the logo of Our World in Data. The x-axis shows the years between 1990 and 2022 in 5-year increments, the y-axis the amount in million tonnes (of the active ingredient). The amount grows from 1990 to 2022 for all types of pesticides (about 1.75 million tonnes total in 1990 to more than 3.5 million tonnes in 2022). The relative abundance of different types of pesticides is shown by dividing the area under the line into different colors. Herbicides take up the largest portion, and the 2022 amount of herbicides is almost as high as the total amount in 1990. Herbicides make up about half of the total, with insecticides and fungicides/bactericides making up almost a quarter each. Narrower areas make up the other types of pesticides (other pesticides, plant-growth regulators, rodenticides). The relative abundances stay

roughly the same. The total amount has continually risen with small dips in some years (all types dip in the same years).

Below the graph, the data source (Food and Agriculture Organization of the United Nations (2024)), the short link (OurWorldinData.org/pesticides) and the license (CC BY) are mentioned.

Figure 3: A graph showing fertilizer consumption between 1961 and 2019. Above the graph, the heading "Fertilizer consumption, 1961 to 2019" and the subheading "Total consumption is the sum of synthetic inputs of nitrogen, potassium and phosphorus, plus organic nitrogen inputs." At the top right is the logo of Our World in Data. The x-axis shows the years between 1961 and 2019 in roughly ten-year intervals. In 1961, the total fertilizer consumption is just above 50 million tonnes. In 2019, the total consumption has surpassed 200 million tonnes. At first, the line grows steadily (up to about 175 million in 1990), then there is a dip for a few years, before the steady rise continues. Another sharp dip around 2008 is quickly recovered and the steady climb continues.

Below the graph, the data source (Food and Agriculture Organization of the United Nations via the United States Department for Agriculture (USDA)), the short link (OurWorldinData.org/fertilizers) and the license (CC BY) are mentioned.

Index of Tables