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Review

Diversification, Yield and a New Agricultural Revolution: Problems and Prospects

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Abstract: The sustainability of society hinges on the future of agriculture. Though alternatives to unsustainable, high-input industrial agriculture are available, agricultural systems have been slow to transition to them. Much of the resistance to adopting alternative techniques stems from the perceived costs of alternative agriculture, mainly in terms of yields. The general assumption is that agriculture that is less harmful to people and wildlife directly will be indirectly more harmful because of yield losses that lead to food shortages in the short-term and agricultural extensification in the long-term. Though the yield gap between industrial and alternative forms of agriculture is often discussed, does industrial agriculture actually produce the highest yields? In addition, to what aspects of the food system is yield relevant? We review the evidence for differences in crop yields between industrial and alternative systems and then evaluate the contribution of yields in determining whether people are fed, the land in production, and practices farmers will adopt. In both organic and conservation agriculture, different combinations of crops, climate and diversification practices outperformed industrial agriculture, and thus we find little evidence that high input systems always outperform alternative forms of agriculture. Yield, however, is largely irrelevant to determining whether people are fed or the amount of land in production. A focus on increasing yields alone to feed the world or protect biodiversity will achieve neither goal. To promote sustainable agriculture, we must move past focusing on these oversimplified relationships to disentangling the complex social and ecological factors, and determine how to provide adequate nutrition for people while protecting biodiversity.

Keywords: yield; organic conventional; high-input; industrial; conservation agriculture; diversification; agroecology; transition; conservation; food

1. Introduction

The world supports an amazing diversity of plants that we have cultivated for food. *Homo sapiens* and many other organisms have helped these plants evolve a huge variety of traits and symbioses. However, in many places, the original system of diverse cultivation has been largely lost. Today, agriculture brings to mind one crop planted in thousands of rows across what was once a complex landscape. Why is this imposing homogeneity problematic, whether in the corn belt of the Midwestern United States or pineapple fields in Costa Rica?

Our “modern” agricultural systems have degraded or destroyed the biological interactions that generate ecosystem services essential to agriculture, such as maintaining soil fertility through nutrient cycling and retention, water storage, pest/disease control, and pollination [1]. Instead, crops within these monocultural systems rely on external inputs such as fertilizers, pesticides, and fossil fuel-driven cultivation to take the place of the services previously provided by nature. Agriculture's reliance on external inputs has many unintended consequences, in terms of climate change, polluted air and water, dead zones in coastal seas, biodiversity loss, and, most basically, the destruction of Earth's fertile soils [2]. These outcomes have had profound implications for human health and the environment [3–13]. Some progress has been made in supporting less damaging agricultural practices, for example the ban of neonicotinoids in the E.U. [14], but widespread environmental and health concerns are far from being alleviated.

Due to their near ubiquitous use, high-input agriculture practices are now commonly referred to as "conventional", despite their relatively recent adoption and even though industrial agriculture would be a more accurate descriptor. Here, we define industrial agriculture by its heavy reliance on chemical inputs, and not by scale because even small farms can have high-inputs. The shift to industrial agriculture was driven in part by the desire to enhance short-term agricultural production, which came at the cost of long-term maintenance of natural service provision [15,16]. However, to maintain Earth's capacity to support agriculture, it is imperative that we undergo a new agriculture revolution to change the way we produce food as soon as possible [17–21].

Instead of homogenizing landscapes with agriculture, what if cropping systems were designed to mimic nature? Agriculture areas would be a fine-grained, mosaic of different crops like orchards, vegetable row crops, flowering field margins and pastures. These landscapes are designed to support a greater variety of wildlife, some of which would help to pollinate crops and control pests. Measures to spatially and temporally diversify farms to mimic nature, collectively known as diversification techniques or agro-ecological, ecologically-intensive, biologically diversified or regenerative farming systems, are shown to be less environmentally and socially damaging than industrial in terms of limiting pesticide exposure, soil erosion and biodiversity loss, while enhancing nutrient, energy and water efficiency (e.g., [1,22–33]).

Agricultural systems have been slow to transition away from industrial, however. A large part of the resistance to adopting alternative techniques to industrial agriculture stems from the perceived costs of alternative agriculture, mainly in terms of yields. The general assumption is that agriculture that is less harmful to people and wildlife directly will be indirectly more harmful because of yield losses that lead to food shortages in the short-term and agricultural extensification in the long-term (which would accelerate the loss of biodiversity, itself essential to agriculture [34]). This sentiment is most bluntly expressed by previous U.S. Secretary of Agriculture, Earl Butz: "Before we go back to organic agriculture in this country, somebody must decide which 50 million Americans we are going to let starve or go hungry" [35]. However, though the yield gap between industrial and alternative forms of agriculture is often discussed, does high-input, industrial agriculture actually produce the highest yields? In addition, when are yields relevant in determining what practice farmers adopt, who gets fed and the amount of land in production? We review the evidence for differences in crop yields between industrial and alternative systems. We also evaluate when yields are relevant to building a sustainable food system.

2. Is There a Yield Gap?

Local factors such as soil, ecosystem service provider diversity (i.e., pollinating insects), climate, labor availability, and many other conditions will determine farm productivity. No suite of farming practices works best everywhere. Several syntheses and meta-analysis, however, have attempted to look for general patterns of yields of industrial agricultural systems in comparison to alternative systems, specifically organic and conservation agriculture. Organic systems use no synthetic inputs, but, depending on the organic standards a farm is adhering to, farms may or may not practice diversification techniques intended to minimize the need for external inputs [36,37]. Enhancing soil fertility is a central tenet of organic farming, however, and many organic standards require the incorporation of diversification practices to achieve this goal. Conservation agriculture is also based on the principles of enhancing soil health and pest control through: (1) direct planting of crops with minimum soil disturbance (no-till); (2) permanent soil protection by cover crops or residue; and (3) crop rotation [38–41]. Inorganic inputs such as fertilizers and pesticides can be applied, though the diversification techniques are intended to minimize the need for them.

Interestingly, the adoption of these systems was driven by very different forces. Many organic organizations began in Europe as a small protest to the agriculture industrialization in the 1920s, eventually spreading globally (please see [23,35] for a more detailed history). Today, certified organic agriculture is practiced on almost 45 million acres (about 1% of the total land in production), mostly concentrated in Oceania and Europe [23,42]. Conservation agriculture rose out of the no-till movements following the environmental disasters of the dust bowl in the U.S., and then gained momentum as fuel prices rose in the 1970s [38,43]. Conservation agriculture is also now practiced globally on 125 million hectares (9% of the total land in production), mostly in South and North America and Australia [38,40]. Livestock can also be incorporated in to both of these systems, though here we focus primarily on crops.

Many different agricultural systems use diversification practices including agroforestry, biodynamic, precision, integrated/hybrid, mixed crop-livestock, perenniation, permaculture, conservation and perennial grain systems [1,23,24,44]. Some of these systems, like biodynamic, have their own certification systems while others do not but are united by shared practices or principles. Because of the ambiguity over what label a specific farm should receive, it is difficult to study the performance of these systems relative to industrial. We thus focus on comparing the performance of the two most widely studied alternative systems to industrial—organic and conservation agriculture—and the diversification techniques that help to eliminate yield gaps where they occur.

2.1. Organic

The most recent and comprehensive meta-analysis (drawing from 1071 organic to conventional yield comparisons from 115 studies collected in 38 countries over a span of 35 years) comparing organic and industrial yields found that organic yields were approximately 15.5% to 22.9% lower than industrial yields [45]. Different crop types (e.g., cereals, fruits and nuts, vegetables) and crop species responded differently to organic management. Cereals (including wheat, barley and potatoes) exhibited the largest yield gap, potentially because the largest effort has been directed at refining seeds and techniques to enhance the yields of these crops in industrial systems [45–47]. Oats, however, had similar yields in both systems [45]. The yields of fruits and nuts were also nearly equal in organic and industrial systems (7 ± 4%). Tomatoes and apples, in particular, performed equally well in both systems [45].

Significantly, incorporating diversification practices into organic improved its production relative to industrial agriculture. When only organic farms plant multiple different crops at the same time (multi-cropping) or plant a sequence of crops (crop rotation), the yield gap is reduced (to 9 ± 4% and 8 ± 5%, respectively, Figure 1a,b, [45]). Using the meta-dataset and the hierarchical, meta-analytic statistical model of [45,48], we also found that when plants that are plowed into the soil, known as green manure, are applied in the organic system, the yield difference was slightly smaller than the overall yield gap, at approximately 16 ± 4% (Figure 1c).

Interestingly, when both organic and industrial systems used crop rotations or multi-cropping, neither system gained productivity relative to the other (Figure 1a,b, [45]), suggesting industrial systems also benefit from the use of diversification practices. Other studies, particularly in the Corn Belt of the Midwestern U.S., have shown similar gains in industrial yields from rotations [26,49,50]. In "continuous corn" where corn is not rotated with other crops, yields are up to 100% lower than in more diverse rotations including nitrogen-fixing plants such as soybeans [49,50]. Similarly, industrial polycultures of grasses and legumes had up to 73% higher yields than each crop in isolation [51].

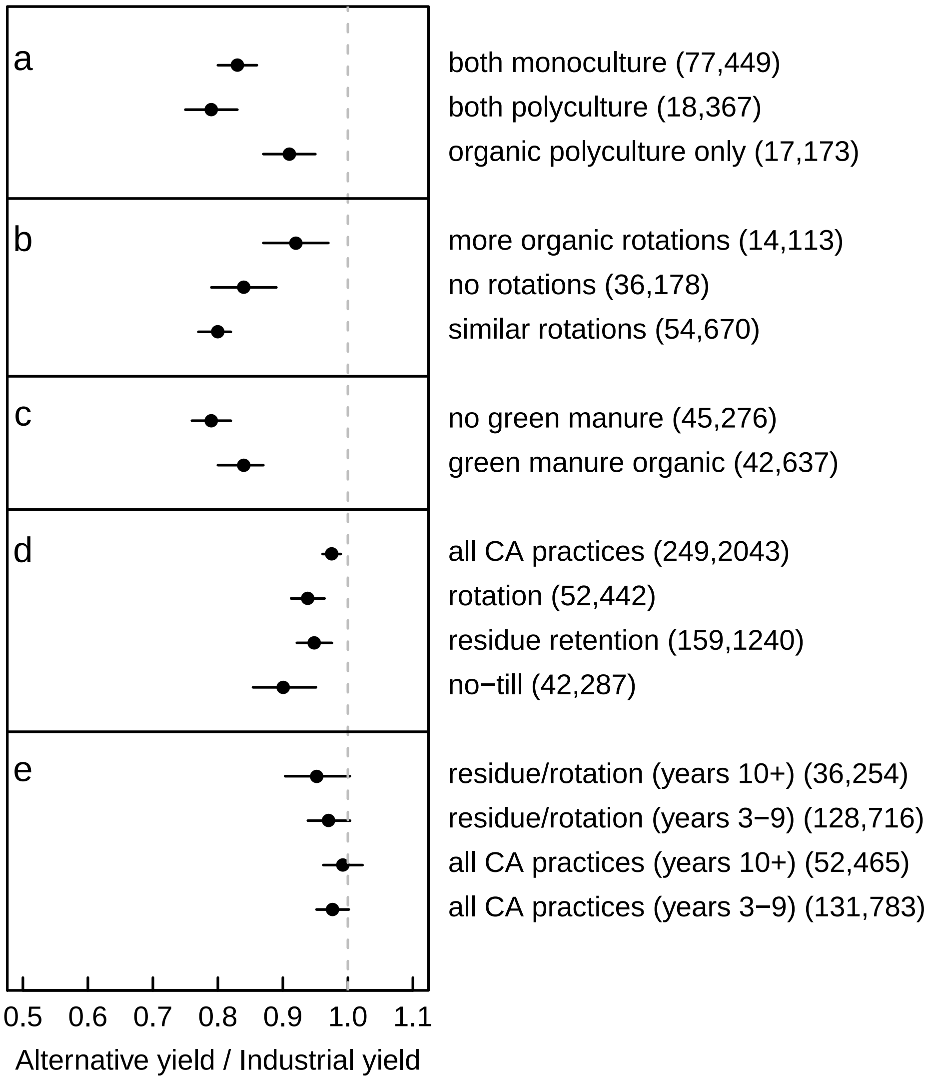

Figure 1. The influence of diversification practices on the yield differences between alternative forms of agriculture and industrial agriculture. Panels (**a**–**c**) represent organic agriculture comparisons from [45] and panels (**d**,**e**) represent comparisons of conservation agriculture (CA) from [39]. In (**a**–**c**), when diversification practices are included only in the organic system, the difference between organic and industrial agriculture is smaller than when both or neither system applies the technique. Similarly, in conservation agriculture, the yield difference is smallest when all three conservation agriculture practices are applied (**d**). Three years or more after conversation to conservation agriculture, yields are statistically equivalent (**e**). Values are mean effect sizes, and 95% credible intervals (**a**–**c**) or bootstrapped 95% confidence intervals (**d**,**e**). The number of studies and observations in each category are shown in parentheses.

In addition to supporting ecosystem services like pest control and pollinator, diversification practices like crop rotations, multi-cropping, and green manure application are often associated with gains in soil fertility [52,53]. Thus, soil management is particularly key for improving the yields of organic systems. The importance of soil management is reinforced by the finding that when nitrogen inputs were similar between organic and industrial systems, the yield gap between the two systems is minimized ($9 \pm 4\%$, [45]).

2.2. Conservation Agriculture

In a global meta-analysis, Pittelkow et al. [39] found that when all three principles of conservation agriculture (no-till, crop rotations, continuous soil cover) were implemented, yields were overall $2.5 \pm 1\%$ lower than industrial yields (Figure 1d). When only one or two of the principles were used, the yield gap was larger (Figure 1d [39]). After three years following the transition from industrial, the yield gap was not statistically significant when at least one other diversification practice was used in combination with no-till (Figure 1e [39]). In addition, under rainfed conditions in dry climates, conservation agriculture yields were 7.3% higher than in industrial systems, likely due to improved water infiltration and greater soil moisture conservation [39,41,54,55].

When conservation management practices are used in synergy with other diversification practices to control pests, further gains in yields may be realized [56]. The push–pull agriculture system, designed as a pest-management strategy for eastern and southern Africa, is such a twist on conservation agriculture [57,58]. Fodder crops are inter-planted to "push" insect pests from the affected crop fields while other trap plants are used to "pull" the insects away from the crops [57]. Implementation of the push–pull system more than tripled yields while also protecting against crop failure [57,59,60].

In both organic and conservation agriculture, different combinations of crops, climate and diversification practices outperformed industrial agriculture (Figure 1 [39,45]). We thus find no evidence to support the blanket assertion that industrial agriculture always produces higher yields.

3. When Is Yield Virtually Irrelevant?

3.1. Feeding the World

Though it is tempting to focus on the seemingly tangible goal of increasing yields through crop breeding, or even refining diversification practices, it is important to recognize when such yield gains will be virtually irrelevant. Most notably, though the primary goal of our food system is to feed people, yield is only one factor within a set of complex socio-economic forces that determine how much food is available and accessible for the hungry [23,61–65]. Although agriculture produces a food surplus at the global scale, two billion people today are either chronically-hungry or malnourished [63,66–68]. Inadequate wages, inequitable distribution of wealth and shrinking social assistance rates are at the heart of our hungry world [69–72]. Ironically, farm workers are among those with inadequate access to nutrition [72]. In some countries like the U.S., some forms of malnourishment are associated with nutritious food deserts and an overabundance of innutritious, cheap calories that also contribute to rising rates of obesity, diabetes and heart diseases [68]. Crop yields are additionally not strong determinants of food security. Studies on child under-nutrition—a reliable and consistent measure of food insecurity—show that, globally, though the quality and quantity of available food contribution to food security, a host of other factors including gender equity and women's education were important determinants [73].

On top of these impediments to getting people the food they need, much of the food we produce never has the potential to become a meal. About 5%–50% of food that is produced globally is wasted [66,74,75]. Concerns about food waste have been remarked on for half a century, and yet significant progress on reducing food wastage has not occurred. Food is wasted across the entire supply chain—from food thrown away on farms due to irregularities in appearance to food wasted in homes when costumers buy or prepare too much. Developed nations waste 30%–50% of the food produced, primarily at the retail and consumer level [74,75]. In developing nations, 5%–35% of the food produced is wasted, primarily at the farm level due to inadequate storage facilities and transportation networks [74,75].

3.2. Determining the Amount of Land in Production

The debate on whether transitioning from industrial to alternative agricultural systems would be beneficial to biodiversity has primarily centered on the debate between "land sparing" and "land sharing". Advocates for land sparing argue that the high yields associated with intensive agriculture will "spare" more land for conservation [76], while proponents of land sharing argue that conservation goals are best served by using more ecologically friendly methods to improve the overall quality of the agricultural landscape [77,78].

The dichotomy between "land sparing" and "land sharing" is based on the false assumption that there is a simple relationship between yields and amounts of land used for production [64]. Often, in fact, yield intensification leads to agricultural expansion and conversion of natural habitats—an example of the Jevons Paradox where resource-use-efficiency increases but consumption rises [79].

The other premise of the debate is that the more wildlife friendly agricultural methods will have lower yields. However, as discussed above, diversification practices that spatial and temporally diversify farms often have better outcomes for biodiversity and yields [36,44,45,50,51,57].

Lastly, the success of conservation interventions depends on land sharing in the broader sense—the sharing of governance, sovereignty, and scenario planning with all inhabitants of a landscape [80,81]. In a global meta-analysis of the success of protected areas, Oldekop et al. [80] found that protected areas associated with positive outcomes for the well-being of the local people were more likely to report positive biodiversity conservation outcomes. Thus, merely setting aside more land without engaging the people that will be interacting with the protected area will not guarantee that conservation goals are reached.

A focus on increasing yields alone to feed the world or protect biodiversity will achieve neither goal. We need to move past focusing on this oversimplified relationship to disentangle the likely location specific, complex social and ecological factors determining how to provide adequate nutrition for people while protecting wildlife. Achieving both is paramount to achieving sustainable food systems because biodiversity provides essential services that support human health and livelihoods [82,83], while poverty and hunger can harm biodiversity (e.g., [84]).

4. When Is Yield Relevant?

4.1. Transitioning from Industrial

The risk of decreases in crop productivity during transition away from industrial agriculture is often a major barrier for farmers considering alternative farming practices. Restoring the soil health and biodiversity needed to provide essential ecosystem services and inputs may take several years, or it may take time for farmers to gain experience with new management practices [39,85]. Any yield changes during transition from industrial agriculture will be dependent on the cropping system, local conditions and extension support and resources aimed at helping farmers implement new management practices (e.g., [39,86]).

Regardless of the mechanism, transition from industrial may be difficult if yields drop without price premiums on products or subsidies from governmental/non-governmental agencies to compensate for the loss [23,39,87–90]. For example, in a global meta-analysis [39] found that farmers transitioning to conservation agriculture experienced a yield loss of around 3% for the first two years. Similarly, transitioning organic farmers may experience yield losses, and thus the usual three-year period before price premiums are realized through organic certification is financially difficult for farmers [23,87–90]. The effect of the transition to organic on yields, however, is variable [45]. Some studies reported organic yields were comparable or higher than in industrial systems within the first year of transition [85,91]. Others saw yields in organic break even with industrial after 1–3 years, [92], while some studies found yields did not reach the level of industrial yields during the three year time period examined [88–90]. Because of the variability in the response of yields to transition, predictions of yield losses cannot be made with certainty, making it difficult for a farmer to plan adequately (particularly given all of the other uncertainties, such as impact of pests, disease and weather, inherent to farming [93]).

In addition, uncertainty in yields and transition costs likely make converting land for organic production unfeasible for farmers with short-term leases. If it takes several years to realize the financial benefits of transitioning, a farmer with a five-year land lease will be unlikely to transition. In places like the Central Coast of California where most farmers have short-term leases, land converted to organic predominantly comes from larger industrial farmers who have the acreage and capital to wait for the financial benefits of transitioning [94]. These newly organic farms, however, often chose to substitute inorganic chemical inputs with their organic counterparts to gain certifications without incorporating diversification practices to limit the need for such inputs [95]. These farms are thus not truly transitioning from industrial agriculture. Organic farmers entering the region need to find an existing organic lease, rent fallow land, or convert small rural residential parcels to agriculture [94]. Thus, new farmers in these areas do not have the tenure to make large strides in transitioning land to alternative agriculture.

Another unintended consequence of yield loss uncertainty during transition is the potential for vertical integration of the supply chain by major food companies. Because of increasing demand for organic products [23], major food brands such as Ardent Mills, General Mills, and Kellogg, are underwriting the transition to organic [96,97]. Growers essentially sign long-term supply contracts in return for the food brands covering the cost of converting their farms to organic production [97,98]. This integration is already common in industrial agriculture [99,100], and thus food brands are expanding their role in the supply chain through incorporating organic farms [98]. In addition, these retailers often demand homogeneous quality and production practices, limiting the techniques farmers can implement. The impacts of such vertical integration are uncertain, but it will likely come at the cost of farmer sovereignty.

To promote transitioning from industrial agriculture and limit unintended consequences of the impacts of such a transition, we must understand the factors that minimize yield losses during transition. Using the meta dataset and statistical model from [45], we found that incorporating diversification practices in the organic system during the first three years post transition minimized the yield loss (Figure 2a–c). In fact, when the transitioning organic system had more rotations than the industrial system, yield were not statistically significantly different between the two systems (Figure 2b). When both systems used polycultures, transitioning systems also did not lose yield relative to industrial, suggesting the transitioning organic system is benefiting from the polyculture more than the industrial (Figure 2a). This result, however, is based on only a handful of studies, so more research is needed to verify this conclusion (Figure 2a). Similar to organic systems in transition, Pittelkow et al. [39] found that, when all three conservation agriculture principles are applied (no-till, residue retention and crop rotation), yield loss in the first two years of implementation are minimized (Figure 2d). Incorporating diversification practices in transitioning systems, therefore, is important for minimizing the potential for yield losses. Further research on the diversification practices that are best able to maintain and boost yields for specific crops and regions will, through curbing the uncertainty surrounding the impacts of transitioning, promote the revolution away from industrial agriculture.

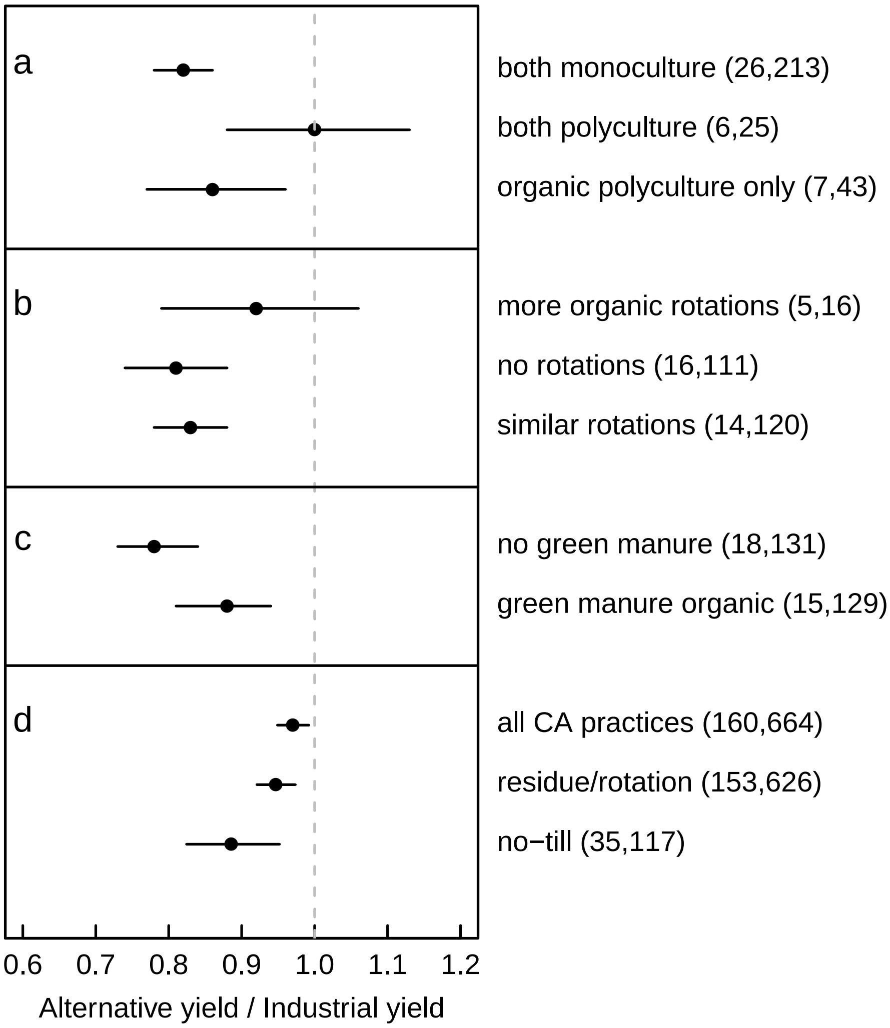

Figure 2. The influence of diversification practices on the yield differences during transition between alternative forms of agriculture and industrial agriculture. Panels (**a**–**c**) represents organic agriculture data from [45] and panel (**d**) represents comparisons of conservation agriculture (CA) from [39]. When diversification practices are applied in the organic system, the yield loss during transition (years 0–3) from an industrial system is minimized, and in the case of crop rotations, not statistically significantly different from zero (**a**–**c**). In conservation agriculture, when all three conservation agriculture practices are applied the yield loss during the first few years (1–2) is also minimized (**d**). Values are mean effect sizes, and 95% credible intervals (**a**–**c**) or bootstrapped 95% confidence intervals (**d**). The number of studies and observations in each category are shown in parentheses.

4.2. Economic Viability

Though yields are only a piece of the complex political, market and educational drivers that determine what farmers farm, they are often a large contributor to the bottom line of farmers [24]. Very rarely will farmers choose to farm in a way that is not economically profitable (but, see [101]). The main factors that determine farming system profitability include crop yields, labor costs, price premiums for product quality and input costs. In addition, systems that enhance positive externalities including biodiversity while minimizing negative externalities such as pesticide contamination will be more economically sustainable in the long-term.

The few studies that have estimated the profitability of diversification techniques, mainly crop rotations and multi-cropping, have found that these practices improved environmental outcomes without lowering profitability in both industrial and organic systems [26,102,103]. In an experimental system in Iowa, Davis et al. [26] found that yields were similar between maize–soybean rotations and systems that incorporated 1–2 additional rotations. Labor costs increased but input costs (especially pesticides) decreased with the number of rotations, so that profits between rotational systems were similar [26]. Similarly, diverse rotations for integrated pest management produced comparable yields but reduced input costs when compared to industrial systems across 48 cropping systems in two major agriculture regions in France [102]. More diverse rotations were often more energy-efficient [102], and used fewer pesticides and fertilizers, lowering freshwater toxicity [102]. Incorporating crop rotations into industrial agriculture thus helps to minimize negative externalities. In addition, here, unlike in lower pesticide usage, did not imply a heavier workload [102].

In a global meta-analysis, Crowder and Reganold [103] found organic system profitability also benefited from longer, more diverse crop rotations. Overall, Crowder and Reganold [103] found that though organic yields were lower than industrial, organic price premiums only had to be 5%–7% for industrial and organic farms to have the same profit, although currently premiums far surpass the break-even-point at 29%–32% [103]. Studies of organic agriculture have also revealed better performance than industrial systems in lowering negative externalities and increasing positive ones through enhancing species richness and abundance, soil fertility, nitrogen uptake by crops, water infiltration and holding capacity, and energy use and efficiency [25,27–32,44].

Furthermore, conservation agriculture, which by definition incorporates crop rotations, enhanced profits relative to industrial. Though no global synthesis of conservation agriculture practices has been conducted, many studies across the world have found that a combination of higher yields (particularly in dry years) and lower production costs led conservation agriculture to be more profitable than industrial [54,55,104–107]. Reduced costs were often the result of labor savings in land preparation [105,108].

In combination with pest management strategies, conservation agriculture can also help protect against catastrophic crop failures [60]. Conservation agricultural also reduces the negative externalities of green house gas emissions, nutrient loss, erosion and run off while improving water quality and retention (reviewed in [109]), soil and above ground biodiversity [41,109]. The push–pull system of conservation agriculture also enhanced positive externalities through bolstering small livestock production, functional biodiversity, incomes and women's empowerment [57,59].

4.3. Yield Resilience

The ability of farms to maintain productivity consistently in the face of extreme weather events will become increasingly important with climate change [19,21,110]. Having a diverse portfolio of agricultural products (e.g., crops and livestock), similar to a diverse stock portfolio, often promotes resilience because farm incomes will be less sensitive to fluctuations in any one product (e.g., [111]). Diversification practices also consistently promote yield stability in response to extreme weather events and particularly droughts [1]. This is likely achieved through promoting soil functions such as water infiltration and storage, which, in turn, increases water uptake efficiency while reducing erosion and runoff [30,36,112]. In hot and dry years, diversification of corn-soybean rotations and reduced tillage increased yield in comparison to systems without rotations by 7% and 22% for corn and soybean, respectively [113]. Similarly, in four out of five drought years, diverse rotations in organic corn-soybean system combined with manure addition statistically significantly outperformed industrial with less diverse rotations [30]. Corn yields were up to 137% higher in the organic system than the industrial, and soybean yields were between 152% and 196% higher [30]. In addition, when all three conservation agriculture principles (no-till, crop rotations, continuous soil cover) are implemented, yields were 7.3% higher than industrial systems in dry climates [39,114].

Increasingly limited ground water supplies and the loss of service-provisioning biodiversity and soil fertility [19,21] will further strain the ability of farming systems to maintain yields with global climate change. To promote yield resilience, we must rebuild and maintain the soil and biodiversity necessary for maintaining yields through incorporating diversification practices [1].

5. Conclusions

Yield is only a small factor in determining whether people are fed adequately, and largely unrelated to the amount of land in production. In addition, we find little evidence that industrial systems always outperform alternative forms of agriculture. Where yield differences were observed, they were minimized by the use of diversification practices (Figure 1). In fact, in all of the systems examined including industrial, organic and conservation agriculture, diversification practices appear to be key in enhancing yields and profit. Diversification practices also contributed to yield resilience in response to extreme weather, which will become increasingly important with global climate change. The magnitude and duration of yield or profit losses following transition, however, were variable, and thus a strong impediment to farmers. Support, through extension and subsidies from governmental and non-governmental agencies, will be crucial for agriculture practices to change [86]. Some European countries offer such subsidies, and these policies should be adopted globally [86]. In addition, we found evidence that when diversification practices were incorporated into transitioning systems, yield losses were minimized or avoided, which should be explored further.

Though we may produce enough to feed everyone if food was distributed adequately, our current production system has already exceeded what our planet can sustain [20]. Simply put, we need to grow our food differently. We need to bring this and other food-related issues to the top of political agendas everywhere. We also need to take steps to increase access equitable distribution [69], reduce food waste and internalize externalities [19]. Steps toward the latter would include adopting farming diversification techniques that reduce use of pesticides and fossil fuel-powered farm machinery, limiting damage to the health of people living in agricultural areas today and to future generations from climate disruption. Many countries in Europe have already implemented policies to encourage farmland diversification and internalizing externalities through Agri-environment schemes and "greening" payments [115,116]. The success of these programs, however, has been mixed (e.g., [117,118]). Research into refining diversified farming techniques has been severely underfunded relative to industrial agriculture [119,120]. The mixed success of the European policies highlights that we must invest in more analytically rigorous, agroecological and socio-economic research oriented at honing diversification practices for specific crops and regions where they are needed most [36,61,121]. At the same time, we should move away from waiting for the definitive science to show what system maximizes yield, and instead look ahead to which social and environmental outcomes we want for our agriculture systems.

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