Financial competitiveness of organic agriculture on a global scale

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To promote global food and ecosystem security, several innovative farming systems have been identified that better balance multiple sustainability goals. The most rapidly growing and contentious of these systems is organic agriculture. Whether organic agriculture can continue to expand will likely be determined by whether it is economically competitive with conventional agriculture. Here, we examined the financial performance of organic and conventional agriculture by conducting a meta-analysis of a global dataset spanning 55 crops grown on five continents. When organic premiums were not applied, benefit/cost ratios (−8 to −7%) and net present values (−27 to −23%) of organic agriculture were significantly lower than conventional agriculture. However, when actual premiums were applied, organic agriculture was significantly more profitable (22–35%) and had higher benefit/cost ratios (20–24%) than conventional agriculture. Although premiums were 29–32%, breakeven premiums necessary for organic profits to match conventional profits were only 5–7%, even with organic yields being 10–18% lower. Total costs were not significantly different, but labor costs were significantly higher (7–13%) with organic farming practices. Studies in our meta-analysis accounted for neither environmental costs (negative externalities) nor ecosystem services from good farming practices, which likely favor organic agriculture. With only 1% of the global agricultural land in organic production, our findings suggest that organic agriculture can continue to expand even if premiums decline. Furthermore, with their multiple sustainability benefits, organic farming systems can contribute a larger share in feeding the world.

sustainable agriculture | food security | organic premiums | meta-analysis | economic

Although agriculture provides growing supplies of food and other products, it is a major contributor to greenhouse gases, biodiversity loss, agrochemical pollution, and soil degradation (1–3). Concerns about the sustainability of conventional agriculture in particular have promoted interest in alternative farming systems that are more environmentally benign. These alternative systems are not widespread and include organic, integrated, conservation agriculture, mixed crop/livestock, and perennial grains (2, 4, 5). Organic agriculture is the most popular alternative farming system in the world, with global sales of organic foods and beverages growing 170% to $63 billion from 2002 to 2011 (6). The majority of these sales (90%) are concentrated in North America and Europe, with Asia, Latin America, and Africa being primarily export producers (6). Although certified organic farming is practiced in 162 countries, organic agriculture currently occupies only 1% of global cropland (6). Growth of organic agriculture is often limited by inexperience with production methods, inadequate marketing and technical infrastructure, low consumer spending power, and government policies (7, 8).

Organic agriculture is contentious, with critics arguing that it is inefficient (9, 10), relying on more land to produce the same amount of food as conventional agriculture. In turn, adopting organic agriculture on too large a scale could potentially threaten the world's forests, wetlands, and grasslands (9, 11). Additionally, skeptics contend that organic agriculture has too many shortcomings and poor solutions to agricultural problems (9, 12) and will become less relevant in the future (10). However, recent international agricultural reports recognize organic agriculture as an innovative farming system that balances multiple sustainability goals and will be of increasing importance in global food and ecosystem security (1, 4, 5). According to a National Academy of Sciences report (5), such multiple sustainable goals for any farming system should include producing adequate amounts of high-quality food, enhancing the natural resource base and environment, contributing to the well-being of farmers and their communities, and making farming financially viable.

Reviews and meta-analyses have shown that although organic agriculture produces lower yields compared with conventional agriculture (13–15), it delivers equal or more nutritious foods (16–18) with less to no pesticide residues (17–19). Such aggregate studies generally support the perception that organic farming systems are more environmentally friendly than conventional farming systems. For example, environmental benefits include greater energy efficiency (20–22); enhanced soil carbon and quality (20–24); greater floral, faunal, and landscape diversity (21–23, 25–27); and less pesticide and nutrient pollution of ground and surface waters (20, 23, 25, 26). Although few studies have been conducted comparing the sociocultural aspects of organic and conventional agriculture, organic farming has been shown to have some sociocultural strengths, such as more humane animal production conditions (28), positive shifts in community economic development and social interactions (29, 30), and greater employment of farm workers and cooperation among farmers (31, 32).

Significance

Some recognize organic agriculture as being important for future global food security, whereas others project it to become irrelevant. Although organic agriculture is rapidly growing, it currently occupies only 1% of global cropland. Whether organic agriculture can continue to expand will likely be determined by whether it is economically competitive with conventional agriculture. Accordingly, we analyzed the financial performance of organic and conventional agriculture from 40 y of studies covering 55 crops grown on five continents. We found that, in spite of lower yields, organic agriculture was significantly more profitable than conventional agriculture and has room to expand globally. Moreover, with its environmental benefits, organic agriculture can contribute a larger share in sustainably feeding the world.

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SUSTAINABILITY SCIENCE

To be sustainable, organic agriculture must also be profitable (8). Moreover, whether organic agriculture can continue to expand globally will primarily be determined by its financial performance compared to conventional agriculture (7, 13). The main factors that determine the profitability of organic agriculture include crop yields, labor costs, price premiums for organic products, potential for reduced income during the organic transition period, and potential cost savings from the reduced use of nonrenewable resources and purchased inputs (33). Although individual studies have compared the financial performance of organic and conventional farms and addressed these factors, no studies have synthesized this information on a global scale. Here, we address this knowledge gap by comparing the financial performance of organic and conventional agriculture with a dataset spanning 55 crops grown on five continents. Using meta-analysis, we identified broad economic sustainability patterns not apparent in primary field research by examining total costs, variable costs, labor costs, fixed costs, gross returns, benefit/cost ratios, net present values, organic price premiums, and yields for organic and conventional agriculture.

Results and Discussion

Financial Performance of Organic and Conventional Agriculture. We conducted a literature survey and identified 129 studies that examined the financial performance of organic compared with conventional agriculture (Datasets S1–S5). Of these studies, 44 studies met our criteria for inclusion in a meta-analysis, representing 55 crops grown in 14 countries on five continents (Fig. S1). Data from these studies were used to compare financial parameters of organic and conventional agriculture using two classifications: (*i*) individual crops ($n = 91$) and (*ii*) cropping systems (which considered multiple crops in a rotation, $n = 84$) (Datasets S1–S5). Previous meta-analyses comparing yields of organic and conventional agriculture only considered individual crops, but not cropping systems (13–15, 34, 35). However, a farmer's financial security is often based on profits from multiple crops grown over several seasons, which is reflected in our analysis of cropping systems. Therefore, we determined whether costs, gross returns, benefit/cost ratios, and net present values differed significantly between organic and conventional crops and systems.

Total costs, variable costs, and fixed costs did not differ significantly between organic and conventional crops or systems (Fig. 1*A* and Tables S1–S3). Labor costs, which are part of variable costs, were significantly higher for organic crops (13%) and systems (7%) (Fig. 1*A* and Tables S1–S3). However, the higher labor costs on organic farms were offset by the reduced use of nonrenewable resources and purchased inputs, such as synthetic fertilizers and pesticides. Organic farms often have higher labor costs because they devote more resources to mechanical pest control, have a greater diversity of enterprises, or need to develop new marketing and processing activities (36). Although one of the successes of conventional agriculture has been its ability to create more with less labor, some have found the extra labor of organic agriculture to be beneficial by helping to redistribute resources and promote rural stability in regions where the labor force is underemployed (37).

When organic premiums were not applied, gross returns, benefit/cost ratios, and net present values were significantly lower for organic crops (−10%, −7%, and −23%, respectively) and systems (−18%, −8%, and −27%, respectively) compared with their conventional counterparts (Fig. 1 *A* and *B* and Tables S1–S6). Importantly, because gross returns without premiums mirror yields, our observed 10% and 18% lower yields for organic crops and systems, respectively, are similar to results from all five meta-analyses comparing organic and conventional yields (13–15, 34, 35). When actual organic premiums were applied, gross returns, benefit/cost ratios, and net present values were significantly higher for organic crops (21%, 24%, and 35%, respectively) and systems (9%, 20%, and 22%, respectively) (Fig. 1 *A* and *B* and Tables S1–S6). These results show that the combination of ample organic yields, similar costs, and organic premiums allowed net present values and benefit/cost ratios to be reliably greater for organic crops and systems. Additionally, total costs, gross returns, benefit/cost ratios, and net present values for organic compared with conventional crops and systems were consistent across the 40-y study period (Fig. S2).

Organic Premiums. From the studies in our meta-analysis, we also determined price premiums that were awarded to organic crops and systems. These values were compared with breakeven premiums needed for net present values from organic agriculture to match net present values from conventional agriculture. If organic agriculture is more profitable than conventional agriculture, then actual premiums awarded are higher than breakeven premiums; if organic agriculture is less profitable, then actual premiums awarded are lower than breakeven premiums.

We found that median premiums were 32% for organically grown crops and 29% for organic systems (averaged across all crops in the system). In contrast, median breakeven premiums needed for organic crops and systems to match the net present values of their conventional counterparts were significantly lower at 5% and 7%, respectively (Fig. 1*C* and Table S7). Organic premiums awarded, and the difference between organic premiums and breakeven premiums, were consistent during the 40-y study period (Fig. S2). The fact that organic premiums are significantly higher than those premiums needed to break even with

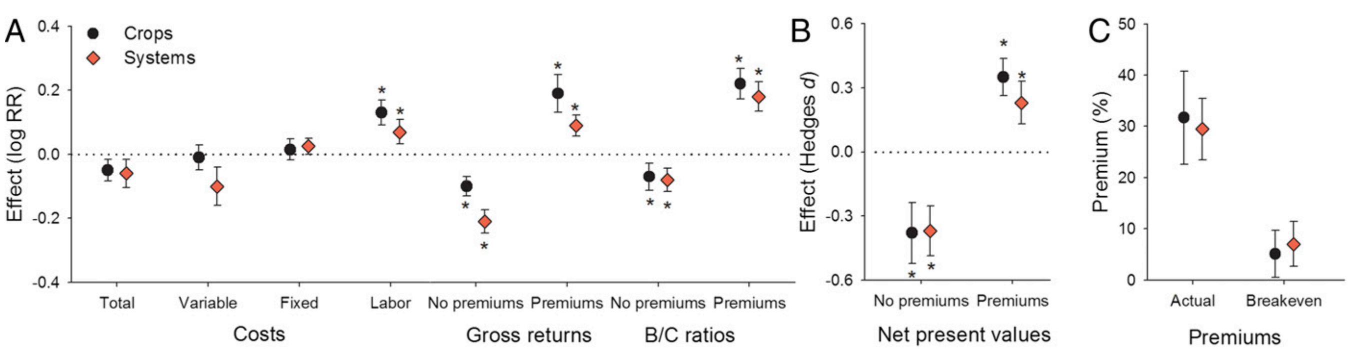

Fig. 1. Financial performance of organic compared with conventional crops and systems. Shown are the median log response-ratios (RR; ±SE) for costs, gross returns, and benefit/cost (B/C) ratios (*A*), median Hedges *d* values (±SE) for net present values (*B*), and organic premiums awarded and breakeven premiums needed for organic net present values to match conventional net present values (*C*). In *A* and *B*, asterisks indicate significant differences from 0. Positive values indicate financial parameters were higher in organic agriculture compared with conventional agriculture.

conventional agriculture provides substantial financial incentives for organic growers to go through 3 y of transition expenses, acquire certification, and establish buyers and markets (36).

Factors Affecting the Financial Performance of Organic and Conventional Agriculture. We used mixed-effects models to examine the influence of 14 categorical variables on costs, gross returns, net present values, benefit/cost ratios, and differences in premiums for organic relative to conventional crops and systems. These 14 variables included crop type, continent, study duration, rotation length, annuals or perennials, legumes or nonlegumes, study type (experiment station, on-farm, or survey), time since conversion, organic status (transitioning or posttransition), crop diversity, nitrogen input, developed or developing country, latitude, and scale (whole-farm or plot) (Tables S8–S12).

We found that several variables (crop type, rotation length, crop diversity, annual/perennial, and legume/nonlegume) significantly affected net present values or benefit/cost ratios in organic-to-conventional crops but not systems (Fig. 2 and Tables S10 and S11). Cereals, fiber, and oil crops had the greatest organic-to-conventional net present values and benefit/cost ratios, whereas forage, vegetables, and other (meat and dairy) produced the lowest (Fig. 2). Organic-to-conventional financial performance was also higher when organic crops were grown in longer or more diverse rotations, in annual compared with perennial systems, and in leguminous compared with nonleguminous crops (Fig. 2).

Few other categorical variables significantly influenced costs, net present values, benefit/cost ratios, or differences in premiums between organic and conventional crops or systems (Tables S8 and S10–S12). Of particular note, our data indicate that organic-to-conventional gross returns without premiums, which reflect yields, did not significantly improve for crops and systems after the 3-y transition period (Fig. 3 *A* and *B* and Table S9). Additionally, organic-to-conventional gross returns without premiums were consistent across the 40-y study period for crops and systems (Fig. 3 *C* and *D*). The 3-y transition period from conventional to organic crop production is often reported as the most difficult time financially for organic farmers because their yields drop and they receive no official price premium for their crops (33, 36). Our data suggest that the lack of price premiums appears to be the major factor limiting the profitability of organic farming during the transition period.

Externalities and Ecosystem Services. If we also put a price on the negative externalities caused by farming, such as soil erosion or nitrate leaching into groundwater, then organic agriculture would become even more profitable because its environmental

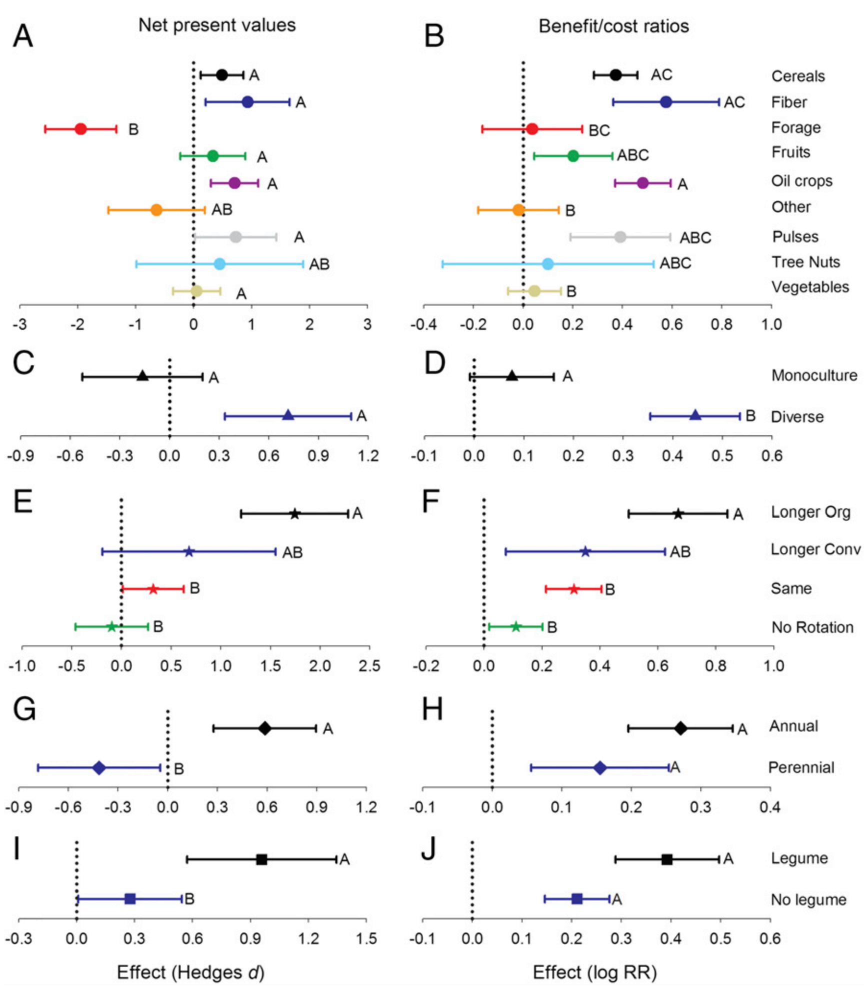

Fig. 2. Sensitivity of net present values and benefit/cost ratios in organic (Org) compared with conventional (Conv) crops. Variables that affected net present values or benefit/cost ratios were crop type (*A* and *B*), crop diversity (*C* and *D*), length of rotation (*E* and *F*), annual or perennial crop (*G* and *H*), and leguminous or nonleguminous crop (*I* and *J*). Values shown are the median log response-ratios (±SE) comparing organic with conventional crops. In each panel, different letters indicate significant differences between values of the explanatory variables.

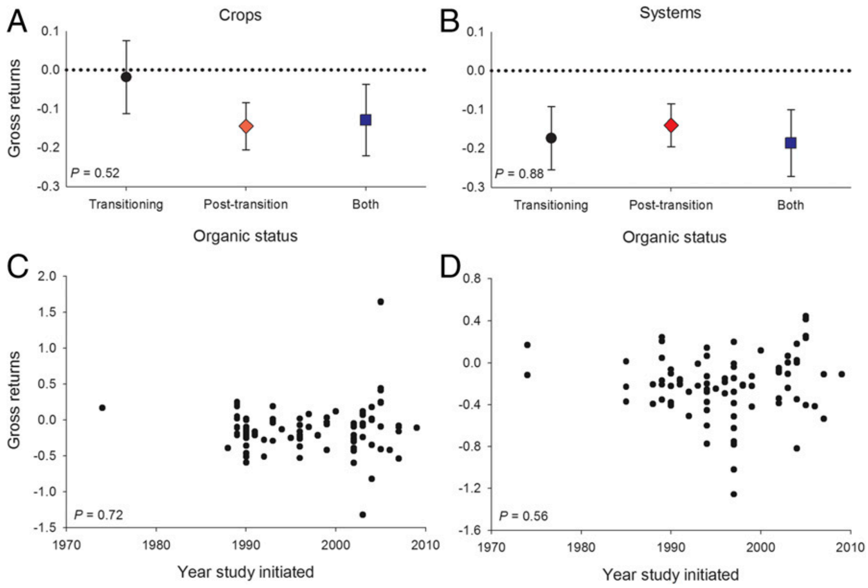

Fig. 3. Gross returns without premiums (which mirror yields) in organic compared with conventional agriculture. Log response-ratio effects (median ± SE) comparing gross returns without premiums in organic compared with conventional crops (*A*) and systems (*B*). Data are presented separately for (*i*) studies that only included the transition period, (*ii*) studies that only included the posttransition period, and (*iii*) studies that only included both periods. Gross returns without premiums in organic compared with conventional crops (*C*) and systems (*D*) plotted against the year studies were initiated.

footprint has been shown to be less than the environmental footprint of conventional agriculture (20–27). Calculating the monetary value of ecosystem services, such as biological pest control or crop pollination, would further illustrate the financial sustainability of agricultural systems (38, 39). Although few studies have accounted for ecosystem services in comparisons of organic and conventional agriculture, conventional practices appear to decrease the ability of farms to provide some ecosystem services relative to organic practices (38, 40). For example, in a study comparing 14 organic arable fields with 15 conventional ones in New Zealand (41), the total economic value of three ecosystem services (biological pest control, soil formation, and the mineralization of plant nutrients) in the organic fields was significantly greater at US \$232 $ha^{-1} \cdot y^{-1}$ compared with the conventional fields at US \$146 $ha^{-1} \cdot y^{-1}$. Factoring in such differences in economic comparison studies would likely make up for price premiums awarded to organic products. As is, organic premiums may serve as a proxy for the monetary value of ecosystem services for those consumers who believe that organic agriculture is more environmentally friendly than conventional agriculture.

Conclusions

Despite lower yields and not accounting for externalities or ecosystem services, organic agriculture was significantly more profitable than conventional agriculture. With breakeven premiums being significantly lower than actual premiums received, our findings suggest that organic agriculture can continue to expand even if premiums decline. However, making farming financially viable is vital, but is only one of four goals that must be met for agriculture to be sustainable. Equally important is enhancing the environment, producing ample crop yields of high quality, and contributing to the well-being of farmers and their communities. Conventional farming has provided increasing supplies of food and other products, but often at the expense of other sustainability goals. Although organic agriculture produces lower yields than conventional agriculture, it better unites human health, environment, and socioeconomic objectives than conventional systems. In a time of increasing population growth, climate change, environmental degradation, and rising energy costs, such agricultural systems with a more balanced portfolio of sustainability benefits are needed. With only 1% of the global agricultural land in organic production and with its multiple sustainability benefits, organic agriculture can contribute a larger share in feeding the world.

Scaling up organic and other farming systems that balance all four sustainability goals with appropriate public policies can create an enabling environment for such sustainable modes of production. The challenge facing policymakers is to develop government policies that support conventional farmers converting to organic and other more sustainable systems, especially during the transition period, often the first 3 y. In addition, such policies can be established that incorporate the value of external costs and ecosystem services of different farming approaches, such as organic agriculture, into the traditional marketplace, thereby supporting food producers for using sustainable practices. Foods would be valued based on health benefits, food security, and ecosystem services, minus any environmental and social costs, provided by the farms that produced them. Such a food system would be both farming system and technology neutral and would allow the public to choose products that push agriculture in a more sustainable direction.

Methods

Literature Survey. We searched the literature to identify studies comparing the financial performance of organic and conventional agriculture. Our search was performed in January 2013 and repeated in June 2014 using the Institute for Scientific Information Web of Knowledge Database and the search terms "conven* and organ*" and "econ* or finance*." Our literature search yielded 3,901 studies that were reviewed. We supplemented this search by reviewing the references in three meta-analyses of conventional and organic yields (13, 14, 35). For any study containing financial data, we also reviewed the references cited to locate other sources. In total, we identified 129 studies that compared some aspects of the financial performance of organic or conventional agriculture. These studies were examined for inclusion in our meta-analysis based on six criteria: (*i*) studies reported gross returns and production costs for organic and conventional treatments, or these data could be calculated; (*ii*) studies had at least three replicates of the organic and conventional treatments; (*iii*) organic treatments were certified organic or following organic certification standards; (*iv*) conventional treatments used recommended rates of synthetic pesticides and fertilizers; (*v*) studies reported primary data not already included in another paper; and (*vi*) the spatial and temporal scales of the organic and conventional treatments were comparable. Forty-four studies met these criteria, representing 55 crops; 14 countries; and the five regions of Asia, Europe, North America, Oceania, and South America (Fig. S1 and Datasets S1–S5). None of the 44 studies had government subsidies for organic or conventional agriculture.

Calculation of Effect Sizes. From these 44 studies, we ran meta-analyses comparing financial parameters of organic and conventional agriculture using two classifications: (*i*) individual crops (n = 91) and (*ii*) cropping systems (which considered multiple crops in a rotation, n = 84) (Datasets S1–S5). For each data point, we calculated effect sizes comparing organic agriculture with conventional agriculture for the following: (*i*) total costs: total cost of production; (*ii*) variable costs: costs that vary according to the quantity of crops produced, such as labor and materials; (*iii*) fixed costs: costs that do not change regardless of the quantity of crops produced; (*iv*) labor costs: wages and benefits paid to workers; (*v* and *vi*) gross returns without and with premiums: the value of crops produced, calculated as price × yield; (*vii* and *viii*) benefit/cost ratios without and with premiums: gross returns divided by total costs; and (*ix* and *x*) net present values without and with organic premiums, which were calculated for each study by determining net returns (gross returns − total costs) and applying a 6% discount rate according to the following formula:

$$NPV = NR_t \Big/ (1+i)^t,$$

where *NPV* is net present value, *NR* is net returns, t is the number of years since a study was initiated when the net returns were received, and i is the discount rate.

Values for premiums received and the year(s) premiums were awarded were taken directly from each study. Some studies did not include premiums for all years if the organic fields/plots were in the transition period; in such cases, premiums were only awarded after the transition period. Moreover, some studies did not include premiums; for these studies, premiums were listed at 0%. Thus, our calculations of premiums were conservative. Both benefit/cost ratios and net present values were calculated because they are important measures of the monetary gain of a venture relative to the costs of executing that venture, producing crops and cropping systems in this case. Net present values, gross returns, and benefit/cost ratios were positively correlated for crops and systems (Fig. S3), suggesting that each metric similarly reflected the financial performance of organic compared with conventional agriculture.

Our primary meta-analysis metric was the log response-ratio, which was calculated with and without weighting (42). Weights were the inverse of the study variance plus a common random-effects variance component (42). We also calculated effect sizes using the Hedges *d* value (43). For net present values, only the Hedges *d* value was calculated because net present values were negative for some studies, such that log response-ratios could not be calculated. For studies that were conducted over multiple years, we averaged financial parameters across years in our calculation of effect sizes. Results using unweighted log response-ratios, weighted log response-ratios, and Hedges *d* values were qualitatively similar (Tables S1–S7), showing that our results were robust regardless of the meta-analysis metric used for analysis. Thus, unweighted analyses are presented in the main text, except for net present values where only the Hedges *d* value could be calculated. Unweighted effect sizes were used because weighted analyses place emphasis on highly replicated but artificial experiments at the expense of whole-farm studies that have less replication but are more representative of real-world agriculture (44).

We calculated effect sizes for individual crops and farming systems. Effect sizes for crops were calculated in two ways: (*i*) individual crops per cropping system or rotation (n = 91) and (*ii*) individual crops per study (n = 77). With the crops/system scheme, for studies that had multiple distinct rotations, financial parameters for crops were calculated independently for each rotation. For example, if a study reported on corn in 2-y and 4-y rotations, financial parameters for corn were calculated separately for each rotation. In contrast, the crops/study scheme pooled financial parameters for crops across different rotations but in the same study. In this case, for the above example, financial parameters for corn would have been averaged across the 2-y and 4-y rotations. Results were qualitatively similar for the two classification schemes for each variable tested (Figs. S2 and S3 and Tables S1–S12). Thus, whenever we reference "crops," we refer to the crops/system scheme.

Study Variables. We gathered data on 14 categorical variables and one continuous variable from studies to determine whether our results were sensitive to these parameters. These variables were as follows: (*i*) crop type (cereals, fiber, forage, fruits, oil crops, other, pulses, tree nuts, vegetables) following Food and Agriculture Organization definitions, (*ii*) continent (Asia, Africa, Europe, North America, Oceania, South America), (*iii*) study duration (very short: one to two seasons, short: three to five seasons, medium: six to 10 seasons, long: >10 seasons), (*iv*) rotation length (none: both systems had no crop rotation, similar: both systems had a rotation of similar length, longer conventional: conventional system had a longer crop rotation, longer organic: organic system had a longer crop rotation), (*v*) annual/perennial (annual crop species, perennial crop species), (*vi*) legume/nonlegume (legume: *N*-fixing crop of the Fabaceae family, nonlegume: not an *N*-fixing crop species, both: both *N*-fixing and non–*N*-fixing crops present), (*vii*) study type (experiment station: plot study on an experimental station, farm: whole-farm comparison study; survey: whole farms compared through surveys), (*viii*) time since conversion (recent: 0–3 y, young: 4–7 y, established: >7 y), (*ix*) organic status (transitioning: study was conducted on farms/plots that were in the process of transitioning to organic, posttransition: study was conducted on farms/plots after the transition period, both: study was conducted both during and after the transition period), (*x*) crop diversity (monoculture: single crop in both systems, multiboth: multiple crops in both systems, multiconv: multiple crops in conventional system only, multiorganic: multiple crops in organic system only), (*xi*) nitrogen input (higher in conventional: conventional had 50% or more nitrogen than organic, higher in organic: organic had 50% or more nitrogen than conventional, similar: conventional and organic received similar nitrogen), (*xii*) country development [developed: very high human development index (HDI), developing: high medium or low HDI], (*xiii*) latitude (temperate: 30–90 °C, tropical: 0–30 °C), and (*xiv*) scale of study (farm: whole-farm comparisons or survey, plot: plots on a farm or experiment station). We also tested the effects of the year studies were initiated (a continuous variable) to determine if effects varied over time.

Data Analysis. We compared effect sizes against 0 using Wilcoxon signed-rank tests because the distributions were nonnormal (27). Effect sizes significantly greater than 0 indicate a higher value for organic agriculture, and effect sizes significantly lower than 0 indicate a higher value for conventional agriculture. Similarly, we used Wilcoxon signed-rank tests to determine if organic premiums received differed significantly from breakeven premiums needed for organic net present values to match conventional net present values. All analyses were conducted in JMP (45).

We also used mixed-effect models to determine if total costs, gross returns without premiums, net present values with organic premiums, benefit/cost ratios with organic premiums, and the difference between premiums received and breakeven premiums needed for organic net present values to match conventional net present values were affected by the 14 categorical variables and one continuous variable collected from each study. Gross returns without premiums were analyzed because this variable mirrors yields. Net present values and benefit/cost ratios without premiums were not tested in mixed-effect models because they are less indicative of actual financial performance of organic and conventional cropping systems than their values with premiums. Mixed-effect models were of the general form as

$$y_{\text{effect}} = \beta_0 + \beta_1 x_{\text{fixed}} + b + \varepsilon,$$

where y_{effect} is the effect size; β_0 is the intercept; β_1 is the coefficient associated with the fixed effect, x_{fixed}; b is the coefficient of the random effect (study); and ε is the remaining variation. Separate models were run for each response variable and fixed variable combination (Tables S8–S12).

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