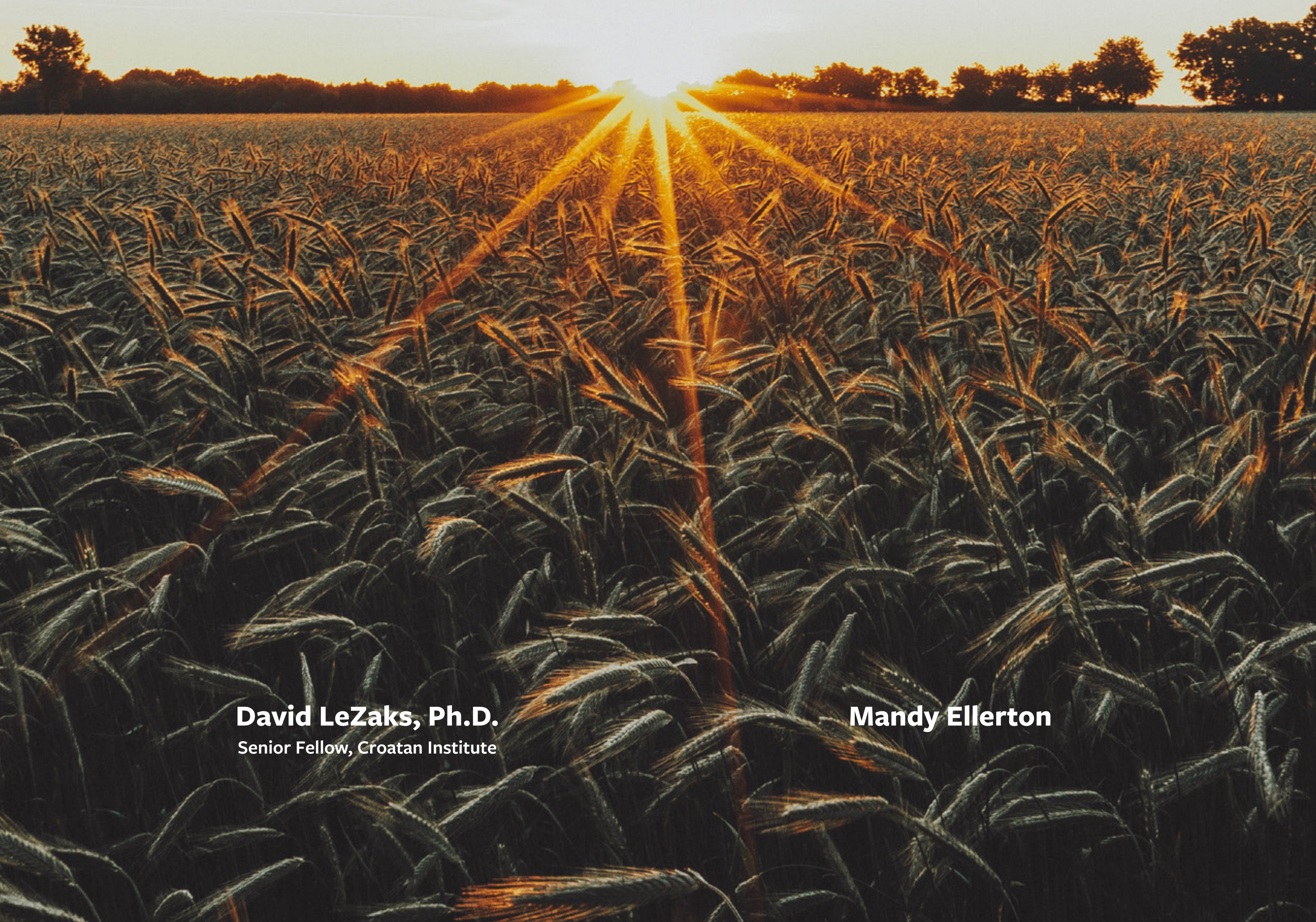
The Regenerative Agriculture and Human Health Nexus:

Insights from Field to Body



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"Take care of the land, and the land will take care of you."

HUGH HAMMOND BENNETT

Director of the United States
Department of Agriculture (USDA)
Soil Conservation Service (1947)

Abstract

As part of the broader regenerative agriculture movement, there is increasing energy around the assertion that agriculture practices and soil health have a connection to human health. But what does the evidence tell us about the connection between agricultural practices and human health? The reality is that the connection between agricultural practices and human health is infinitely complex and dynamic.

This paper explores the evidence connecting agriculture practices to human health outcomes. In reviewing this evidence from field to body, we are left with a number of summary reflections, namely that growing more nutritious food does influence human health, but that we have a lot of work to do to transform systems and maximize the potential that more nutritious food has to offer in the realm of human health. We hope that this paper deepens the discussion about the connections between agriculture, food, human health and environmental health and positions the burgeoning movement to take strategic action.

Foreword

As a mom, dietitian, chef, food system professional and advocate, I have dedicated 30 years of my personal and professional career to transforming food systems. I have provided education and led behavior change therapy for patients living with food-related chronic illnesses. My business has created quality food products that nurtured a regional food system. And, most recently, I have been collaborating with stakeholders to investigate and develop new pathways for regional regenerative foods to enter the market.

However, we are everyday more aware of the stark and painful reality that we need to change both how we grow food and how we tend to people's health and well-being. Food currently produced by our flawed system contributes to soaring levels of chronic non-communicable diseases, environmental degradation, and economic collateral damage. And impoverished communities, which are disproportionately Black, Indigenous and communities of color, along with rural communities, as ever, bear the brunt.

Basil's Harvest is a woman-founded and woman-led nonprofit that exists to help usher in these much-needed system transformations. We are nurturing a more healthy, equitable and resilient food system by identifying and highlighting the important connections between the health of people, farms and soil. Our work connects farmers, institutions, and corporations to build just and regenerative supply chains. We curate experiential learning programs, oversee collaborative research to expand understanding, and work hands-on with leaders to support them in building and sustaining a more resilient food system.

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In 2019, Basil's Harvest began the Regenerative Agriculture in the Heartland (RAH) initiative with two purposes: to identify institutional supply chain opportunities for small grains and regenerative (and organic) small grain farmers in Illinois; and to bring health professionals, farmers, and institutional foodservice providers together to reduce fragmentation across the system, create champions for regenerative agriculture, and advance a multi-value approach.

As part of these efforts, Basil's Harvest partnered with David LeZaks, Ph.D. and Mandy Ellerton to explore what the research says about the connections between agriculture and human health. David and Mandy's collective work seeks to bring about a complete transformation of how our healthcare and agriculture systems work, with a particular emphasis on making microbiota central to the study and conversation around those systems. As leaders in the movement to restore soil and human microbiomes, we were thrilled to engage David and Mandy on this particular effort.

As energy grows around the human health benefits of regenerative agriculture, this paper seeks to answer a seemingly simple question: what do we know about the connections between regenerative agriculture and human health? In their exploration David and Mandy found a beautifully complex set of findings. I'm left with an even stronger conviction that agriculture and human health are, indeed, connected and that it's time to act on what we know. Ultimately, this paper is meant to bring more cohesion and energy to the growing movement connecting agriculture and human health and to spark further conversation and action.

We have a lot to do together. We can't wait to meet you out there in the fields, across supply chains, in markets and neighborhoods, at clinics and hospitals, and my favorite place of all, around kitchen tables over shared meals, all doing our part to do better for our families and communities.

In hope and solidarity,

Erin Meyer, MSFS, RD
Founder and Executive Director, Basil's Harvest

Introduction

The assertion that agriculture practices and soil health have a connection to human health is an exciting proposition that is gaining energy and attention. Exciting enough that a movement connecting agriculture and nutrition is emerging—a movement that envisions transforming our agriculture systems in order to transform our health. The implications are staggering. If the connection between agriculture and human health is borne out, it could help engender massive transformations across food, agriculture, health and the broader environment.

The possible human health benefits of more nutrient dense food, grown in healthy soil will only ever be one part of a larger, holistic case for transforming these systems. There is already robust discussion of the broader climate, environmental, human rights and economic benefits of regenerative agriculture.[*] While we exclusively examine the human health dimensions of regenerative agriculture in this paper and wholeheartedly champion

[*] There is vigorous discussion about the definition of "Regenerative Agriculture", which has become a catch-all phrase, most often referring to practices that improve soil health. Other similar agriculture frameworks or modalities include: biodynamic farming, conservation agriculture, agroecology, permaculture, agroforestry, managed intensive grazing, holistic management and biological agriculture, to name a few. Definitions of "Regenerative Agriculture" are diffuse at best and at worst, neglectful of the Indigenous wisdom they often appropriate. Newton et al. 2020 reviews multiple definitions of regenerative agriculture, the majority of which concentrate on environmental and social impacts. The evidence and connections in our report argue for a broader definition that is inclusive of positive and negative impacts to human health and that honors Indigenous wisdom. However, in absence of a better term, we use the term "Regenerative Agriculture" throughout to refer to agriculture practices that seek to improve the nutritional value of food.

a greater focus here, we are under no illusions that the human health dimensions alone are the full story.

But what does the evidence tell us about the connection between agricultural practices and human health? Despite growing assertions that regenerative agriculture,[1] in particular, benefits human health, as the Rodale Institute "Power of the Plate"[2] paper put it, "this link between soil health and human health is largely unexplored and must be advanced."[**] The reality is that the connection between agricultural practices and human health is infinitely complex and dynamic.

We like to think of the journey from field to body as containing a series of metaphorical "levers" and "dials", each of which can be flipped or dialed to improve the chances that food can arrive in the hands of people in a maximally nutritious state and perhaps sustain or improve someone's health. There is evidence that suggests which levers and dials need to be flipped and moved to improve human health. And there is ample opportunity to learn more in further research.

What follows is an exploration of the research connecting agriculture practices and systems and the relationship to human health outcomes. It is not meant to be a comprehensive analysis, but an opportunity to spark further conversation. We start by outlining some of the leaders and organizations who are asserting that soil health is connected to human health and what, exactly, they are asserting. We offer a framework for categorizing and better understanding different levels of nutritional interventions: from the most basic level of replacing "unhealthy" foods with "healthy foods" all the way to considering nutrient density and interventions that tend to human microbiomes.

The bulk of the paper explores the state of the evidence using a framework that organizes the journey from field to body. Our exploration actually begins at the end of this journey, by discussing our ultimate goal: human health. We then skip back to outlining what the evidence tells us about nutritional

After reflecting on the evidence about this journey from field to human body, we are left with a number of summary reflections.

First and foremost, we are left with the conviction that growing more nutritious food does influence human health.

** While this is true of Western science, we assert that it may not be true globally. Traditional and Indigenous wisdom from around the world regularly articulates firm and foundational understanding about the connection between agriculture and human health.

dimensions of food and nutrient density. Next we look at the evidence surrounding how food harvesting and processing impacts nutrition. We then spend time examining what the evidence says about food access, purchase and preparation, with particular time spent discussing race and gender equity dimensions and time spent looking at methods to make nutrients more bioavailable. Finally, we look at evidence regarding the body's ability to digest and absorb nutrients.

After reflecting on the evidence about this journey from field to human body, we are left with a number of summary reflections. First and foremost, we are left with the conviction that growing more nutritious food does influence human health. And that this nexus of regenerative agriculture and human health calls for an inclusive movement made up of a diverse group of organizations and leaders working in concert to improve the human condition. But crucially, this movement must center race and gender equity in order to be successful. This movement also needs a new vocabulary, because how we talk about nutrition and nutrients does not yet adequately capture the complexity and dynamism of food. That very complexity and dynamism also means that despite a collective commitment to science and data, we will never definitively understand exactly how nutrient density influences human health. Not in any Western scientific sense, anyway. And yet, in embracing the unknowns, we must also have the conviction to say that we still know a lot. And we know enough to act.

It is our sincere hope that this paper engenders a deepening of the discussion about the connections between agriculture, food, human health and environmental health. Now let's dig in.

The Concept

The mantra that "cheap food is actually very expensive" is rooted in the food system's orientation to optimize toward a very small number of outcomes while externalizing social and environmental costs. Post-WWII agriculture has focused almost solely on using chemical inputs and breeding to increase the quantity, stability, and processing characteristics of agricultural outputs, while reducing the cost of food. In many cases this appears to have been at the expense of nutritional quality of the food and increased exposures to residues and contaminants, especially for those who produce our food. This transformation may have, in fact, increased yield and increased discrete nutrients such as iron or vitamin D, which may have had some near-term positive effects. But this agricultural transformation did not consider the long-term trade-offs of destructive environmental and health outcomes. Today, nutrients, as broadly considered in this paper, are rarely considered in the market value of food.

Evidence is mounting that regenerative agriculture practices—in particular, strategies that improve soil health—have incredible benefits for the climate, biodiversity, water, and building community wealth.[3] A growing number of voices have also begun to assert human health benefits from eating food grown in healthy soil. They assert that healthier soils lead to more nutrient dense[***] foods, which leads to healthier humans. They see evidence that the microbial health and diversity of soil is connected to the microbial health and diversity of humans. Across both agriculture and diet, we understand that diversity is crucial to resilience. A diverse set of plants and animals increase the resilience of the landscape and a diverse diet improves the resilience of the body and its resident microbiota.

As the rates of diet-related illness, weakened immunity and mental health issues tick ever upward, with concomitant skyrocketing healthcare costs, these voices are seeking to raise consciousness that declining soil health, fertility and biodiversity are linked to biome dysbiosis, nutrient loss and poor nutrient processing, which disrupts optimal nutrient uptake across the food web. They believe this plays a central role in the significant rates of illness and degraded health we see in the modern era. What is more, they believe that more fully understanding and incorporating the value of nutrients will reveal the true market value of full spectrum nutrition.

There are a number of organizations and leaders who have begun to champion the human health benefits of regenerative agriculture, with a variety of different theories of change and approaches. These include: Basil's Harvest, Bionutrient Food Association, the Center for Regenerative Agriculture and Resilient Systems at the University of California Chico, Funders for Regenerative Agriculture, Farmer's Footprint, David Montgomery & Anne Biklé, Mark Hyman, Daphne Miller, Jill Clapperton, Stone Barns Center, the Periodic Table of Foods Initiative, Weston A. Price Foundation, Brightseed, Teak Origin, Culinary Breeding Network, Row 7 Seed Company and the Rodale Institute, which issued a groundbreaking paper in 2020 entitled *The Power of the Plate: the Case for Regenerative Agriculture in Improving Human Health*. The Nourishment Economies Coalition also brings together social entrepreneurs from around the world that have built successful businesses that link the health of people on the land through a variety of economic

*** Nutrient density is a metric that has been defined by several organizations in different ways to provide a method of comparison between foods and their nutritional and energy components. The methodologies behind the usage of those metrics and the types of nutrients that are or are not counted can vary widely. In this paper we will use the word "nutrients" to refer to all of the complex compounds found in food: macronutrients (protein, fat, carbohydrates), micronutrients (vitamins, minerals, trace elements and bioactive food components such as antioxidants and polyphenols). We also recognize that some constituents of food, such as fiber and bioactive compounds may not be traditionally incorporated into commonly used nutrient density metrics, but have nutritional implications for both humans and their microbiota.

activities.[****] There are a number of actors also coming together around the "food is / as medicine" moniker.[4]

In many ways, the assertion is logical. It stands to reason that healthier soil grows healthier crops and animals and that humans that eat this healthier food are themselves healthier: healthier soil → more nutrient dense food → healthier humans. It is also tied to traditional and often Indigenous wisdom from a variety of peoples and cultures from around the world. We shorthand this logic and wisdom as "Regenerative Agriculture → Human Health."

As we'll see in subsequent discussion, while logical, this assertion is far more complex than it might seem at face value. And in fact Regenerative Agriculture → Human Health adherents are often asserting different things. We find it helpful to start discussions about Regenerative Agriculture → Human Health with a framework (developed by David LeZaks and Eric Jackson) that categorizes nutritional arguments/interventions and how they relate to human health into four different "Levels of Nutritional Interventions". All have been used at one time or another to argue that Regenerative Agriculture → Human Health. Each of these levels are crucial to human health, in some cases directly and in others, indirectly. However, the list builds from interventions that are currently most embraced/least complex (Level 1) to those that are least embraced/most complex (Level 4).

To date, most interventions focus on Levels 1 & 2 (Replacement & Free From Chemical and Drug Inputs). While laudable and necessary, interventions in these levels will only return the food system to a baseline state where access to fresh, safe, and healthy food is the norm. We are still quite far from that baseline. It is clear that to regain the nutritional wisdom[5–7] that our species once had, we must also develop and implement interventions across Levels 3 & 4 in order to improve outcomes across the interconnected environment, agriculture, food, and health systems.

Evidence is mounting that regenerative agriculture practices—in particular, strategies that improve soil health—have incredible benefits for the climate, biodiversity, water, and building community wealth.

**** More information about them can be found: https://nourishn.com/affiliates/

The Four Levels of Nutritional Interventions

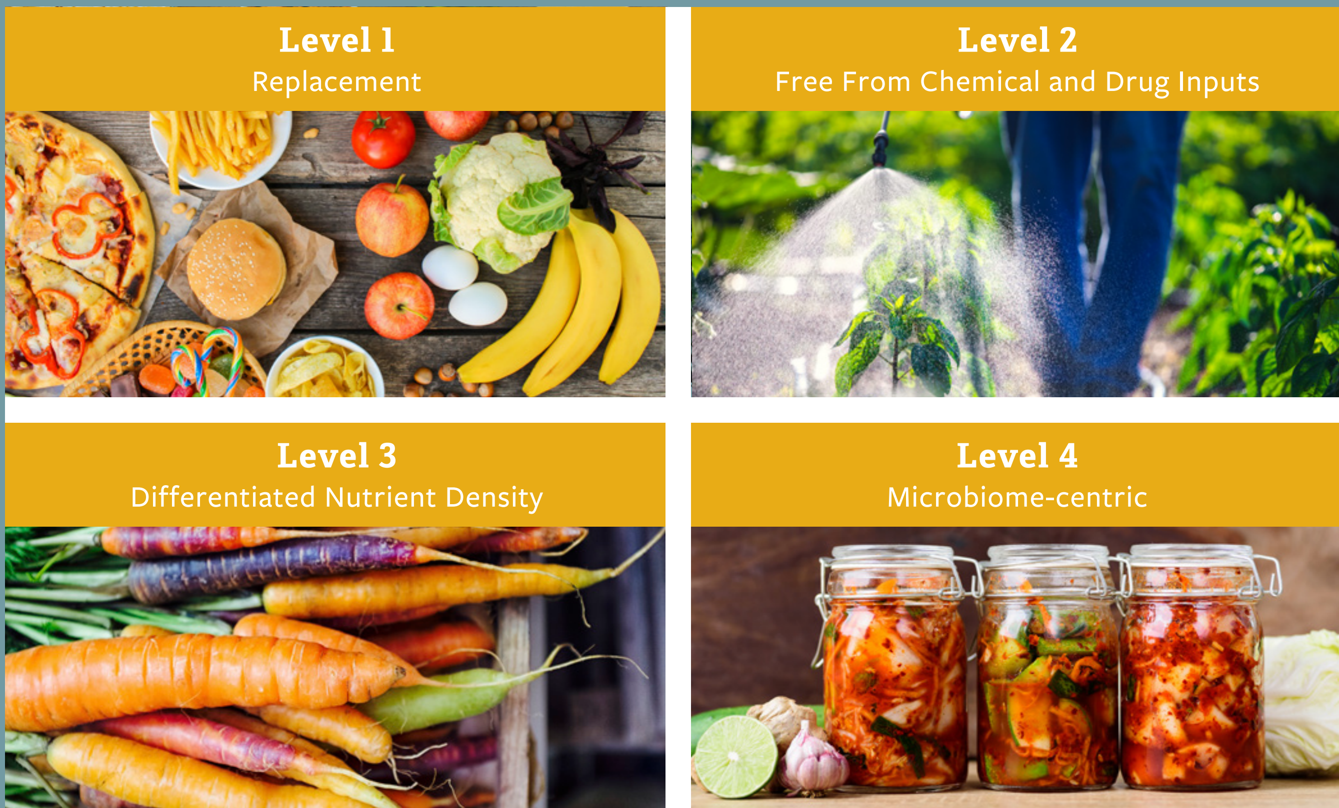

Figure 1: The four levels of nutritional interventions, a framework developed by David LeZaks and Eric Jackson.

Level 1: Replacement

Interventions in this category seek to replace ultra processed food with "healthy food", such as unprocessed, whole foods like fruits, vegetables, meat, fish, whole grains, healthy fats etc. (though there is still a great deal of debate about which of these foods is "healthy", such as whether or not saturated fats are healthy and whether or not red meat or highly processed meat alternatives are healthier). Interventions in this level include CSA prescription programs, medically tailored meals and nutrition education initiatives, to name a few.

Level 2: Free From Chemical and Drug Inputs

These interventions seek to remove agrichemicals from agricultural and food production due to the well-established harmful effects on humans. Most prominently this includes the "Organic" certification/movement (no industrial pesticides, no sewage sludge, no synthetic fertilizers), efforts to address the over-use of antibiotics and resultant antibiotic resistance, and a growing movement to ban the use of specific chemical formulations like glyphosate/Roundup (herbicide) and neonicotinoids (insecticide). Some of the assertions that regenerative agriculture practices benefit human health have to do with the fact that these practices do not rely on agrichemicals, which then reduces water and air pollution, direct exposure for farm workers, or residual exposure on/in the foods themselves. In food processing, this can extend to food additives, such as flavoring that trick the brain into thinking the body may be ingesting nutrients that may not actually be present, as well as food preservatives and colorings.

Level 3: Differentiated Nutrient Density

This refers to the idea that certain agriculture practices, in particular those that improve soil health, can improve the nutritional quality of foods. Recent analytical advances have shown that not all carrots, for example, are created nutritionally equal—that depending on how they're grown (soil, management, genetics, climate, etc), a carrot can be more or less nutritious.[8–12] Evidence shows that at worst, the nutritional quality of many foods grown conventionally have declined substantially over time,[13–16] and at best there is a wide variability in bioactive compounds such as polyphenols.[17, 18] There are demonstrated nutritional differences between livestock products from pasture raised animals that have better nutrient density — better CLAs, omega 3:6, vitamin A and vitamin E levels.[19, 20] Climate change is exacerbating this phenomenon as well.[21–25] There is a growing body of evidence suggesting a relationship between health outcomes and eating more nutrient dense foods including shifting perceptions of hunger[26] and positive impacts to non-communicable diseases.[27] Companies and researchers are now seeking to elucidate the differentiated nutrient density and complex compounds in foods coming from different production systems and plant/animal genetics.

Level 4: Microbiome-centric

This level refers to the power of the soil's microbiome to directly influence the human microbiome. Deeper understanding of the importance of microbes to human health is rapidly unfolding and a societal reckoning is beginning, not just about the possible microbial connections to food, but about microbial connections to other dimensions of health, including childbirth, antibiotic use, etc. Some Regenerative Agriculture → Human Health assertions have to do with the microbial health of the soil and the possibility that these benefits transfer to humans. Right now these interventions mostly encompass research and new products asserting gut microbiome-influencing properties, but more systemic interventions are likely on the horizon.

The evidence that follows touches on each of these levels to some degree. However, because the evidence base for Levels 1 and 2 are well established, we will spend most of our time discussing what evidence exists related to Levels 3 and 4. Our intention is not to downplay the importance of Level 1 approaches such as food boxes or vegetable prescriptions, as not nearly enough of the population eats sufficient amounts of fruits and vegetables.[28] We understand that enabling cultures of health requires more holistic approaches that encompass value webs in agriculture, food, health and the broader environment.

The Evidence

We have attempted to depict the journey from field to body as a way to organize and understand the Regenerative Agriculture → Human Health evidence (Figure 1). In this paper we will not delve into all of the evidence around which practices create more nutrient dense food as the principles and interventions to regenerate soils are well documented elsewhere. Instead, we focus first on the ultimate outcome: "human health", then we go back to the beginning of the journey to discuss "more nutritious food," and then some of the key milestones along the journey from the field to the body.

Figure 2: The pathway in which nutritious food travels from the field to the body while also acknowledging the body's ability to assimilate and use those nutrients.

Human Health

If Regenerative Agriculture → Human Health is ultimately about human health, let us start there. Rates of chronic illness are skyrocketing (as are the healthcare costs associated with treating people with these illnesses).[29] It is abundantly clear that nutrients and the human microbiome are the building blocks for most bodily functions and that insufficient nutrients and disrupted human microbiomes are at the heart of chronic illness. The fundamental questions related to nutrition and human health are thus:

1. What nutrients does someone need?
2. What enables their body to absorb those nutrients?

KEY REFLECTIONS

- **It's important to distinguish between what it takes to keep people healthy and what it takes to heal those who are already sick.** There is also a difference between merely treating symptoms among those who are sick and healing their underlying illness altogether, especially when it comes to chronic illness and autoimmunity.

- **Nutritional needs change over the course of one's life.**[30,31] What an infant needs nutritionally, versus an adolescent versus someone in later stages of life are all different, considering that the communities of our microbiota are also changing through life stages.[32] What is more, a mother's diet before conception and during pregnancy has a strong influence on a child's later health.[33]

- **The human microbiome has become the darling of the scientific world—and for good reason.** New studies continue to emerge that link the human microbiome to key bodily systems including the gut, immune and neuroendocrine systems, with cascading levels of complexity. In addition to food-related impacts on the human microbiome, there have been larger societal shifts (e.g. sanitation, urbanization, novel biocides) that have fundamentally shifted the relationship between human and environmental microbiomes.[34–36] While there is still much more to learn, the disruption of the human microbiome (especially the human gut microbiome) has been linked to issues besides the obvious intestinal issues (e.g. inflammatory bowel disease and irritable bowel syndrome): metabolic diseases, hypertension,[37] mental health issues (depression, anxiety),[38] neural development challenges,[39] cognition and behavior issues,[40,41] the formation of both type 1 and type 2 diabetes,[42–44] non-alcoholic fatty liver disease/insulin resistance,[45] cardiovascular disease,[46] celiac disease,[47] to name a few and cite only some of the ample evidence. We eat to feed ourselves, but we also eat to feed our microbiome. In particular, there is abundant research showing how absolutely critical fiber is to the health of the gut microbiome.[48–51]

- **Humans need a mix of nutrients to fuel all bodily functions—nutrients that are far more numerous and complex than those listed on a nutrition label.** All these nutrients come from food as well as from microbes, which can also synthesize micronutrients (for example, B vitamins) de novo as well. Without sufficient nutrients or nutrient processing by the gut microbiome, human health is vulnerable and can fall into a state of infection and/or disease. Research has also indicated that without proper micronutrients, genomic damage can occur as well.[52–54] New understanding about what nutritional compounds may influence human health continue to emerge. For example, polyphenols are increasingly thought to play a role in the maintenance of human health.[55–63]

- Food systems, food policy, conventional healthcare and conventional dietary guidance rely heavily on the idea of "Recommended Daily Allowances" (RDAs) for human intake of nutrients. However, **RDAs are fundamentally flawed because what nutrients each person needs (and in what form) and which foods are most optimal to supply those nutrients (see the Digestion and Absorption section for more) varies significantly.**[64] This is the idea of "bio-individuality". For example, some microbiome research has demonstrated that dietary interventions to heal gut dysbiosis do not uniformly work.[65] This bio-individuality stems from the very complex interactions between: genes, microbiome, human metabolome (meaning what nutrients and metabolites are already present in the body) and even culture and preferences.

- The idea of bio-individuality could tempt healthcare systems further into more reductionist, highly targeted, "personalized medicine" interventions. While some personalized medicine shows promise for reshaping healthcare (as we know, one size definitely does not fit all—even when it comes to treating the same disease state in different people), relying wholly on personalization is ultimately futile when we take into account the infinite complexity of compounds in foods, the genetic makeup of the patient, their microbiome and their dynamic metabolome. Some research is instead indicating that all people benefit from incredibly diverse diets.[66] In other words, **expose people to as many nutrients as possible and you may be in the best position to give the body what it needs at any given time.**

It is abundantly clear that nutrients and the human microbiome are the building blocks for most bodily functions and that insufficient nutrients and disrupted human microbiomes are at the heart of chronic illness.

- **The COVID-19 pandemic has also demonstrated the connections between nutritional deficiencies and human resilience.** Many non-communicable diseases that have increased risk factors for COVID-19 are associated with chronic inflammation.[67,68] Health disparities, many of which are connected to racial and economic inequalities, influenced COVID-19 impacts.[69] Treatment and prevention of these diseases and their precursors may help reduce complications from COVID-19. More specifically, there have been specific connections between the state of the gut microbiome and COVID-19 outcomes, with patients suffering from dysbiosis and related diseases suffering severe consequences.[70–73] Already, as a result of the pandemic, nutrition research has emerged as a top priority to better connect our food and health systems and place their joint focus on improving human health outcomes.[74,75] This could alleviate the outsized impacts of the current pandemic, prepare us for future pandemics, and improve the general health of our society.

- **Both soils and human bodies are complex ecological systems with interdependent microbiota.** We eat several times a day and the nutritional composition of those meals (good, bad, and otherwise) affects short-term outcomes such as satiety and fulfillment. Longer-term dietary patterns and the nutritional make-up of those meals affects long-term health outcomes. Persistent use of junk food, repeated courses of antibiotics,[41,76,77] low-fiber diets and exposure to pesticides can all act as perturbations to the gut microbiome. These minor perturbations can add up over time, reducing the resilience of the gut microbiome to the point where there is a functional change in the ecology of the gut microbiome (dysbiosis) resulting in an increased risk of disease.[36,78–80] These same patterns occur within agricultural soil microbiomes, plants, insects, animals and each of their microbiomes as well. Manage the soil with diverse crop and livestock species, keep it covered, avoid chemical or physical disturbance, and the soil will provide numerous benefits. A lack of care for the soil and its microbiota through a series of minor perturbations could shift the functioning of the soil into another state that is neither good for the plants, animals, or broader environment.[81] Both soil and human bodies—in fact all life—need biodiversity in order to be resilient.[82] For soil, it means diverse plants; for plants, it means diverse soil and diverse insects; for people it means a diverse diet of whole foods without residues that harm or deplete the diversity of the human microbiome.

More Nutritious Food

The mechanisms of how and why food grown in healthy soils is healthier are complex and still under investigation. There are an extraordinary number of agricultural variables that could influence the nutrient characteristics of food, including crop and livestock genotype, soil type, management history, input usage, water, pest, and disease stress, and weather.[83] And the diverse array of past and current agricultural practices appear to influence a multitude of nutritional compounds, in ways we are beginning to understand more and more. There is emerging, but ample evidence that food grown in healthy soil is more nutrient dense.

KEY REFLECTIONS

- **The nutrient levels of foods grown with conventional agriculture appear to have deteriorated over time.**[84] That said, it is extraordinarily hard to compile retrospective datasets, as the methodologies change over time, as do other environmental and genetic variables. The specific nutrients that are tracked may also not necessarily be able to tell the full story of the changes to our food over time, given that these studies have a relatively narrow set of nutrients that are investigated.[85]

- From a broader perspective, **there are few economic signals that emphasize the nutritional integrity of a product**. Instead, markets have valued shelf-stability, year-round availability, and standardization, leading to the proliferation of ultra-processed foods. Reductionist research, dietary guidelines and food policy have also tended to undervalue and underemphasize full-spectrum nutrition.[86] These same tools, if redirected could be leveraged to place economic value in the marketplace of not only producing safe, nutritious food, but ensuring the delivery of the panoply of nutrients from soil and plant to animals and people.

- **If modern economics has influenced the shift of our food systems to prioritize aspects of quantity and simplicity (as opposed to quality and diversity), taste and nutrition have also been deleteriously affected.** As Mark Schatzker pointed out in his book, *The Dorito Effect: The Surprising New Truth about Food and Flavor*,[87] 600 million pounds of flavorings a year are added to food to replace flavors (e.g. nutrients) inherent to food that we have systematically selected against in favor of characteristics that serve today's market needs. The chemicals in these foods confuse our brains and dilute our nutritional wisdom, leading us to make choices that in the short-term seem to satiate hunger and bring pleasure, but in the long-term lead to overconsumption and may lead to increased probability of disease.[88] In one study, shifting from a highly-processed, low nutrient dense diet to one that was minimally processed and had a higher nutrient density (inclusive of antioxidants and phytochemicals) "mitigates the unpleasant aspects of the experience of hunger even though it is lower in calories."[26]

- **Our vocabulary around nutrients, nutrient density, and nourishment are in a state of rapid evolution.** These terms cut across medical, agronomic, and policy realms and don't yet fully capture what we know about the amount and quality of various elements, molecules, and compounds that exist in food.

- **Generally, data around macronutrients and micronutrients are tracked by USDA, and assumed to fall into a discrete range regardless of production or husbandry practices**. New science is highlighting more variation than previously understood, which in many cases can be tracked to stewardship practices that encourage healthy soil management. Examples in species crops, such as oats,[89] rhubarb,[90] strawberries,[91] tomato,[92] squash,[93] wheat,[94,95] spinach,[96] kale,[97] lettuce,[98,99] eggplant,[100] carrot,[8] milk,[20,101–110] pork,[111] chicken / eggs,[112–117] beef,[19,103,118–126] and cross-species reviews[9,127–131] are well documented in the literature.

- **Studies have shown changes in macro and micronutrients related to specific agronomic practices and the changes to the soil as a result of those practices**[12,94,132–135] There appears to be an even stronger linkage between healthy soils and plant secondary compounds[127]. Interestingly, not only do levels of nutrients vary, but the microbial species that colonize the food we eat differ based on the management system used. For example a comparison between conventional and organic apples shows that organic apples had a more diverse microbiome.[136] Studies have shown that exposure to more diverse microbiota, from multiple sources, has positive health implications.[35,137,138]

- **There are also emerging theories and findings about "nutritional dark matter"[139,140]: not-yet-well-understood substances in foods that influence signaling between cells by modifying genetic expression.** Nutritional databases maintained by the USDA track ~150 nutritional components, while new analytical approaches have identified more than 26,000 biochemical compounds.[140] The hypothesis is that agriculture practices may be able to influence these substances as well.

- **Climate change also affects the nutritional quality of foods.**[21,22] With higher carbon dioxide levels in the atmosphere, plants make more sugars, which dilutes the nutrients that they incorporate into their tissues and fruits. It is unknown whether changes in plant genetics or improvements in soil health can combat the nutritional changes in plants due to increases in atmospheric carbon dioxide.

- **Relationships between taste and nutrient density have evolutionary origins.**[141,142] While the original quest for energy and nutrients is still present, many of us have lost our nutritional wisdom—in particular Black, Indigenous and communities of color—due to colonialism, cultural genocide and systemic racism.[7] As we emerge from the era of cheap processed food whose flavors have been artificially added, there are abundant opportunities to recreate the relationships between taste, cultural and traditional wisdom, nutritional quality and short and long-term health outcomes. Research is ongoing between the relationship between taste and nutrient density, as there are complex relationships to be better understood. For instance, phytonutrients (generally thought to be health-promoting) are often bitter in their flavor, a characteristic that is rarely sought after.[143] Microbiome research is also uncovering relationships between oral microbiota and the responsiveness to different food compounds.[144]

- **Regenerative organic agriculture practices notably do not use chemical interventions.** This reduces human chemical exposure both directly from eating the foods and also from contaminated water, air and soil.[145–151] Substances like glyphosate negatively impact arbuscular mycorrhizal fungi, and other important probiotics in the soil, limiting the pathways that nutrients flow from the soil to the plant.[152] Regenerative agricultural practices also steward soil and don't disrupt with chemical or physical disturbance. There is also a complex relationship between pesticides and plant secondary compounds. Without any pest pressure, plants have little reason to use their own defense mechanisms and these defense mechanisms actually create compounds that are beneficial to humans. Many pesticides also have a negative impact on soil microbiota and related soil flora and fauna.[153–155] These dysbiotic conditions can also pave the way for pathogen proliferation and antibiotic resistant organisms which can travel from soil to human. Additionally, as opposed to regenerative agriculture, in industrial agriculture that relies on synthetic fertilizers,[156] plants create fewer mutualistic relationships with the soil microbiome, thus diminishing nutrient uptake. For example, arbuscular mycorrhizal fungal networks that trade carbohydrates from the plant for inaccessible soil nutrients are often significantly reduced in conventional systems.

Harvest & Processing

We've explored briefly how regenerative agriculture practices can make foods more nutrient dense. We've explored what it means to be healthy, including critical links between nutrients and disease. However, food takes a long journey from the soil to a point where the body has extracted, transformed, and utilized nutrients. The next step on that journey is harvesting and processing. Unfortunately, there is minimal research to indicate how harvesting, processing and distribution practices affect nutrient qualities, although there is some evidence suggesting that just because a nutrient or bioactive compound is present at harvest or collection, doesn't mean that it is present or bioavailable at the time of consumption.[157]

KEY REFLECTIONS

- **There is some evidence that harvest time can influence the nutrient density of food.** Such studies include those looking at antioxidants in strawberries;[158] antioxidants and phenolics in olives:[159] polyphenols in peppers.[160] Some produce is picked before it is ripe and is artificially ripened en route to its final destination. This process may affect the nutrition in the food when it reaches the consumer.

- **There are other dimensions of harvesting and processing that may have an impact on the nutrient density of foods**, but have yet to be comprehensively studied. These include:
    - **Grain Processing and Milling:** Flour milling using stone mills keeps the bran, germ, and endosperm intact, unlike roller-milling which usually removes the germ to increase shelf stability. Stone milling has been shown to yield a more nutrient dense product[161]. Additionally, stone milling results in larger particle sizes which are more likely to remain intact until they reach the gut, providing food to the gut microbiome.[162]

- **Pasteurization and homogenization:** There are intense and controversial debates about whether or not pasteurizing dairy products and honey has an effect on nutritional quality[163]. There is also discussion about the degree to which homogenization affects the nutritional quality of dairy products.
- **Refrigeration and freezing:** There is some evidence that flash freezing or freeze drying may preserve nutritional qualities better than other methods.[164–168]
- **Storage:** Conditions before point of sale or consumption may influence nutrient qualities. Supercritical carbon dioxide treatment and storage was found to degrade a range of nutrients in apples[169] while the length of storage for wheat affected polyphenol, flavonoid and antioxidant levels.[170]
- **Ultra-processing:** There are many different types of processing methods that are used in foods, but many have not undergone studies of how they impact a range of nutrients that may be in the original foods. Examples can be drawn from a range of studies that investigate nutrients and bioactive compounds and changes due heat, pressure, and other forms of food processing.[171–174]

Just because a nutrient or bioactive compound is present at harvest or collection, doesn't mean that it is present or bioavailable at the time of consumption.

- As we continue to understand the **critical role that polyphenols** have in maintaining human health, it will be especially important to study how these compounds are affected by a variety of processing mechanisms in order to maximize their delivery to the body.[56,57,63,175–180]
- **Harvesting and processing look a lot different for home farming operations where the distance and timing between harvest, home storage and consumption may be small.** However, there are likely dimensions of home harvesting and processing that are relevant to preserving nutrient quality and should be further explored.

Access, Purchase & Preparation

After foods have been grown, harvested, processed and distributed, the question then becomes how people access and purchase the foods. Obviously this becomes a moot point for the home grower, but the vast majority of people purchase their food from someone else—in some cases directly from the grower, but in most cases through a third party. The concern is that just because farmers are able to grow incredibly nutritious food, doesn't mean people can access it. Sometimes this is a logistical challenge, but most often it is a racial and gender justice issue; Black, Indigenous, People of Color (BIPOC), low income and working class people (ironically a lot of rural people and farmworkers, despite their proximity to farmland), along with women and non-binary people face systemic barriers that can make it next to impossible to either purchase the food they want or have the time, energy and tools to prepare it. This is a highly studied and discussed aspect of human health (e.g. discussions regarding social determinants of health[181]) and so we won't delve into all of the research here, but it is an absolutely critical part of the journey from the soil to the human body and worthy of some discussion.

KEY REFLECTIONS

- **Food apartheid is real.** This refers to the systemic racism and inequities that make it harder for some people, in particular BIPOC and rural people, to access high quality food. That means that in some communities, there are very few grocery stores, and even fewer that are accessible with public transportation or, in the case of a rural community, without a very long drive. One's only option for buying any kind of food whatsoever is often a convenience store or gas station with very limited fresh fruits and vegetables, let alone high-quality foods grown with regenerative practices. According to USDA, 19.1% of Black households and 15.6% of Hispanic households were food insecure in 2019.[182]

- **Today, regeneratively grown foods cost more than conventionally grown foods.** It is well-documented that food grown with conventional agricultural practices is artificially cheap due to subsidies that artificially drop the prices and due to negative externalities that are not integrated into the cost of food but are instead pushed onto the environment and broader society. Until we prioritize and protect nutrition for everyone as a resource and right, low-cost, low-nutrition food may be all that is accessible for many, especially those people living in poverty, which are disproportionately BIPOC. What's more, social programs like the federal government's Special Supplemental Nutrition Program for Women, Infants and Children (WIC) and Supplemental Nutrition Assistance Program (SNAP) do not necessarily provide easy access to regeneratively grown foods.

- **Even if someone can financially afford the more nutritious food, the reality is that the majority of regeneratively grown foods are purchased in a whole state, which requires time and energy to prepare at home.** This is an often-overlooked equity issue as well. There are the extreme cases of people living in poverty or near poverty, again disproportionately people who are BIPOC, who are working multiple jobs just to make ends meet and thus have very little time for preparing whole foods. In addition, gender equity is a major obstacle. With a significant number of women[183] participating in the labor force in the United States and with women continuing to do the majority of the housework,[184] in particular meal preparation, women are often tired and looking for meal short-cuts like processed and ultra-processed foods. There are programs and companies nibbling around the edges of these problems, seeking to improve access for some Black, Indigenous, people of color, people living in poverty and women. But it's not until we achieve true justice that this problem will be resolved. That means living wages, gender and racial pay equity, more affordable housing and more gender equality in housework. If we care about more nutrient dense food actually improving human health, the regenerative agriculture and nutrition movements must be in solidarity with racial and gender justice movements as well.

- **Access also pertains to accessing foods that are culturally appropriate and values-aligned.** For example, if you are Jewish and keep kosher, you will need access to kosher foods and if you are Muslim and follow Islamic dietary guidelines, you will need access to halal foods. Finding regeneratively grown foods that are also kosher or halal may be difficult in most cases. But even beyond these specific dietary needs, each of us has cultural traditions and cultural foods. Ideally, every cultural group could find access to its special foods regeneratively grown.

- Beyond questions of access, there are numerous other factors that may influence someone's food purchasing decisions. Although there is not abundant research on the topic, **a variety of inputs and interventions likely influence consumers in their food purchases, ideally to purchase more nutritious foods.** Some possible influences include:
    - Marketing techniques, such as marketing terminology, media and frequency of marketing exposure
    - Labeling like "local" or "natural" or "regenerative" and certifications like "organic"
    - Recommended Daily Allowances and Dietary Guidelines for Americans
    - Use of meal planning and shopping lists
    - Knowledge about nutrition
    - Food addiction[185]
    - Healthcare provider recommendations

- Humans have been cooking their food for almost two million years.[86] **Cooking, along with various methods of food preparation, helps unlock many types of nutrients from food and increases their bioavailabilty.**[157,187,188] For instance, soaking and cooking beans and other pulses helps remove trypsin inhibitors.[189] Vegetables and fruits, especially those rich in polyphenols and antioxidants, have a varied response to cooking methods, and further research is needed to identify the best preparation methods for these products in ways that maximize the delivery of nutrients.[190–194] Other food preparation methods, such as sprouting grains, generally increase nutrient bioavailability.[195–198]

- Foods are most often eaten in combination with other foods. Traditional and Indigenous wisdom, including Ayurveda,[199] suggest that eating certain foods together can promote health and improve nutrient absorption. There is some evidence that **combining certain nutrients can enhance absorption.** For example, meals combining legumes and grains (like rice and beans) are widely understood to make a "complete protein" because they contain complementary amino acids. Ascorbic acid has also been shown to enhance the body's ability to absorb non-heme iron.[200] Bioaccessibility of phytochemicals in foods is typically quite low, but combining with some other foods has been shown to either inhibit or enhance their bioaccessibility.[201]

- **Fermentation has been used over the ages[202] around the world not only as a preservation method, but also to increase the bioavailability of nutrients[203–205] and increase exposure to microbes.[206]** Fermented foods have been shown to have a positive influence on the structure and function of the gut microbiome, along with other positive health benefits.[207–210] Diets rich in fermented foods have been found to increase gut microbiome diversity and decrease markers of inflammation.[211]

Digestion & Absorption

The human digestive system is one exquisite tube, from mouth to, let us say, "tail". Along this digestive journey key moments occur that prepare, extract and absorb nutrients. However, damage to these systems is chronic in modern society and is likely a significant cause of chronic illness and disease, in part because a damaged gut prevents proper absorption of nutrients, damages the all-important gut microbiome and is notoriously difficult to heal. In other words, a food can arrive in a maximally nutritious state to someone's plate, but if their body is not functioning optimally, it may not actually be able to reap the food's benefits.

KEY REFLECTIONS

- **Ingesting a nutrient does not mean that the body will be able to properly digest it or be able to use or assimilate it.** For example, the majority of polyphenols remain intact until they reach the gut and rely on gut microbiota to process them.[57] The state of the digestive tract and gut microbiome will ultimately affect whether or not many nutrients that are consumed are actually absorbed.

- **The bioavailability of nutrients is often increased when ingested with complementary nutrients**. For instance, vitamin D facilitates calcium and phosphorus absorption[212] and black pepper increases the bioavailability of curcumin from turmeric.[213] While many studies and initiatives have focused on the nutrients and their dynamics within a single food or product, it is the relationship between various foods, the mechanisms of the body, and the microbiome that need to be taken into consideration to unlock the full-spectrum value of a nutrient.[214,215]

- Awareness is building about the centrality of the digestive system in human health. There are cascading negative effects when the digestive system is damaged, conditions often referred to as "Leaky Gut", intestinal permeability and dysbiosis. **A damaged gut does not properly absorb nutrients.[216]**

- Digestion begins in the brain[217]. When a person sees or smells food the brain initiates digestive functions by, for example, beginning to salivate and excrete digestive enzymes. That means for proper digestion, the food must be not only prepared well, it must also be appealing to the person eating it. This has a cultural dimension in that you may find your own culture's traditional foods more appealing than those of the dominant culture's foods. It may mean that **access to traditional foods may have a direct effect on the body's ability to digest.**

- **What's more, the person must be in a parasympathetic state[218] (read: calm) in order for the body to properly engage its digestive systems.** Meaning, if someone is chronically stressed or traumatized and thus chronically in a sympathetic nervous state, which disproportionately affects BIPOC and people living in poverty, it may be more difficult for them to digest and absorb the nutrients available in the food.

- Leslie Korn's concept of **"Nutrition Trauma"** is also relevant here. She defines Nutrition Trauma as "the disruptions in access to endemic, natural food resources due to overwhelming forces that make inaccessible foods that are bio-culturally and bio-chemically suited to healthy digestion and nutrient utilization. Nutrition Trauma occurs when introduced foods overwhelm the capacity of the local (indigenous) peoples to digest and metabolize these new foods, which often cause conditions that were unknown or rare before the colonial process. While this definition evolved in response to my work with indigenous populations, Nutrition Trauma is applicable to all people whether by choice, addiction, or conditions that overwhelm their capacity to digest, thus resulting in chronic illness."[219] The lack of access to nutritious and culturally appropriate foods we discussed before takes its toll. **And so even when more nutrient dense foods are introduced, the body may be in such a state of trauma and dysbiosis it can't properly unlock the nutrients of the food it now has access to.[220]**

- **These challenges of digestion and absorption can compound over generations:**
    - Disruptions to digestion and absorption and the effects that compound over generations of unhealed and additional trauma.[221]
    - Micronutrient deficiencies can lead to genetic changes that are expressed within the current generation in the form of disease or be passed onto the next generation.[222]
    - Exposure to agricultural chemicals, such as glyphosate, can induce epigenetic changes that have been shown to affect future generations more than the generation that was exposed to the chemical.[223]

- Stomach acid is a commonly misunderstood and too-often maligned part of the digestive process. The very word "acid" evokes the image of pain and indigestion in the average person's mind, due in large part to prolific advertising for over-the-counter and prescription medications that neutralize or reduce stomach acid or even block its production altogether. In reality, **stomach acid is an absolutely critical step in the digestive process, and is critical for nutrient absorption in particular.[224]** Stomach acid not only helps break down food, it is also a signal for subsequent digestive processes like bile excretion from the gallbladder. Additionally, there are critical bacteria that function optimally at properly low pH levels in the stomach. Neutralizing stomach acid can create imbalances in the gut microbiome that adversely impact digestion. With the well-documented over-prescription and use of stomach acid blocking medications, such as proton pump inhibitors, it leaves many people less able to properly digest and unlock the nutrients in their food.[225,226] That means that even if someone is eating a highly nutritious food, if they lack sufficient stomach acid, they may not be able to break down and absorb the nutrients and they may continue to damage their digestive functions.

- Although beyond the scope of this paper, it is important to note that there are abundant efforts to better understand how to heal a damaged gut. **It is notoriously challenging to heal damaged or "traumatized" digestive systems and gut microbiomes.** Some research has found that loss of microbial diversity over generations leads to extinctions of certain microbial species and cannot be recovered[221]. That said, there is some emerging promise found in Fecal Microbial Transplants (FMT)[227]. Beyond the extraordinary measure of FMT, there are abundant specialists, diets, products and protocols that show some promise in healing dysbiosis.

Summary Reflections

- **Growing more nutritious food influences human health.** It's easy to get caught up in reductionist thinking that draws attention only to individual studies or even individual nutrients. And the scale can feel so small. A little more magnesium here, a bit more antioxidants there can seem like negligible improvements or deficiencies for a food or even for a human body. But, when you zoom out and look on an epidemiological level and at the overall patterns in the research, it is clear that the cumulative effect of more nutritious food influences human health. The more nutritious and the more diverse our diets are, the more we're epidemiologically loading the dice for decreasing the prevalence of disease in a community or population.

- **The relationship between regenerative agriculture and human health is complex.** Just because something is grown exquisitely and leaves the field with a maximum amount of nutrients doesn't mean that it will arrive at a place of purchase in a maximally nutritious condition, that someone will be able to access and purchase it, that it will be prepared in a way that preserves or maximizes the nutrients or that the person eating it will be able to properly digest and absorb the nutrients the food has to offer. There is a bi-directional relationship between agricultural practices and human health. All along the journey from field to human body there are levers and dials we can change and move to maximize the potential that the food will have a positive impact on a person's health.

- **The regenerative agriculture and human health nexus warrants a movement.** There are real people, real businesses and real organizations working all across the journey from field to body. Some of them already care deeply about maximizing nutrition. Some are caught up in the conventional systems that prioritize quantity over quality, but will be relieved to find a different way. Some are already working in partnership. Others are in competition. In order to bring about this transformation in improving the human condition, we need to have actors doing their part to maximize nutrition at every step of the way and they often need to work in concert. Not everybody needs to care about everything on the journey from field to human body, but the movement needs to consider all of it.

- **Race and gender equity are inextricably linked to the success of this movement.** Racism and gender oppression are a significant part of the problem: racist and economically unjust systems that make nutritious food inaccessible to many BIPOC and low-income people. Women shouldering economic burdens alongside household burdens, too often left with the sole responsibility of feeding

their families, but too exhausted to do the work of preparing more nutritious food. Community after community stripped of their cultural traditions and traditional foods. Community after community left in a state of compounding trauma. Recognizing and repairing these injustices is a crucial part of this movement. But more than that, in order to bring about a Regenerative Agriculture → Human Health transformation, we need everyone at every step wholly engaged and included. That means an actively anti-racist and inclusive movement with BIPOC and women leaders at the core. A movement that recognizes how and when it has been part of the problem. A movement that is willing to do the hard work of healing and repairing.

- **We need a new vocabulary.** As mentioned earlier, the word "nutrient" just doesn't capture the incredible complexity of the compounds found in food. We need a new vocabulary and a new taxonomy. There are already calls to better define regenerative agriculture. Among other things, the definition does not properly acknowledge the traditional wisdom of Indigenous people who have been tending land and growing food in these ways for generations. And working definitions to date have not fully embraced the human health benefits of such practices.

- **We'll probably never know exactly how nutrients in food affect human health.** Foods, agriculture systems, human bodies, animals and the broader environment are all complex, dynamic systems—not to mention the complex microbial systems that co-exist with them. That means it will be nearly impossible to demonstrate causality. And there will be dimensions of the Regenerative Agriculture → Human Health journey that we will never completely understand, certainly not in any Western scientific sense. We should continue to champion research and data, but can't wait for the one, unifying research study to definitively prove that soil health → more nutritious food → human health. The directionality of the evidence is clear. Ultimately, we are likely best served by paying closest attention to the overall outcomes of our systems and interventions.

- **We know enough to act and we must make changes all across the journey from the field to the human body.** Much is known about the complex relationships of how regenerative agriculture contributes to human health. We can and will know more. But it is not scientific understanding that is holding us back. We already know enough to act. In response to skeptics, we must remember that absence of evidence is not evidence of absence. Some of these things are knowable, it's just that no one has sought to know them. The economics of food and agriculture systems still value quantity over the holistic nutritional quality of food and so, all too often, voices urging us to wait before acting are those that benefit from the status quo. They're terrified that we may finally get the gumption to stand by our research, stand by our wisdom and act.

This paper is not exhaustive nor definitive. It is meant to spark a new kind of conversation about Regenerative Agriculture → Human Health. We are at an exciting moment where leaders and organizations are urging us to see the connections between regenerative agriculture and human health. Many of these leaders and organizations are already flipping levers and turning dials to ensure that our systems can grow nutritious food, that it is accessible to everyone in a maximally nutritious state and that bodies are strong enough to unlock those nutrients. Together we can build on this momentum to fully explore the complexity of the Regenerative Agriculture → Human Health movement. New opportunities for true and just transformation will emerge: new partnerships, new research, new experiments, new levers and dials to move. In the future we plan to document more about these bright spots—across sectors, across the Four Levels of Nutritional Interventions and across the journey from field to body—in order to help usher in a systemic strategy and support this burgeoning movement. We hope it helps put us all closer to the vision we all imagine: improving health while improving environmental outcomes as well. We look forward to the conversation. And the ensuing transformation.

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