FEEDING THE DEVELOPING WORLD WITH SUSTAINABLE AGRICULTURAL METHODS: POSSIBILITIES. CONSTRAINTS, AND PROPOSALS

Wasiq Khan
Department of Economics
Franklin College Switzerland
wkhan@fc.edu

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ABSTRACT:

This study will use data comparing the inputs needed and cereal produced on sustainable versus industrial farms in developed countries to assess the land, labor, water, energy, and infrastructural requirements for 'scaling up' and transferring these sustainable methods to developing countries where almost all world population growth will occur over the next 40 years. Recent studies describing projected growth in world food demand, descriptions of future sources of world food supply, as well as trends in productivity and climate will be consulted to determine how much sustainable food production will occur in poor countries, how much will be sourced in rich countries, and, as a result of the poor-rich output differential, what the size of world food trade would be under sustainable methods and whether this world food trade would produce negative externalities large enough to undermine the gains envisioned in the world wide adoption of sustainable cereal farming methods. Data for farm productivity will be collected from recent studies comparing output and input levels on working farms as well as on wheat cultivation carried out in agricultural research centers where sustainable methods are tested. The paper will discuss ambiguities in standard definitions of 'sustainable agriculture' by providing a more coherent definition for agricultural practices that eschew inputs such as synthetic pesticides, non-organic fertilizers, as well as the unsustainable exploitation of stressed fresh water sources. The study will provide an accounting of input requirements as well as net output levels to enable more structured thinking regarding the possibilities and constraints implicit in proposals aiming to feed a growing world population using largely sustainable farming methods.

Introduction

Since January of 2011 the world has seen major riots break out and governments toppled over the price of food. Sentiments present in recent revolutions in Tunisia and Egypt, as well as in foreboding signs in Algeria and Yemen, have been echoed by smaller demonstrations throughout the developing world. Again and again one of the major rifts cited as a cause of these protests is an increase in the price of basic foods. There is widespread speculation that incidences of political upheaval will become even more frequent in the future as a result of growing problems with food shortages.

The question of what to about the current state of global food security is looming on the horizon as one of the major topics in the field of agriculture in the coming decades. As various programs and initiatives in the world of international development become increasingly interested in environmental health and sustainability, many of the principles of sustainable agriculture are gaining attention in questions pertaining to issues of agricultural development and food security. For this reason, the viability of sustainable agriculture as a method for feeding the worlds' population is of ever-increasing importance.

In this paper a review is conducted of multiple studies on the yields of sustainable agriculture and the potential of the market to price said products in a way that makes sustainably produced crops viable as a food source in even the poorest nations of the world. First hand data is also reviewed and a hypothetical scenario is constructed that shows the amount of people that could be fed if the top cereals-producing nations were to adopt sustainable methods of agriculture. The results show that given current levels of production, a switch to sustainable agriculture would be able to feed the world.

Literature Review

Most of the existing literature surrounding the topic is organized into two broad schools of thought. The first consists of mostly agricultural scientists who have conducted first hand studies of yields from sustainable agriculture. These studies have been done over the course of many years, and abide by the general ramifications of what sustainable agriculture is defined as. The conclusions brought forth by this school of thought center around answering the question of how different yields from sustainable agriculture are from industrial methods in a controlled environment. The majority of the studies argue that based on comparative tests, sustainable farming methods do not produce yields that are dramatically lower than conventional methods within the controlled system.

The second school of thought constitutes of other scholars, who do not fundamentally disagree with the results obtained by researchers in the first school, but rather disagree that this model could be applied on a large scale and still be economically viable. The majority of these discussions deal with the impracticality of sustainable agriculture as it would have to implement in developing nations, and how it would fair in the market system. Conclusions reached by these papers range from the speculation that sustainable agriculture would be too logistically difficult to implement in nations that do not possess agricultural infrastructure, to those that doubt the viability of sustainably produced crops in a fair pricing system because of their inability to compete with conventionally produced crops.

One frequently cited study was compiled by Bill Liebhardt, a professor at the University of California Davis and the former director of the University of California systems' Sustainable Agriculture Research and Education Program (SAREP). Professor Liebhardt compiled research data from seven major state universities and found that across a broad range of crops tested over 10 years, organic production yielded 95% of similar crops grown under the conventional high-input framework. For only wheat, this statistic was 97%[1]. These numbers offer strong indication that yields from sustainable agriculture are sufficiently high enough to rival the amount of food produced under the industrial food-production framework.

Another famous study on the yields of sustainable agriculture was done by a team of researchers from the University of Michigan. The team used data from 293 samples to construct a set of estimates on the total caloric yield of major crops under the sustainable agriculture system. The results showed that given a conservative estimate of yields, global organic production would produce 2,641 kilocalories per person per day[2]. This is well above the caloric requirement for a healthy adult of around 2,100 calories per day. A researcher at the Danish Institute of Agriculture Sciences, Niels Halberg, ran a similar study and came to conclusions similar to those of the Michigan team[3].

Relevant case studies have also been done in response to the United Nations' Millennium Development Goals. The Millennium Villages Project (MVP) was created in response to Millennium Development Goal 1, to eradicate extreme poverty and hunger. The project was implemented in 10 countries in Sub-Saharan Africa, which represent a wide array of ecological zones.

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[1] Liebhardt, Bill. 2001.
[2] Halweil, Brian. 2007: 9
[3] Halweil, Brian. 2006.

The focused crops in most of these Villages are cereals[4] and in most cases the seeds and fertilizers were purchased locally[5], adding to the sustainability of the agricultural practices. What is most interesting about the MVPs is that they used some amount of artificial fertilizers, but no herbicides or insecticides were used. The lack of these chemical inputs did not result crop failure[6], but instead increased crop yields from an average of 1.08 tons per hectare to 4.4 tons per hectare[7]. For the sites cultivating maize, only about 0.9 to 1.3 tons per year is needed to satisfy the caloric need per household per year[8].

The study conducted also found that the cost of shipping food aid from the United States is greater than that of producing the same amount within the country. Food aid from the US cost $806 per ton in 2008[9], whereas the average input cost per hectare of Maize production in the MVPs was $254 per hectare[10]. Additionally, it was found that organic inputs in the soil over time could increase harvest yields through promoting improved fertilizer efficiency and soil quality[11]. This would result in an increase in yields but with a reduction in the fertilizer requirement.

The resulting assumption of many of these studies is discussed in a paper submitted to the International Conference on Organic Agriculture and Food Security of the Food and Agriculture Organization of the United Nations. The paper summarizes the results of studies in organic agriculture production by stating that the switch to

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[4] Nziguheba, et. al. 2010: 9
[5] ibid, 89
[6] ibid, 88
[7] ibid, 92
[8] ibid, 96
[9] ibid, 101
[10] ibid, 99
[11] ibid, 106

sustainable agriculture can reduce output in industrial societies, but can increase output drastically in developing societies[12].

This is backed up by a study done by researchers at the University of Essex, Rachel Hine and Jules Pretty, who studied compilations of data on organic agriculture studies that covered 9 million farms on a total of 30 million hectares and found that yields from organic practices increased productivity by 93%[13]. The assumption one can make based on these results is that the loss in productivity as a result of the switch to sustainable agriculture in the developed world is more than offset by the increases seen in the developing world.

The data presented above cover a wide range of approaches to the study of sustainable agriculture yields. However, there are missing parts from all of these studies. In the case of the Michigan researchers and other studies like it, they do not take into account externalities such as transport costs and long-term viability of the system. These studies cover a basket of foods, as opposed to just cereals: The basic food of most peoples. If there were a focus on cereals only, more areas would be self-sustaining as cereals grow easily in a broader range of climates. In this way, there is no attempt to quantify the maximum potential production of basic crops, which would change the estimates considerably.

In the case of the Millennium Villages Project case studies, they are extremely helpful in suggesting sustainable agriculture could usher in an African Green Revolution. However, there is not much discussion as to the economic benefits of the MVPs, such as the increased labor demand, or the long-term environmental implications of the use of

[12] Halweil, Brian. 2007: 9
[13] Halweil, Brian. 2006.

sustainable methods. According to Bill Liebhardt, the figures used in studies on sustainable agriculture yields do not reflect other benefits, such as improved soil quality that translates into higher yields during times of drought[14]. The lack of a broader scope in these case studies also makes it difficult to assume the same methodology could be applied to other areas of the world.

Additionally, the MVPs are not entirely sustainable yet. The goal of the project is to reduce reliance on artificial chemical inputs, but in studies conducted so far there is still a reliance on chemical fertilizers to increase crop yields. In order to understand the impact of entirely sustainable methods of farming on rural communities, there must be a reduced reliance on artificial chemical inputs.

For the sake of this paper, the arguments of both sides presented above are taken into account in the discussion portion. However, for the calculations presented detailing the ability of sustainable agriculture to feed the world, it is assumed to be a hypothetical scenario in which nations that are already the highest producers of cereals were to completely switch to sustainable methods. The point being only to demonstrate that based on yield data and current levels of production, sustainable agriculture is a viable option. Discussion on the externalities and economic and social viability are presented in the discussion portion, but play no role in the calculations.

I chose to look specifically at the production of cereals and the potential of cereals to feed the human population if only grown by sustainable methods. The reason for this is that grains constitute over 70% of human intake of food calories, and occupy 69% of global croplands[15]. Cereals as defined by the World Bank include the following crops:

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[14] Liebhardt, Bill. 2001.
[15] Glover, Jerry D., and John P. Reganold. 2010: 41.

Wheat, Rice, Maize, Barley, Oats, Rye, Millet, Sorghum, Buckwheat, and Mixed grains[16]. I do not intend to discuss the implications of Genetically Modified crops separately from traditionally bred crop because of uncertainties involved with classifying the technology as sustainable or unsustainable.

My study uses the available statistics for the above crops, and calculates the total availability of such crops if they were produces by sustainable methods. The daily human intake is then compared to the potential production capacity for cereals to conclude that the world population can be fed with sustainable agricultural means.

Features of Industrial Agriculture

Industrial agriculture is the term used to describe the form of agriculture most commonly undertaken in the developed nations. This agricultural form is characterized by the use of monoculture crops. That is, the cultivation of only a single crop planting season after planting season. The purpose of monoculture is the practice results in the centralization and expansion of farms. This allows for the emergence of economies of scale and a reduction in costs. The reduction in the cost of production in farming translates into a drop in the price for certain key commodities, such as wheat, corn, and soybeans.

Another characteristic of monoculture crops is only one variety of the crop is planted. This allows for easier manipulation by the farmer because only one species of the plant needs to be tended to. However, the danger associated with the use of only one crop is the reduction in genetic diversity, and therefore increased vulnerability to blights, pests, or other unforeseen disasters that could wipe out whole harvests.

[16] World Bank Indicators: Cereal Yield (kg per hectare)

To combat the increased risk from monoculture, industrial farms require high inputs of pesticides and herbicides. An unvaried crop base leaves little natural defense against disease, as the lack of genetic diversity means that a single virus can wipe out the whole population. Similarly, a single crop does not welcome diversity in animals, which could act as natural safeguards against pests and weeds. As a result, artificial pesticides and herbicides must be used in place to prevent the destruction of the crop.

Similarly, the intensive use of land means the soil becomes depleted of nutrients quickly. To ensure the continued prosperity of the crop yield, the fields must be laden with increasing amounts of fertilizers. The fertilizers replace the nutrients that would normally be fixated back into the soil if it were left fallow.

Additionally, in industrial agriculture operations the plants are separated from the animals. In traditional farms, the two are often cultivated together in a symbiotic relationship. Industrial operations displace the natural system and instead use human intervention to imitate the relationships created in nature.

Features of Sustainable Agriculture

Sustainable agriculture serves as an alternative to the industrial agriculture model. The sustainable agriculture model is based on the ramifications set by the National Organic Standards Program of the USDA. These ramifications include the prohibition of the use of synthetic chemicals, genetically modified organisms (GMOs), and sewage sludge[17]. In essence, the sustainable model eliminates artificial methods of increasing yields and instead focusing on the growing capacity of the natural inputs.

[17] Pimentel et. al. 2005: 574

The methodology behind sustainable agriculture involves using a variety of techniques that increase productivity without negatively affecting the environment, such as crop rotation, soil enrichment, and natural pest predators. Crop rotation is the practice of growing different crops in the same field instead of planting the same crop one season after another. This simple practice can be hugely beneficial in ensuring the long-term health of the soil, as rotating crops with nitrogen-fixing crops replenishes the soil with nutrients. The alternation of crop types also works to keep pest populations down. Crop rotation disrupts the breeding cycles of pests and does not offer a constant food source as monoculture crops do. As a result, this eliminates the need for artificial herbicides and pesticides.

Similarly, soil enrichment practices can replenish the health of the soil, eliminating the need for artificial fertilizers. One of the most commonly used methodologies to replenish the soil is with the use of cover crops. These are crops that are planted in between growing seasons, but are not harvested for any particular use. These crops act as a stabilization force for the soil by preventing erosion of the topsoils and suppressing weeds. The use of such crops greatly reduces the need for artificial inputs to combat said problems. Another form of soil enhancement is the practice of leaving the residue left from the growing season on the fields. This residue is plowed into the topsoil layer, and replenishes the soil with nutrients that otherwise would have been swept away. This practice also reduces the need for artificial fertilizers. These forms of soil enrichment ensure the long-term productivity of the soil, and also heighten crop yields without the use of artificial chemicals.

The use of natural pest predators is less common because of its limits, but is still effective in reducing the need for pesticides and herbicides. The known predators of common pests are introduced to the area surrounding the crop, and therefore act as natural checks on the population of pests. The use of chemical pesticides often kills off the predators, therefore increasing the populations of the pests themselves. But if the populations of these predators, mainly birds and insects, were left unhindered, their survival could provide a solution to pest problems that does not involve the use of chemicals.

Food Requirements

As a part of my study is to calculate the total population that could be fed on sustainably produced cereal crops, it is beneficial to clarify the standard I will use for this calculation. Based on one study, the minimum calories per person per day needed to maintain health is 2100 calories. This amounts to 219 kg of maize per person per year[18]. According to another source, 200 kg of grains contains the calories needed to sustain a healthy person each year[19]. Based on these estimates, and others that range from 2,000 calories per person per day to 2,200 calories per person per day, I plan to base my estimate on the average of 2,100 calories needed per person per day to maintain a healthy lifestyle.

Data

I chose to perform my empirical analysis based on the worlds' top twelve cereals producers. Figure 1 lists those countries, along with the total cereal yield yearly and the total cereal yield per hectare.

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[18] Nziguheba, et. al. 2010: 91
[19] Raziq, Dr. Abdul. 2010.

Figure 1: Total Cereals Yield per Year (Top 12 Producers)

Country	Yield (kg per Ha)	Land Under Cereal Production (Ha)
China	5535	86,897,300
USA	6624	60,951,300
India	2647	100,703,000
Russia	2388	40,351,600
Indonesia	4694	16,312,500
France	7293	9,611,460
Ukraine	3486	13,112,300
Germany	7119	7,038,500
Bangladesh	3972	12,363,400
Vietnam	5064	8,541,800
Australia	1650	20,322,000
Pakistan	2674	13,453,700

Source: FAOStat, World Bank Indicators

As shown, the total yield for the top twelve cereal producing nations is 1,654,204,459 metric tonnes per year. Because the total world production of cereals was 2,287,000,000[20] in 2008, the amount produced by the top twelve producers accounts for 72% of global production.

The predominant industrial system relies on additional inputs to achieve the level of output described above. Presented bellow is the average amount of fertilizers needed to achieve the yields described in the previous figure. The units are in kilograms per hectare of arable land.

Based on estimates stated in the literature review of this study, the average person needs between 200 and 219 kilograms of cereals per year to maintain a healthy lifestyle. For simplicity purposes, I use the average of 210 kilograms per person per year to estimate the total population that could be fed each year given current levels of production in the top twelve world cereal producers.

[20] "Global Food Supply Gradually Steadying"

Figure 2: People Fed Under Current Agricultural Model

Country	Cereal Yield (kg per Year)	People Fed per Year
China	4.79853E+11	2285014762
USA	4.02247E+11	1915462900
India	2.65826E+11	1265838571
Russia	1.05571E+11	502718952.4
Indonesia	76574994000	364642828.6
France	67798345000	322849261.9
Ukraine	52399200000	249520000
Germany	47723389000	227254233.3
Bangladesh	46905000000	223357142.9
Vietnam	43256300000	205982381
Australia	34366642000	163650676.2
Pakistan	31683200000	150872381

Source: World Bank Indicators

The result equates to about 7.877 billion people that could be fed at healthy dietary levels on the current yields of the top twelve cereals producing nations.

Now I will estimate the potential population that could be fed if the top twelve cereals producers worldwide were to shift from industrial agriculture to sustainable agriculture. To do this, I assume that the same amount of land would be under cultivation in the nations studied, and economic factors, such as wage, interest rate, and government subsidies to agriculture remain constant.

Unlike the industrial system, under the sustainable agriculture model, there are no inputs of artificial fertilizers. Organic fertilizers may be used, but they are considered internalized in the system according to this model. This is because organic fertilizers take the form of either soil enhancers[21], or organic compost. Both of these, however, are taken from the agricultural environment itself, and therefore should not be considered as an external input into the system.

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[21] Discussed in section one of this study

Using an average estimate based on the studies presented above, one can surmise that output of cereals in nations where chemical fertilizers are heavily used would decrease about 6% with a transition to sustainable agriculture.[22] This includes decreases resulting from the absence of chemical fertilizers in the growing process. The estimate was arrived at using the widely cited work of Bill Liebhardt, whose study is discussed in the literature review of this paper. He conducted a thorough study over a large span of time, and over a variety of crop types. Therefore, I use his estimate of a 6% decrease in the sustainable system because of the validity his study holds.

However, the increase in yield from the use of sustainable crops in nations with a relatively low chemical fertilizer input would rise about 10%[23]. This number was arrived at through a compilation of multiple studies on sustainable farms across India, the Philippines, and Indonesia. The paper was presented in a report of the Food and Agriculture Organization of the United Nations, and can therefore be relied on as one of the most complete and accurate estimates possible. For this reason, I have chosen this number as the benchmark for which I will estimate the increase that can be obtained in nations that are lesser developed.

In calculating the production capacity under a sustainable agricultural system, the same general methodology is used as for calculating productivity under the industrial system. When the top 12 cereals producing nations being used in this study are separated into developed and developing countries, using the World Bank definition, we categorize them thus: Developed nations include the United States, France, Germany, and Australia. The developing nations are China, India, Russia, Ukraine, Indonesia, Bangladesh,

[22] Liebhardt, Bill. 2001, compiled average.
[23] Ravanera et. al. 2010: 50

Vietnam, and Pakistan[24]. Using the assumptions listed above, and assuming that, for demonstrational purposes, only agricultural land currently producing cereals is converted to the sustainable production of cereals, the data for the potential output of cereals under the sustainable model is given.

Figure 3: Potential Food Production Under the Sustainable System

Country	Area Under Cereal Production	Total Cereal Yield In Sustainable System (MT)	Total Cereal Yield (kg per Year)	Mouths Fed per Year
United States	60,951,300	378112376.5	3.78112E+11	1800535126
France	9,611,460	63730444.3	63730444300	303478306.2
Germany	7,038,500	44859985.66	44859985660	213618979.3
Australia	20,322,000	32304643.48	32304643480	153831635.6
China	86,897,300	527838410	5.27838E+11	2513516238
Ukraine	13,112,300	57639120	57639120000	274472000
Russia	40,351,600	116128078	1.16128E+11	552990847.6
India	100,703,000	292408710	2.92409E+11	1392422429
Bangladesh	12,363,400	51595500	51595500000	245692857.1
Indonesia	16,312,500	84232493.4	84232493400	401107111.4
Vietnam	8,541,800	47581930	47581930000	226580619
Pakistan	13,453,700	34851520	34851520000	165959619

Source: World Bank Indicators

Based on the data presented above, the total estimate of the number of people that could be fed per year if the top twelve cereal producing nations switched to the sustainable system is 8.27 billion people, which effectively represents the carrying capacity of the earth with a transition to sustainable agriculture. Therefore, the conclusion is that is the top twelve cereals producing nations were to switch to sustainable agriculture, they could feed over 8.2 billion people, which is substantially more than the 7.877 billion people that could be fed under the current industrial system.

Differences in Factor Inputs

[24] World Bank Indicators: Country and Lending Groups

Differences in output per worker are mainly a result of differences in other factor inputs, such as capital and fertilizers. It follows that the differential in output between sustainable and industrial agricultural methods can be quantified by the differences in capital inputs, or in the case of sustainable agriculture, lack thereof.

There have been many studies done analyzing the differential in output as a result of different factor inputs. One study cited in a report to the Food and Agriculture Organization of the United Nations (FAO) provided statistics on sustainable agriculture projects spanning across India, the Philippines, and Indonesia. The study found that a switch to sustainable agriculture in these areas caused a 23% increase in the production cost per hectare. However, the increase in cost was offset by around a 10% increase in yields in both rice and wheat[25]. A similar study done at Pisa University, and discussed in the same FAO report, found that organic systems save on average 34%[26] of the energy used by the industrial system. This reduction in energy is due to a combination of reduced need for chemical inputs, such as petroleum derived fertilizers and pesticides.

One often-raised problem with the use of organic fertilizers as opposed to chemical fertilizers is that organic fertilizers do not achieve yields at a level necessary to provide food. However, many studies have been conducted showing that the use of organic fertilizers, such as cover crops, improve yields 60-80% over the yield with no fertilizers at all[27]. An example of how a compromise can be used to improve yields to a level of food security is demonstrated in the Millennium Villages Project, as described in the first part of this study. The project used chemical fertilizers to begin with, because

[25] Ravanera et. al. 2010: 50
[26] ibid p. 92
[27] Nziguheba et. al. 2010: 106

there was insufficient access to a supply of organic fertilizers[28]. The project transitioned in organic fertilizers to compliment the chemical fertilizers, as organic fertilizers provide benefits that artificial fertilizers do not, such as improving over all soil quality and providing a layer of nutrient-rich biomass to the topsoil.

Additionally, externalities besides fertilizer input can affect yields. One major contributing factor to higher yields is the development of agricultural infrastructure. For example, the development of more efficient irrigation systems and transportation networks. According to one report, better water management techniques alone within a sustainable framework can increase production 73%[29]. However, farmers in developing nations are unable to generate an income that would support such a transition[30]. Therefore, policies that promoted development in agricultural infrastructure would need to be put in place. This would increase productivity and the food available per capita within the sustainable agricultural model.

Differences in Price

A major concern with transitioning to sustainable agriculture that must be considered is the difference in food prices that would arise from the increased cost of sustainable systems in developed nations, including as a result of reduced yield in developed nations and the price premium paid to sustainably produced crops.

To date, many studies have cited an increase in the price premium of organically produced crops. But where do these premiums come from? Analysis shows that a large part of the price differential in developed nations comes from the increase in costs,

[28] Nziguheba et. al. 2010: 106
[29] Pretty, Hine. 2001: 15
[30] Selby, T

mainly due to increased labor input and the cost of organic certification[31]. However, in these same countries, consumer studies have shown that individuals are willing to pay a premium on organic crops because of the added health benefits, which could add to the price premium demanded.

One study found that in Australia, price premiums on organic wheat over conventional wheat average on the order of 30-50%.[32] Another done by Agri-Food Canada reported a price premium of 175%[33] for wheat in Canada, the statistic being variable depending on market supply. An additional study on price premiums found that there was higher over-all profitability in the organics market than in the conventional market, and that the total profitability was dependant on price premiums[34]. However, despite the variation in price premiums, a study conducted of market prices in both the United States and Canada found that the market prices for organic crops vary less than prices in the conventional market.[35] This could be due to the fact that yields for organic crops also tend to vary less than those of conventionally produced crops. Similarly, the Rodale Institute study found the standard deviation for net returns is lower for sustainable agriculture than for industrial methods.[36] This is most likely due to the implementation of methods that improve soil quality, and therefore give organic farmers higher yields in drought seasons, and leave crops less prone to diseases, than in conventional farms.

Direct costs associated with the transition from the industrial model to sustainable agriculture come from the loss of productivity once artificial chemical inputs are no

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[31] Emmens, J. 2003: 11
[32] ibid, 5
[33] ibid, 6
[34]ibid, 14
[35]ibid: 5
[36]Pimentel et. al. 2005: 576

longer used. One study found that without herbicides corn yields would be reduced by 19%[37]. To make up for loses, more acreage was placed under corn cultivation. Another study found that eliminating the use of insecticides and fungicides would decrease agricultural output in the United States by 2-26%[38]. Elimination of herbicides would decrease production 0-53%[39]. A third study found that a transition to sustainable agriculture would decrease yields by 10-20%[40].

Another direct cost of particular concern is the additional labor input needed in the sustainable system. According to an analysis of the Rodale Institute study, sustainable agriculture systems require 35% more labor[41] to achieve the same yields than production under the industrial model. This is more of a concern in the developed world because of the high cost of labor, in contrast to the developing world, which has lower wages. A major argument against the transition to sustainable agriculture that has arisen from this fact is that an increase in labor input could raise the price of the food crop. However, the same Rodale study found that labor costs are roughly equal between the two systems[42]. This is because though there is additional labor needed; this labor is spread out over the growing season so the labor cost on a per hectare basis is about the same between the two systems[43]. This is in contrast to the industrial models, which requires heavy labor inputs in spring and fall but very little in the summer, when most of the work is mechanized. This results in an equalization of labor costs that, being equal, would have no impact on the prices of the respective outputs.

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[37] Taylor and Frohberg. 1977: 30
[38] Fernandez-Cornejo et. al. 1998: 470.
[39] ibid, 470.
[40] Selby, T
[41] Pimentel et. al. 2005: 576
[42] ibid, 576
[43] ibid, 576

Although this decline in productivity would decrease the consumer surplus, producer surplus would actually increase as a result of an increase in the price of the crop[44]. In this way, the economic losses associated with sustainable agriculture would fall on the consumer. However, it is also the consumer who internalizes the costs of the industrial model in the form of health and environmental damage. Therefore, the loss in agricultural surplus should be considered as a trade off instead of a pure cost.

An additional factor that must be taken into account when assessing the differences in prices is the difference in petroleum input between the two systems. A study conducted over 22 years by the Rodale Institute, comparing the costs and yields of organic and conventional farming methods for soybean and corn. The petroleum intensity of the industrial system is an important factor in determining the price of the output because of how much is needed. In the Rodale study, there were 5.2 million kilocalories of energy input per hectare of corn in the industrial system, whereas under sustainable methods, energy inputs were 28-32% less.[45] This figure accounted for all fossil fuel inputs for machinery, fertilizers, and pesticides. Given the fact that there is widespread speculation oil prices will continue to rise in the future, it is likely that very soon the price of production for industrial crops may far outstrip that of sustainable agriculture.

Externalities

When looking critically at the cost differentials between organic and industrial agriculture, it is important to note the fact that prices do not reflect the complete cost of the agricultural system.

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[44] Taylor and Frohberg. 1977: 33
[45]Pimentel et. al. 2005: 575

A great deal of research has been conducted attempting to put a price on the external costs of the industrial agricultural system. One study concluded that the total cost of industrial agriculture in the United Kingdom, the United States, and Germany combined is £24,594 million per year[46]. This amounts to £154 per hectare of arable land in these nations. In contrast, the study found that in the UK, organic agriculture produces *positive* externalities of £75-125 million per hectare per year[47]. Additionally, a study by David Pimentel found that the human health costs alone from pesticides in the United States totaled about $1.229 billion annually.[48]

Figure 4: The Costs of Industrial Agriculture vs. the Benefits of Sustainable Agriculture

Industrial Agriculture	Health Costs per Year	Total per Year
US	$-1.229 billion	$-9.6 billion
US + UK + Germany		£-24.594 billion
Sustainable Agriculture	**Positive Externalities Generated**	**Total**
UK	£75-125 million per hectare	£11.98-19.96 billion

Source: Pretty et al 2001, and Pimentel, David 2005

Altogether, the total environmental and social costs of pesticide use in the United States total more than $9.6 billion per year.[49] If these numbers were factored into the price or their respective goods, the differential in price would alter drastically in favor of organically produced agriculture, making up for the increase in labor inputs in the sustainable model.

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[46] Pretty et. al. 2001: 267
[47] ibid, 7
[48] Pimentel, David 2005: 232
[49] ibid, 248

Another important externality that one must consider is the existence of a demand for sustainably produced foods. Assume that the price is not adjusted to include the cost of environmental and health externalities as described above. Would consumers be willing to pay more for organic foods even though they cost more? Many studies indicate they would.

One study conducted in Argentina evaluated consumer willingness-to-pay for organic products. The survey found that 75% of consumers said they would buy organics more frequently if they were cheaper. Although the price consumers were willing to pay for organics was below the market price, it was near the market price[50]. This indicates that only a small reduction in the price of organics would translate into a much larger consumer demand. Similar research in India into the potential demand for organic foods let to a projection of 16%[51] of the entire foods market potentially being controlled by the organics sector.

These studies are backed up by other indirect indicators of the demand for sustainably produced crops. In the United States, for example, certified organic farmland increase 74% between 1997 and 2001. Included in this was a 55% increase of the area under wheat cultivation[52] alone. Additionally, the ITC concluded that major markets for sustainably produced foods exist in Western Europe, North America, Japan, and Australia. These markets incorporate export opportunities for developing countries along with demand for domestic products[53]. This indicates that both the developed world and the developing world can gain economically from a switch to sustainable agriculture.

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[50] Rodriguez et. al. 2010: 15
[51] Menon, M. 2010: 67
[52] Emmens, J. 2003: 5
[53] Emmens, J. 2003: 5

Many studies have concluded that under the industrial agricultural model to date, enough food is grown in the form of basic commodity crops to feed every human being. The reason hunger is commonplace in many parts of both the developed and developing world is not that there is not enough food, but rather that the infrastructure does not exist to transport food from the field to those who need it.

According to the World Agricultural Outlook Board, there is set to be a grains surplus for the foreseeable future. A major factor that must be considered, however, in the distribution of this food is that the lack of infrastructure raises the cost of transportation to remote areas[54]. A case study conducted in Zambia and Zimbabwe found that with the implementation of a rural infrastructure development plan, agricultural growth and food security can be achieved[55]. Despite this, there is huge production potential for sustainable agriculture in developing nations[56]. According to one statistic, one third of the world's organic land is in countries on the list of recipients of Official Development Assistance[57]. The largest producers of this set of countries are Argentina, China, Brazil, and Uruguay.

Carrying Capacity

This is a particularly pressing issue in developing nations. The global population is projected to grow to 8.9 billion by the year 2050, with the majority of said growth taking place in developing areas of the globe[58]. As the demand for food increases in these regions, farmers may be driven to use slash and burn agriculture, or other highly destructive methods to produce large quantities of food quickly. One study shows that an

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[54] Gregory et. al. 2005: 2145
[55] Wanmali and Islam 1997: 268
[56] Pretty, Hine. 2001: 22.
[57] Willer, Youssefi. 2010: 12
[58] UN World Population to 2300: 4

increase in population density often results in an increase in agricultural intensity[59]. However, an increase in the available labor base would also lead to a transition towards the cultivation of more labor-intensive crops, which can enhance the land[60]. The increase in labor demand would also drive up wages and increase employment in rural areas[61]. If there were an effort to promote sustainable methods in the production of these labor-intensive crops, population growth would prove beneficial to the agricultural environment.

Indeed, it would be logical to support the development of sustainable practices, as studies have shown that the degradation of agricultural land leads to the impoverishment of farmers[62]. If such sustainable criteria are met as population increases, farmers would have more incentive to care for their land, which in turn leads to policies that favor land-enhancement[63]. This was exemplified in the case of Malawi, which has been dubbed the 'first African Green Revolution country'. The success of Malawi is mostly attributed to subsidized inputs to farmers on the community level[64], which has stimulated the development of sustainable agriculture initiatives as well as the building of infrastructure connecting producers with the market.

The potential for sustainable agriculture to stimulate growth has also been studied in the former East Germany, where 10%[65] of agricultural land is organic. Studies conducted there have proved that sustainable agriculture can initiate rural development,

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[59] Vasey, D. 1979: 280
[60] Templeton; Scherr. 1997: 27.
[61] Selby, T.
[62] Templeton; Scherr. 1997: 22.
[63] ibid 58.
[64] Nziguheba et. al. 2010: 104
[65] Schäfer et. al. 2010: 44

even in rural areas under population or land pressure[66]. The integration of rural agricultural areas into the broader market not only stimulates growth in rural areas, but also has positive affects on urban areas. One study also finds that the organic sector has the potential to stimulate sustainable growth on the global scale[67]. In this way, the transition to sustainable agriculture would facilitate economic development in communities worldwide.

In the course of this paper, it has been proven that a transition to sustainable agriculture would produce yields exceeding the level produced under the industrial model in developing nations, and would not substantially lower the yields in developed nations. This leaves as necessity a discussion of the practical advantage this information gives us. That is, can this level of agricultural production feed the global population?

A study published in the journal *Ecological Economics* analyzed trends in yield data in an attempt to quantify the carrying capacity of cereals production globally. The study found that yield growth patterns under the existing industrial system fit a logistical growth trend, and that the developed world had hit the upper limit of this trend while the developing world is still growing. One regional analysis suggested that in Asia, the upper limit for rice yield is 8.6 tones per hectare.[68] The results of this study indicate there is a defined growth rate in yield production necessary to keep up with population growth, though depending on how close a region is to reaching the upper limit of cereals production, this level may or may not be achieved. For example, in sub-Saharan Africa the yields of cereals would need to quadruple by 2050 to make the growing population

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[66] ibid, 44
[67] ibid, 44
[68] Harris, Kennedy 1999: 450

self-sufficient.[69] Is this level achievable given Africa's low level of agricultural productivity? Yes. With a transition to sustainable agriculture, the yields in Africa would grow by at least 10% over the current levels. Some studies suggest that the difference on highly undeveloped agricultural land could even be higher[70]. This increase is sufficient enough to be able to support sustained population growth.

However, it is extremely important to bare in mind the fact that this agricultural growth has its limits. The study mentioned above provides statistical proof that there is an upper limit to agricultural production. This implies that although a transition to sustainable agriculture will provide food for the projected population in 2050, there is little chance growth would continue at similar rates beyond this time period. Therefore, a solution is needed that will ensure steady yields far beyond this time frame, and careful attention must be paid to methods that will not degrade soils or pollute water supplies, as both of these problems could in the future mean a decrease in cereal yields.

[69] Harris, Kennedy 1999: 452
[70] Nziguheba et. al. 2010: 106

Conclusion

Shown below is a comparison summarizing the findings of this study. As shown, the sustainable production method for cereals yields more product globally than the industrial model of agriculture:

Figure 4: Yield Comparison

Country	Cereal Yield Under Industrial System (kg/yr)	Cereal Yield Under Sustainable System (kg/yr)
USA	4.80E+11	3.78E+11
France	4.02E+11	63730444300
Germany	2.66E+11	44859985660
Australia	1.06E+11	32304643480
China	76574994000	5.28E+11
Ukraine	67798345000	57639120000
Russia	52399200000	1.16E+11
India	47723389000	2.92E+11
Bangladesh	46905000000	51595500000
Indonesia	43256300000	84232493400
Vietnam	34366642000	47581930000
Pakistan	31683200000	34851520000

This concludes that if the top cereal producers were to covert to sustainable methods of agriculture, global yield would increase contrary to long-held speculation. This would ensure higher agriculture yields with lesser inputs in the long run, as opposed to declining yields and higher input requirements under the industrial agriculture system. Not only does this guarantee the health of the agricultural environment and its production capacity, it also translates into more people being fed around the globe in the long run, as shown in the comparison below:

Figure 5: Comparison of Amount of People Fed

Country	People Fed per Year Under Industrial System	People Fed per Year Under Sustainable System
USA	2285014762	1800535126
France	1915462900	303478306.2
Germany	1265838571	213618979.3
Australia	502718952.4	153831635.6
China	364642828.6	2513516238
Ukraine	322849261.9	274472000
Russia	249520000	552990847.6
India	227254233.3	1392422429
Bangladesh	223357142.9	245692857.1
Indonesia	205982381	401107111.4
Vietnam	163650676.2	226580619
Pakistan	150872381	165959619
Total	7877164090	8244205768

This demonstrates the necessity of a transfer to sustainable methods to increase food security and the carrying capacity of agriculture globally. There is every indication that the productivity of the industrial agricultural system will have diminishing yields as the agricultural environment is degraded, and as a result require more energy-intensive chemical inputs to maintain the level of yields that have already been achieved. With a population increase that will continue well into this century, a decline in the growth of agricultural yields is something that we cannot afford if we wish to deter mass starvation and famine.

The solution is a transition to sustainable agricultural methods. These methods provide equal or increasing yields in both developed and developing nations, and do so without undermining the agricultural environments' ability to sustain these yields, as the industrial system does through the loss of topsoil among other problems. This would not only ensure a steady supply of food in the coming decades, but also far into the future.

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