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Making Conventional Agriculture Environmentally Friendly: Moving beyond the Glorification of Organic Agriculture and the Demonization of Conventional Agriculture

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Abstract: The article reviews the most recent research surrounding the potential role of organic agriculture in providing food for the planet. It challenges the claims of organic agriculture's environmental superiority compared to well-managed, conventional agriculture. The relative advantages of these contrasting approaches to farming in areas such as aggregate land requirements, biodiversity/habitat loss, water quality, land degradation and climate change are considered. Legitimate concerns about conventional agriculture's adverse environmental and health impacts need to be addressed and many harmful practices transformed. Nonetheless, careful, sustainably-run, conventional operations can avoid many of the pitfalls and hazards which are often associated with high-input agriculture. The higher yields provided by conventional agriculture offer a more sustainable strategy than a chemical-free agricultural system at the global level for meeting the needs of burgeoning populations and reducing agriculture's aggregate environmental impact.

Keywords: organic agriculture; conventional agriculture; sustainability; comparison

1. Introduction

The task of providing food for the 11 billion people who are expected to inhabit the planet by the end of the century constitutes one of the most fundamental challenges facing humanity [1]. Conventional agriculture (non-organically certified), as it is often called—where farmers typically utilize synthetic, chemical inputs—provides 98.9% of the world's food at present [2]. However, it is well to remember that what is considered "conventional" today is relatively new in the course of human history. Only a little more than a hundred years have transpired since Fritz Haber developed a process for mixing nitrogen and hydrogen to produce ammonia that could be converted into synthetic fertilizer [3]. Up until World War II, pesticide usage was minimal with chemicals such as DDT only becoming available commercially in 1945 [4].

For most of human history, family farms using organic practices was the norm. Of course, there were far fewer people to feed. Notwithstanding, periodically, even in Europe, famine and massive mortality due to hunger were commonplace [5]. Today, smallholders (who work 20 hectares of land or less) still make up 85% of the world's farmers [6]. Although most lack certification, many could be categorized as essentially organic, low-input operations. Yields in these farms are low relative to more intensive agriculture [7]. While significant progress has been made in improving food security, one in nine people living on the planet is still defined by the United Nations Food and Agriculture Organization (FAO) as "hungry" [8]. It is estimated that "undernutrition" causes over three million deaths among children annually or 45% of all child deaths [9]. Most of the people who face food shortages live in local communities that rely on small, low-input operations. This phenomenon will only become more pronounced as Africa grows by three billion people [10].

Demand for organic products is increasing around the world, particularly in Western developed countries. Currently, Australia has the highest percentage of certified organically farmed land of any country, with some 23 million hectares under cultivation. India has the greatest absolute number of recognized organic farmers. From a global perspective, organic agriculture enjoys its greatest popularity in Europe. As of 2017, 26% of the world's organic croplands are concentrated in Europe—higher than any other continent [2]. European incentives for organic practices are the most generous legislated today [11]. The rising demand for organic products in Europe means that its standards for organic certification and its veneration of organic produce have influence far beyond its borders [12].

Proponents of organic agriculture frequently point out the many drawbacks of conventional, industrial, agricultural practices. They claim a range of benefits which organic agriculture purportedly provide:

- Organic agriculture eliminates chronic [13] and acute [14] exposures to toxic pesticides among farm workers [15], consumers [16] as well as surrounding aquatic [17] and terrestrial ecosystems [18].
- Organic produce has higher nutritional value [19] with greater vitamin [20] and mineral content [21]. It is also argued that organic produce tastes better due to its higher sugar content, and keeps longer due to its high metabolic integrity and superior cellular structure [22].
- Organic farming fosters healthy soil [23] and soil microbiota [24] facilitating the availability of nutrients to plants [25].
- Organic agriculture avoids genetic mutations and development of immunity among insects, reducing the pest outbreaks that pesticide use can unintentionally foster [26].
- By eliminating the expense of many inputs—including insecticides, herbicides and synthetic fertilizer—organic agriculture costs less and is economically competitive [27].
- By relying on inputs that exist in nature, organic agriculture offers a more harmonious orientation towards the natural world and, as such, constitutes a preferable ethical strategy for humankind [28].

Empirical evidence supports some of these claims. For instance, of 15 meta-analyses found in the scientific literature, 12 concluded that there was evidence that organic food was more nutritious and contained more antioxidants, vitamin C and omega-3 fatty acids than conventional produce [29]. However, organic agricultural "true believers" also tend to exaggerate the benefits of chemical free agriculture, creating a caricaturized version of conventional agriculture and its deleterious environmental consequences. It should be noted that there are several comprehensive evaluations in reputable publications (albeit some are disputed [30]) that fail to confirm the averred nutritional advantages of organic produce [31]. In *short, the jury is still out*.

Advocates also often conveniently overlook research indicating the many instances where conventional agricultural systems actually show better environmental outcomes than organic alternatives. Frequently, factors associated with the total food system enterprise (e.g., distance of crop delivery or methods of plowing) will dominate the relative sustainability of a given farm operation, regardless of its utilization of chemicals and inputs. Most importantly, notwithstanding the actual magnitude of potential risks from conventional agriculture, its higher yields relative to organic agriculture cannot be dismissed, especially in a planet where expanding population levels make food security a paramount concern for humanity. The question that policy makers at the macro-level need to answer is: "Given present technologies and anticipated demand for food, should organic agriculture be scaled up as the normative approach to farming at the global level?" This article considers the question based on criteria associated with global environmental sustainability, and unequivocally concludes that the answer is "no".

To reach this conclusion, this article reviews the most recent research surrounding this critical debate, questioning the claims of organic agriculture's absolute environmental superiority. The relative advantages of the different approaches in areas such as aggregate land requirements, biodiversity/habitat loss, water quality, land degradation and climate change are considered. Broader aspects of sustainability, involving the economic and social issues that affect food security, are of course also important and cannot be separated from deliberations about an optimal global strategy for feeding the planet. Clearly, not only the total volume of production matters with regards to a population's ability to feed itself, but also the accompanying distribution systems along with public policies regarding distributive justice and equal access to food across societies and nations. Many commentators have made the point that, in theory, enough food is already grown on the planet to adequately feed more people than presently live on earth [32,33]. The problem can surely be framed as one of distribution and distributive justice. However, these broader socio-economic issues involve complex political dynamics and lie beyond the scope of the present article.

Legitimate concerns about conventional agriculture's adverse environmental and health impacts need to be addressed and many harmful practices transformed. Yet, careful, sustainably-run, conventional operations can avoid much of the environment abuse which is often associated with high-input agriculture. Data suggest that there are circumstances where responsibly run conventional agricultural operations may actually cause less environmental damage than large scale, organic farming operations. Rather than clinging to a given ideology, sustainable practices that improve environmental performance should be integrated into both existing organic and conventional farm operations. Effective, sophisticated management will allow more food to be grown on less land with only modest off-site impacts, something which is not only economically sensible, but ecologically critical.

2. The Land Requirements of a Global Transition to Organic Agriculture

An evaluation of the conventional/organic agriculture dilemma at the global level needs to begin with the implications for food security. Although many different assessments have been made [34], the most recent estimates calculate that, altogether, some 38% of earth's terrestrial surface is occupied by agriculture: roughly 12% of ice-free land is used to raise crops for human consumption while pastures cover another 26% [35]. When one considers the large areas of the earth's surface covered by deserts or inhospitable mountain regions, the proportion of lands with actual agricultural potential that are utilized for farming is actually far higher. Each year, there is increasingly less land available for non-agricultural usage, not to mention the other forms of life with whom humans share the planet.

The scientific literature consistently reports significantly higher yields among conventional agricultural farms than in organic operations. One of the most comprehensive reviews ever conducted, published in the prestigious journal *Nature*, found that, while yield differences can be contextual, organic agriculture has "34% lower yields when the conventional and organic systems are most comparable" [36]. In November, 2017, a different European research team published the latest meta-analysis contrasting the productivity of conventional versus organic agriculture in *Nature Communications*. They reached similar conclusions [37]. Clearly, the economic conditions of the farming community, the climate and soil types, the kinds of crops grown, etc. create site-specific contexts which affect agricultural performances. When aggregated, however, data about crop yields consistently show that harvests for organic agriculture are smaller.

Using standard demographic projections, it can be assumed that global agricultural output will need to increase by at least 50% to feed nine billion people in 2050 [38]. The most recent estimates suggest that, given present consumption patterns, the transition to a fully organic system would require 30% more land usage than conventional agriculture [37]. This shift would deliver meaningful reductions in N surplus and pesticide use. To attain such benefits, the study considered alternative scenarios, modeling the implications for land use if consumer demand and consumption patterns could be altered. The results indicate that, if an organic agricultural transition was accompanied by a 50% drop in food wastage and consumption of agricultural products, additional land would not be required. Clearly, public policy needs to do more to find ways to reduce the extraordinary levels of food which are produced but never consumed. Nonetheless, it is not clear whether this can be achieved any time in the foreseeable future, creating the conditions necessary to make organic systems sufficient at a global level.

These findings highlight an important dynamic which appears repeatedly in organic/conventional comparative studies. In terms of improving overall environmental sustainability, *there are factors more important than whether chemical inputs are utilized by farmers*. The potential role of transforming consumption patterns—in particular transforming meat-intensive diets—as part of a global food security strategy, is well-recognized. In other words, reducing chemicals is important—but reducing meat consumption and its detrimental environmental impacts is more important. This is not to suggest that slashing chemical impacts in many cases will not produce environmental and health benefits. Often it will. However, there are other priorities for global sustainability. For instance, Garnett (2014) identified three distinct approaches for attaining greater global food security [39]. The first involves increasing the efficiency by producers and decreasing the impact of present conventional agriculture through technological innovation. Another strategy would transform the food delivery system by changing the relationships among actors (producers and consumers) in the food system. Here, the problem is framed in terms of inequality or imbalances. The most intuitively appealing for many might be the third approach: "demand restraint", where consumers curb consumption of high impact foods. This involves policies that reduce the prodigious carbon footprint, water footprint and land requirements created to meet the demand for beef and other meat-based diets [40].

The trouble with such hopeful scenarios is that they fly in the face of what is actually happening on the ground around the world. To begin with, the number of people living on planet earth who will need to be fed by the end of the century, in the "medium variant" projected by the United Nations, is now considered to be 11 billion. The high variant scenario reaches an astonishing 16 billion [41]. Meanwhile, the amount of arable land lost to land degradation and desertification is on the rise.

The Millennium Ecosystem Assessment commissioned by the United Nations brought together 1360 experts from 95 countries, evaluating the condition of the earth and the ecosystems services which support life. The 2005 report characterized *desertification* as the global environmental scourge affecting the largest number of people on the planet [42]. In many countries, the scope and the severity of land degradation have only gotten worse over the past decades. A 2017 study by the United Nations confirmed that: "*Over 1.3 billion people are trapped on degrading agricultural land: farmers on marginal land, especially in the drylands, have limited options for alternative livelihoods and are often excluded from wider infrastructure and economic development*." [1]. At the same time, burgeoning populations are steadily usurping the planet's most fertile lands. One projection calculates that between 2000 and 2030, as much as 3.3 million hectares of prime agricultural land *per year* will be lost to the proliferation of urban sprawl [43].

Most of the projections and scenarios for addressing such challenges in the face of global population growth, the relentless spread of urban development and desertification trends all rely on a high level of global governance and cooperation [44]. Unfortunately, this level of international commitment has been elusive in addressing other, complex global challenges [45]. For example, ever since the paradigm of carbon wedges was introduced as a tangible path forward for greenhouse gas emission reductions, the possibility of effective climate change mitigation has been available [46]. However, notwithstanding many impressive national efforts—worldwide—emissions continue to rise [47]. Where carbon footprints have been reduced, it has not been lifestyle changes so much as technological innovation (accessibility to natural gas, reduced solar and wind energy costs, and green building) that led to progress [48].

It would seem that agriculture is no different. Like many hypothetical visions of a sustainable future, the notion that changing food consumption patterns would allow organic agriculture to feed the world on lands comparable in size to those presently exploited for conventional agriculture, is a utopian one. There is absolutely no empirical basis for such optimism. The UN Food and Agricultural Organization reports that the world food economy is actually being driven by a shift in diets towards increasing meat consumption. Of course, it would be well to have a far more significant global educational effort to reduce meat, and especially beef, in diets around the world. But, it would be a mistake to build agricultural policy around a presumption of such a campaign's success when trends point in the opposite direction. For instance, recently, the FAO co-authored a report with the OECD anticipating a 1% annual growth in meat products, and over a 2% annual increase in dairy products over the coming decade [49].

Much of the anticipated growth in meat consumption can be attributed to rising per capita consumption in developing countries, alongside the massive population increase occurring there. There is nothing new to these trends. For some time, the demand for meat in the developing world has been increasing by 5–6% annually, with dairy products also showing a 3.4–3.8% annual increase [50]. Perhaps the greatest contributor to this momentous trend is China, which already consumes more meat than the rest of the OECD countries combined. These dietary inclinations are reflected in the 6% annual increase in animal feed consumed by China during the past decade. During this period, annual consumption of pork increased in China alone by 11 million tons—some 59% of the total global increase.

The trends in China are not anomalous. Even in developed countries, where campaigns exist to reduce meat consumption, the FAO/OECD experts see no signs that demand for beef and veal will drop over the coming years. Indeed, global annual consumption of beef increased by six million tons over the past decade and is expected to increase by 1.2 percent a year during the coming decade [50].

It is hard to urge developing countries to reform their diets when their average per capita consumption of meat is expected to remain but a third of that in developed nations, notwithstanding a growing preference among affluent countries for poultry and fish over beef. In other words, rather than meat consumption dropping by 50%, which would enable an organic transition to be land-utilization neutral, animal production will probably be doubling. Barring technological breakthroughs in in vitro meat cloning and other forms of meat substitutes [51], the rising demand will likely be translated into a parallel increase in the amount of land required for grazing and feed as seen in the Amazon Basin.

These changes will lead to an unprecedented loss of wildlife [52] and continued "Sixth Extinction" dynamics [53]. The world desperately needs to stop the hemorrhaging of habitats that support wildlife and forests. *The notion of increasing the lands required for crop production by over 30% to accommodate an organic revolution is unjustifiable ecologically and realistically, not implementable.*

3. Biodiversity and the Organic/Conventional Divide

Increasing land cultivation globally to usher in a new organic age would also have an enormous, destructive impact on biodiversity. This can be looked at from both the micro and the macro perspectives. Undoubtedly, at the micro-level, agricultural systems that rely on poisons to ensure crop yields have a far more negative effect on surrounding biodiversity than organic farms, that completely avoid such chemicals. This is indeed borne out in numerous studies, such as the one showing that German organic grasslands are home to a greater numbers of plant species than comparable conventional fields [54]. Other studies report greater diversity and density of spiders [55], earthworms [56] and nematodes [57]. More uncommon plant species are found in organic fields than in conventional ones [58]. In research involving mammal [59,60] and avian species [61], findings are consistent.

Yet, the picture that emerges is different at the macro-level. That is because of the critical role habitat loss plays in the planet's present biodiversity crisis [62]. While there are myriad causes behind the world's unimaginable loss of 52% of total wildlife between 1970 and 2010, chemicals are not the primary driver behind this ecological devastation: Invasive species, pollution and most of all, compromised or fragmented habitat are the predominant drivers [52].

This insight is at the heart of the "*land sparing*" position, which sees maximizing habitat protection and sanctuaries as the paramount priority for conservation strategies [63]. Even advocates who favor a strategy of "*land sharing*" [64] would be quick to agree that agricultural efficiency is a paramount priority if any land at all is to remain for the other creatures in the new, 10-billion-person-planet-earth reality. Integrated pest management, which reduces chemical usage dramatically, makes sense economically and ecologically, validating the position that pesticides should always be used as a last result. In sensitive habitats (e.g., adjacent to aquatic ecosystems), spraying should generally be proscribed. Nonetheless, because a global transition to organic agriculture would supplant such prodigious amounts of habitat, it is hard to argue that such a transition would have a positive effect on the planet's disastrous biodiversity trends.

4. Water Quality and Off-Site Environmental Impacts

It is generally assumed that organic farms are more harmonious with the surrounding environment than "conventional operations". Many studies, however, reach the opposite conclusion. Water quality constitutes such a case. For instance, a 2014 Israeli study measured water quality across the entire unsaturated zone beneath newly established greenhouses, contrasting intensive organic methods with the impacts of comparable conventional agriculture. Measurements of the nitrate concentrations in the root zone beneath the organic greenhouse (greater than one meter) were extremely high, averaging 357 mg/L with peak NO_3 concentrations reaching 724 mg/L. This was an order of magnitude higher than levels measured at similar depths below the greenhouses with conventional farming. Those farms that used drip irrigation measured average nitrate concentrations at only 37 mg/L.

In contrast, researchers established that the conventional farms were delivering fertilizer to the root zones more efficiently, with high concentrations of 270 mg/L; these levels quickly dropped in the deeper part of the vadose zone. At the same time, measurements in the root zones of organic operations showed relative shortages of nitrate. The researchers concluded that downleaching of nitrates below the organic farms was a direct result of nutrient release from the compost to the soil during the early stages of the growing season. During this stage in the growth cycle, young organic plants have low nutrient uptake making percolation of nitrates into the vadose zone and ground water ineluctable [65].

Similar results can be found in livestock operations. When free range, organic, and conventional broiler chicken systems were compared for off-site impacts on water resources, the organic chicken was found to have a higher eutrophication potential. This was attributed to the nutrient leaching that took place when raising organic crops and the differences in chicken feed contribution [66]. The point here is not that conventional farmers are inherently more virtuous or invariably produce less nonpoint source water pollution than their organic colleagues. Rather, it seems that good management ultimately determines the nature of environmental impacts, far more than does the utilization or abstention of chemicals in agricultural operations.

5. The Ambiguous Lessons Offered by Environmental Life Cycle Analysis

Any discussion of global sustainability today needs to seriously consider the implications of a policy for mitigating climate change. In assessing the carbon footprint of organic versus conventional agriculture, it is well to think systemically rather than intuitively. It turns out that the total carbon footprint of agriculture has far more to do with a range of other factors than whether the produce is grown organically or conventionally. *Life Cycle Assessment* (*LCA*) research, which assesses the environmental impact of a product, process or activity from "cradle to grave" has been applied to assess disparate environmental impact for a broad variety of crops [67]. Considerable attention has also been paid to milk production [68].

A Swiss group of researchers reviewed 34 *LCA* studies that compared organic with conventional agriculture. They found that much of the research suffered from a range of methodological flaws, from small sample sizes to inadequate differentiation of specific farming system characteristics, with only a limited number of impact categories assessed. In almost every case, while conventional agriculture showed higher yields *per hectare*, organic products, generally had lower environmental impacts *per area*. Nonetheless, several studies reported exceptions to this rule: from the negative impacts identified during the life cycle of organic beans to the greater eutrophication and acidification caused by some organic beef, pig and poultry operations as well as tomatoes wheat and potatoes [69]. A recent, even more comprehensive, analysis by Clark and Tilman essentially reaches the same conclusions [70].

LCA research also reveals that some popular wisdom about conventional agriculture's "egregious" environmental performance has little empirical support. Many generalizations about organic agriculture's superior environmental results do not hold up to rigorous evaluation A study comparing 29 organic (1.5% of total certified organic operations) with conventional farms in Australia found that organic farms have higher direct energy use, energy related emissions, and greenhouse gas emissions than conventional operations [71]. A range of pollution sources associated with food production may be far more important than the effects of fertilizer and pesticide usage: these include transportation of produce and market structures [72]. A common finding is that when yields are balanced against environmental footprint, the total environmental impacts per unit of product are similar [73]. Accordingly, in assessing greenhouse gas release, when the functional unit of analysis is the production area, organic operations appear advantageous. However, if the analysis uses emissions per kilocalorie of food grown or kilogram of agricultural product, conventional operations actually show a smaller carbon footprint [74].

This same phenomenon often emerges in the many evaluations conducted that compare organic with conventional dairy operations [75]. Organic milk production frequently comes out ahead, especially when an "allocation factor" that considers the price differential is figured into the equation [76]. Organic milk operations have also been shown to have higher on-farm acidification potential and global warming potential per kilogram than conventional dairy farms. This implies that higher ammonia, methane, and nitrous oxide emissions occur in organic farms per kilogram of milk produced than for conventionally produced milk. In addition, results show lower land use per kilogram of conventional milk in comparison to organic milk [77].

There are several explanations for this relatively, superior performance of non-organic dairies. Cederberg and Mattson attribute the higher methane footprint of organically raised cattle to the fact that the cows spend more time in the pasture. From an animal welfare perspective, this is surely a highly desirable feature. However, it also means that the diet of organically-raised cattle is dominated by roughage fodder, which produces more methane than conventional operations [78].

This mixed-environmental verdict about organic agriculture's environmental virtues can be found in a typical meta-analysis of environmental performance conducted on European agricultural operations:

> *"Organic farms tend to have higher soil organic matter content and lower nutrient losses (nitrogen leaching, nitrous oxide emissions and ammonia emissions) per unit of field area. However, ammonia emissions, nitrogen leaching and nitrous oxide emissions per product unit were higher from organic systems. Organic systems had lower energy requirements, but higher land use, eutrophication potential and acidification potential per product unit. The variation within the results across different studies was wide due to differences in the systems compared and research methods used."* [79]

In short, while there are unquestionable environmental advantages when food is grown organically, many comparative studies do not support blanket assumptions of organic agriculture's off-site, environmental superiority [80]. Tradeoffs in environmental metrics and indicators, it seems are unavoidable.

6. Agriculture's Carbon Footprint and Contribution to Climate Change

As both conventional and organic farming appear to display different advantages for different environmental criteria, the question becomes: *What is a society's environmental priority?* In other words: *Can these studies offer meaningful insights for informing national and global policies?* Many environmental advocates prioritize climate change as the paramount environmental challenge facing the world today [81], because of both its irreversibility and the vast numbers of peoples and ecosystems affected.

That explains why it constitutes a specific environmental target included among the seventeen, generally generic, sustainable development goals adopted by the United Nations for the planet [82].

LCA analysis indicates fairly clearly that significant reduction of agriculture's "carbon footprint" can be achieved by consuming seasonal fruits and vegetables and reducing transport of produce via airplanes. This assumes that there is no heating with fossil fuels associated with fruit and vegetable production, as found in vegetables production in some greenhouses [83]. For instance, Meisterling (2009) found that organic wheat produces roughly 30 g less CO_2-eq per 0.67 kg wheat flour (1 kg loaf of bread) than conventional wheat systems, assuming that the produce travels identical distances. This is due to the carbon footprint associated with the synthetic nitrogen utilized during cultivation. If, however, organic wheat is transported a greater distance than conventional wheat, any carbon-associated advantage quickly disappears [84].

Most important of all, it is well to remember that beef production creates more greenhouse gas emissions than all other food production combined [85,86]. The "big picture" of a global shift to organic food production that emerges from even a cursory analysis is that any carbon inventory will be dominated by the prodigious amounts of manure that will be required to restore nitrogen to the soil—and the methane that the livestock that provides the manure will generate. The logic is fairly simple: As the soil becomes depleted of nutrients, there are limitations on the replacement rates of nitrogen fixing plants. For intensive agriculture, additional fertilization becomes critical, therefore, for maintaining high yields over time.

Eschewing synthetic fertilizer is axiomatic to organic farming. While there is considerable geographic variation in application rates subject to local conditions [87], by spreading manure on a regular basis, soil fertility can indeed be maintained and boosted. Farmyard manure, or the decomposed mixture of excrement with litter and residual fodder is deemed critical to most organic agricultural operations. First, it is credited with supplying plant nutrients (and micronutrients), improving the structure and water holding capacity of soils and even contributing to the control of parasitic nematodes by alternating the balance of microorganisms in the soil [88].

The problem, however, is that generating the manure to ensure adequate nitrogen and phosphorus in the fields and orchards to produce food for 10 billion people involves the unimaginable expansion of the planet's cow population. Norman Borlaug won the Nobel Peace Prize for his extraordinary contribution to improving crop yields through improved crop varieties. He argued, that even if it was possible to marshal sufficient organic material to preserve soil fertility through applying animal manures, human wastes and plant residues to the soil, the nutrients would still not be enough to feed more than four billion people on present cultivated lands. Cropland would have to be expanded "dramatically". (As he quipped: "[Organic approaches] can only feed four billion–I don't see two billion volunteers to disappear." [89]). In 2007, Borlaug calculated that producing food organically for 6.2 billion people would require increasing the planet's cattle population *almost tenfold*, from the 1.5 billion cows living at the time to the 10 billion required to support an organic food system. Today, there are already 1.4 billion more people to feed than when Bourlaug made his calculations. Given the carbon footprint of cows, the additional methane emissions associated with organic manure-based operations are almost unimaginable. Other studies [79,90] such as the 2016 evaluation by a team from Washington State University published in *Nature Plants* conclude that reliance on manure exacerbate problems of soil acidification and off-site eutrophication, with organic operations exhibiting higher leaching and emissions per unit of production, relative to conventional fertilizer use [91].

7. Desertification and Land Degradation Under Different Agricultural Regimes

Climate change is not the only significant global ecological challenge for which organic agriculture constitutes an imprudent policy preference. The United Nations Convention to Combat Desertification was designed to facilitate improved land stewardship [92]. Estimates of degraded lands on the planet vary widely, ranging from 1 to 6 billion hectares. One systematic assessment calculates that some 40% of croplands are affected by soil erosion [93], with degradation found on roughly one-quarter of all lands on earth [94]. Several studies suggest that the scourge of desertification may be more successfully addressed and soil conservation more effectively achieved with conventional farming.

In many circumstances, preventing erosion and restoring soil integrity can be done more expeditiously with conventional agricultural methods than through organic practices. This appears to be particularly true in the drylands. What matters most is reducing mechanical tillage and grazing intensities to disturb topsoil as little as possible. In a series of recent experiments in semi-arid areas, following harvest and prior to cultivation, there seemed to be no statistically significant difference in soil loss between organic and conventional plots [95]. However, the research team also found that fields that had been cultivated using organic methods were often more susceptible to wind erosion than conventional plots, where no-till plowing or other practices left higher levels of vegetative cover [96].

In short, what ultimately matters for land stewardship is the extent of mechanical tillage rather than the actual inputs—conventional or organic—utilized in a given agricultural operations [97]. This was among the conclusions reached in a major life cycle analysis of an Italian team that compared organic and conventional olive growing [90]. Ensuring adequate vegetative cover has always been a key to enhancing soil organic carbon [98]. In other words, erosion control is ultimately a function of tillage methods and application of practices such as terracing or contour and no-till ploughing. The effect of agricultural chemicals or organic methods appears to be inconsequential.

8. Making Conventional and Organic Agriculture More Sustainable

There is a tendency on both sides of the organic/conventional divide to caricaturize the other and cherry pick extreme examples of environmentally problematic practices. The truth is that for some time, sustainable alternatives have been available for conscientious, conventional farmers. For example, synthetic fertilizer can cause massive nonpoint source water pollution when applied excessively and inappropriately. However, drip irrigation systems that have been around for forty years offer a far more efficient delivery mechanism—allowing well-run, conventional operations to generate trivial nitrate contamination [99]. Indeed, reliance on composted manure for providing nutrients in organic farm operations has actually been shown to cause greater groundwater pollution rates than comparable "conventional" farms that utilize liquid fertilization techniques through drip irrigation in comparable operations.

It would be erroneous to conclude that studies like these mean that in every situation, organic chicken operations, for example, constitute a hazard to water resources or that utilization of synthetic fertilizers will always produce less groundwater contamination than manure application will. Nonetheless, it suggests that in areas where aquifers already suffer from elevated nitrate levels, conventional irrigation using drip fertigation probably offers a more sustainable approach. As the world considers how to feed the three billion more people who will soon be living on the planet, strategic decisions about food production need to be pragmatic and evidence-based, rather than ideological. A wholesale transition to organic agriculture does not appear to be the best way to improve the environmental performance of global food systems. As Clark and Tilman concluded in their assessment of 742 agricultural systems and over 90 unique foods: "*Our analyses show that dietary shifts towards low-impact foods and increases in agricultural input use efficiency would offer larger environmental benefits than would switches from conventional agricultural systems to alternatives such as organic agriculture or grass-fed beef.*" [70] Criteria for agricultural policies need to include efficiency, economics and the environment. Insights from both organic and sustainably managed conventional agriculture are valuable.

This means that one size does not fit all: both geography and human capacity matter. Most LCA research that provides the empirical foundations for organic advocates has been conducted in Europe. Africa is different. Numerous studies have considered the considerable challenges facing farmers in Sub-Saharan Africa [100–102]. A common denominator recommended for creating the quantum leap in yields that is so necessary for future food security on the continent involves a shift towards higher-input agriculture. New African agricultural initiatives have been particularly vulnerable to pest infestations, when careful, targeted use of appropriate chemicals could have averted the collapse. This is reflected in the impressive results associated with new "farmer kits" which provide a full package for African farmers that includes synthetic fertilizers, pesticides, appropriate seeds and family-irrigation packages [103]. While there are fewer studies comparing organic and conventional farms in Africa, there is little reason to believe that organic agriculture will outperform conventional farms there. Indeed, due to the higher requirements for sophisticated knowledge among farmers, agricultural aid assistance that supports organic farming may not even generate the level of yields found in Europe and the U.S.

This dynamic is summed up by organic agriculture expert Don Lotter in a 2015 article entitled: *Facing food insecurity in Africa: Why, after 30 years of work in organic agriculture, I am promoting the use of synthetic fertilizers and herbicides in small-scale staple crop production*. Based on his work in semi-arid regions of Tanzania, he reached the conclusion that organic crop production was not feasible for local small-scale farmers there as it requires skill sets which they presently lack, along with considerably more land to grow the same amount of calories. Maize is the dominant crop grown by the local, Tanzanian small holders. That means that the ongoing nitrogen needs are considerable, requiring conscientious soil fertility management.

Lotter argued that the most cost-effective and sustainable approach involves a combination of "organic Green Revolution methods" including herbicide-mediated zero tillage conservation agriculture, via backpack sprayers. His fieldwork not only reports substantially increased conventional maize yields when using herbicide-mediated zero tillage systems, but also highly effective erosion control as well as a five-fold increase in rainwater capture in soils. Lotter concluded that *"the risks of glyphosate use are substantially outweighed by the benefits of increased food security and crop system sustainability."* [104] This is the kind of pragmatic perspective required in seeking optimal agricultural strategies. Although the paradigm is not new, recently the strategy of sustainable intensification" [105] has gained considerable traction, with the United Nations Food and Agriculture Organization advocating it as a central policy theme [106]. The low level of yields in Africa for some time have been associated with sub-optimal fertilizer levels found in small farm operations [107,108]. While the United Nations Environmental Program cites certain potential benefits associated with the low external inputs and reliance of local materials associated with organic agriculture, it also identifies the level of knowledge required as a significant challenge [109].

There is a tendency to romanticize organic farms as small, socially responsible, family-run and environmentally conscientious, operations. This may have characterized the early days of the organic food movement. Surely there are many farmers who still embody this ideal of human food production taking place in harmony with the earth. However, it is also well to remember that organic agriculture has become a big business and as such, ironically utilizes many of the practices that organic farmers of old found so pernicious. As of 2015, the organic market generated about 80 billion dollars in crops [110]. Present trends suggest that the market will double during the coming five-years [29]. Organic food production today in many countries bears little resemblance to the stereotype image of intimate, symbiotic interactions between a farmer and her beloved fields.

Some twenty years ago, a team from the University of California, Berkeley posited that the explosive growth in the organic agricultural industry was both *"the cause and the effect of a proliferation of new entrants who are attempting to capture the lucrative niche markets that are lurking behind organic products and the organic labels."* The researchers found that new organic farmers and their production systems "increasingly mirror agribusiness practices" [111]. This process became known as "conventionalization" and has since been identified in a range of countries across the planet. Accordingly, while there may still be more small organic operations than the more sizable, corporate versions that emulate "agribusiness" production models, the larger farms' market share is becoming increasingly dominant.

Already, in 2001, in a *New York Times* article, best-selling author and noted food commentator Michael Pollen described a phenomenon whereby small organic farm operations were being acquired by large corporations: *"The label assured me that most of these additives are organic, which they no doubt* *are, and yet they seem about as jarring to my conception of organic food as, say, a cigarette boat on Walden Pond. But then, so too is the fact (mentioned nowhere on the label) that Cascadian Farm has recently become a subsidiary of General Mills, the third biggest food conglomerate in North America*." [112]

One indication of this trend emerges from the most recent official data about certified organic farms in the U.S. between 1994 and 2011: the number of certified organic operations increased three-fold. During the same period, the amount of cropland expanded six-fold. Thus, we see that, in Oregon, the majority of organic farm operations (60.5%) are small—fewer than 25 acres. However, more than 20% farm more than 100 acres [113,114]. It is these larger farms that increasingly produce a higher percentage of the country's certified organic food. As described by McGee and Alvarez in their 2016 article "*Sustaining with Changing: The Metabolic Rift of Certified Organic Farming*", the resulting performance does not deliver the environmental dividends expected of organic agricultural operations.

This is hardly a U.S. phenomenon. Signs of a "conventionalization process" were already reported in Ontario by 2002 [115]. A recent EU study reflected the increased size of organic operations, reporting that the average size of the labor force of fully organic farms farm was 1.5 annual work units while non-organic farms were only 0.9. German studies confirmed the shift in its organic production [116]. More recently, the shift towards conventional practices in organic farms was identified in southern Spain [117] as well as in Italy and Portugal where researchers identified an increase in the size and a drop in the environmental conscientiousness of organic farming practices [118]. Similarly, the average size of an organic farm holdings was 41 hectares, more than twice the average conventional farm in Europe [119].

Evaluating organic farms in the Yunan Province, Chinese researchers described a situation where: "*nonagricultural capital injection in 2012 led the company ...... to adjust its business strategy with rapid expansion, during which social values, such as energy recycling and community building, had been easily bypassed and replaced with commercial interests*" [120]. This process is not only driven by market forces. Frequently, it is encouraged by government policies. For instance, the Chinese agricultural agencies have begun to encourage an expansion in the size of organic farm operations [121].

In a competitive market, there are plenty of areas where organic agri-businesses adopt the same industrialized methods that are at the core of the conventional agriculture critique. The public often assumes that "organic" constitutes the only sustainable and healthy way to raise food. That is because of public relations and marketing that often present organic products as the sole "environmentally-friendly" alternative presented at supermarkets. However, it is entirely possible to imagine other lines of produce, reflecting integrated pest management and optimal applications of synthetic inputs, that produce better environmental results than a strictly organic regime. For the many people on the planet who find the cost of paying for a healthy diet challenging, this constitutes a preferable strategy. Organic agriculture constitutes an ideal of sorts. Every effort should be made to minimize the utilization of agricultural chemicals and reduce their toxicity. Total elimination of agricultural chemicals, however, should not be an objective function for international agricultural policy to pursue.

Rachel Carson's ideas from over fifty years ago still inform present impulses to make agriculture sustainable. Her book *Silent Spring* lobbied for *limits* on pesticides—not their elimination. Carson never called for an outright ban on DDT, suggesting simply that farmers: "Spray as little as you possibly can" [122]. Surely, what is known today about the carbon footprint of the beef industry suggests that this should constitute a higher priority for environmental advocates than expansion of organic agricultural operations. Considering the challenging agricultural road ahead for meeting the needs of growing populations, a responsible perspective should focus less on a chemical free world in which we might want to live, and more about the real world of highly productive, low impact agriculture and the creative research needed to attain it. For the present, it offers the most promising strategy for feeding future generations.

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