Energy Inputs to Agriculture

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0. Introduction

The story of the use of fossil energy resources since the beginning of the Industrial Revolution over two hundred years ago is often told in terms of the development of our current modern, predominantly urban, lifestyles, characterized by the incredible scientific and technological progress of these two centuries. Not so often do we hear about how fossil energy resources, combined with scientific and technological progress, have changed the way we produce the food we need to survive. How much energy is being used in what form in agriculture? How has this come about historically, what does it mean, and where is it going in the mid-term future? This paper is an attempt to give a brief answer to these questions.

1. How fossil energy came to be used in agriculture

Energy, as we experience it in our lives, is a solar "gift". Life began on earth about 3.5 b yrs ago when certain chemical compounds became able to reproduce themselves through the ability to make direct use of incoming solar energy; autotrophs, which are able to produce their own energy through the direct use of solar energy. The development of the type of photosynthesis which releases oxygen, as in green plants today, occurred between 3 b and 2 b yrs ago.(1) Later in the evolutionary process, life forms not able to make direct use of solar energy (heterotrophs) emerged, and these were dependent for the energy for life on the autotrophs. They ate them. Thus emerges a picture of earth that existed up until the end of the last ice age, perhaps 15,000 years ago.

At that stage, mankind lived a "hunter-gatherer" existence. It is unsure when man became able to use fire (the conscious use of inanimate energy for cooking, defense and so on), but the archaeological record shows that fires were regularly used by about 40,000 yrs ago.(3) Agriculture, the conscious and organized use of plants and animals by mankind in an attempt to capture a larger fraction of solar energy income for human use, is thought to have begun around 10,000 yrs ago. This situation remains largely unchanged (a certain amount of technological innovation taking place in agriculture in the meantime – rice cultivation, the introduction of farming rotations, and so on) until about the middle of the 19th century when the work of chemists such as Justus von Liebig (4) resulted in the possibility of using inorganic chemicals as fertilizers. The industrial revolution also brought together the use of coal and machinery in the invention of the steam engine, which later found many applications as labor-saving technology in farming.

Note on fossil fuel formation: The coal, formed from layers of plant remains generally in the Carboniferous Period 345-280 m yrs ago, and oil and natural gas, believed to have been formed from sediments of microscopic planktons, or diatoms, mostly in the Jurassic and Cretaceous Periods, 190-65 m yrs ago, that we use as our major energy sources now, has its energetic origin in solar radiation, as does all life.(2)

In the 1840s, Rothamsted (UK) experiments showed that applications of nitrogen fertilizers offered the best path to higher grain crop yields, but it was not until 1887 that symbiotic nitrogen fixation in legumes was discovered. The big problem for agricultural progress at the end of the 19th century was that the ability to fix nitrogen by artificial means had not yet been invented.(5)

The world currently has about 1.5 Gha of farmland under production.(6) and there is little room for expansion of this without the destruction of forests, wetlands and so on, or moving into inferior farmlands. Around 235 Mha of new farmland, mostly for wheat production, was created as the grasslands of North and South America, Australia, and Russia were brought under cultivation between 1850 and 1920. Yields were still low – about 1.5 ton/ha in the best European farming – but the population was rising, and the newly urban population was also beginning to consume more animal-derived foods – meat and dairy products. The land horizon was beginning to come into view, and it was recognized that only way to feed the growing population with its increasingly urban diet was to intensify the agricultural production of food on more or less existing farmland. Thus, William Crookes was led to proclaim in September 1898 that, "The fixation of nitrogen is vital to the progress of civilized humanity." (7)

Note on population: Although increases and decreases in (the rate of growth of) human populations is a complex matter involving many socio-economic factors, the basic physiological factor involved, all other factors being equal – no natural or man-made disasters, for instance – must be the relative availability of food. That the human population of the world has risen from 1 billion early in the 19th century to over 6 billion at the beginning of the 21st century must be due in no small part to the ability of man to appropriate a larger share of incoming solar energy through the application (as machinery or chemicals) of inanimate energy forms, primarily fossil energy.

Crookes did not have very long to wait. Fritz Haber (1868-1934) began work on ammonia synthesis from hydrogen and nitrogen ($N_2 + 3H_2 \leftrightarrow 2NH_3$) in the summer of 1904. Success came on July 2, 1909 in an experiment which indicated ammonia yields of about 10% at 10 Mpa (10 million pascals – about 100 atmospheres) and 500^oC. This was carried out with an experimental converter, a pressurized tube 75 cm tall and 13 cm in diameter, in Haber's experimental laboratory.(8)

This apparatus was upgraded into a pilot plant device by Carl Bosch (1874-1940). Bosch's work was carried out so quickly that planning for a commercial plant of 10 t NH_3/day began in April 1911, but was upgraded to 30 t NH_3/day in November 1911. Construction at Oppau began May 7 1912, and was completed on September 9, 1913 (the day of first NH_3 production). NH_3 was converted to ammonium sulphate for fertilizer. However, war broke out on August 4, 1914, and NH_3 production was redirected to the production of nitric acid for war munitions. A new and very large ammonia plant, built at Leuna, was completed in April 1917. This represented the completion of "preparations" for supplying the world with artificial nitrogen fertilizers, but these did not become the dominant means of supplying fixed nitrogen for agriculture till the 1930s, rapid increase in their use coming in the 1950s and onwards.(9)

The next step in the food and energy story is the introduction of hybrid (high yielding varieties – HYV) varieties of the main staple grains, maize, wheat, and rice. The first commercial hybrid maize was introduced in the US in 1929. The higher yields of the new varieties of maize made it possible to increase land productivity. By the end of WWII, hybrid maize had replaced traditional varieties. In itself, this does not increase energy consumption, but besides the fact that the farmers must buy new seed each year, hybrid maize introduced an array of corollary farm products such as fertilizer, insecticides, herbicides, and other pesticides; the equipment used to apply these chemicals; and the enormous and enormously expensive machinery used to harvest maize. The higher yield of the hybrids had the overall effect of sustaining chronic overproduction, thus forcing farm prices down as cash inputs increased, contributing to the degeneration of soil quality, and helping to sustain human population increase through the increased availability of cheap food. In other words, by the 1930s the "modernization" (industrialization, mechanization and chemicalization – energy intensification) of agriculture in the US was basically complete with respect to maize, and this would soon spread to other advanced nations and other important crops. However, disease epidemics began to appear in US maize in the 1970s due to genetic similarity of maize crops grown over vast areas, and due to the decline in disease resistance of the plants resulting from the deterioration of the soil after several decades of chemical fertilizer use. This has stimulated the increasing use of toxic pesticides, and the race against nature to develop disease- and pest-resistant varieties, resulting in the development recently of genetically modified crops.(10)

2. The Green Revolution

In 1944, Norman Borlaug arrived at the International Center for the Improvement of Maize and Wheat (CIMMYT) near Mexico City. He was working on HYV wheat, but breeders found that the varieties that would produce increased yields when supplied with increasing amounts of nitrogen fertilizer caused the wheat plants to "lodge", limiting both the amount of nitrogen that could be used and the resulting yields. To solve this problem Borlaug experimented with Norin 10 (originating in Japan as a cross between a Japanese variety called Daruma, and an American wheat variety called Fultz), a Japanese "dwarf" variety. He incorporated the "dwarfing gene" from Norin 10 into the Mexican wheat varieties he was studying. The result was a shorter wheat that could withstand far greater fertilizer applications without lodging. The new wheats were 20 to 40 inches tall, compared to 50 to 60 inches for traditional varieties. They had stronger stems and roots, more flowering heads, and more grains per head – larger harvesting index. This was the beginning of the Green Revolution (GR).(11).

The process was soon repeated with rice at the IRRI in the Philippines. A dwarf variety of rice, IR8, was introduced to Asian farmers in 1966 and immediately boosted rice yields and harvests. However, IR8 quickly proved to be susceptible to a variety of pests and diseases and was followed in succeeding years by IR20, IR36, IR60, IR62, and IR64 in order to stay ahead of the pests and diseases. The result of the GR however was the "modernization" (industrialization, mechanization and chemicalization – energy intensification) of agriculture in much of the rest of the world, the developing countries. As the GR package requires fertilizers, irrigation, pesticides, and inevitably leads to the use of machinery.(12)

From the end of WWII until about the mid-1980s, the introduction of high-yield crops and energy intensive agriculture (the GR) led to increased crop production. World grain output expanded by a factor of 2.6 in this period, while the world population doubled from 2.5 to 5 billion. The success of the Green Revolution lay primarily in its increased use of fossil energy for fertilizers, pesticides, and irrigation to raise crops as well as in improved seed. It greatly increased the energy-intensiveness of agricultural production, in some cases by 100 fold or more.(13) Large grain yield increases resulted in a massive improvement in land productivity. A secondary effect was that large areas of cropland could be continuously monocropped, eliminating the need for traditional rotation systems. Farm machinery was widely introduced, thereby raising labor productivity at the expense of use of more fossil fuels.

However, the GR engendered several problems, briefly:

- reduction of biodiversity as HYVs replaced traditional crop varieties,
- destruction of soil fertility through the heavy use of chemical fertilizers,
- increase in nutritional imbalances due to monocropping and abandoning of rotational practices,
- chemical contamination and pollution with the resultant effects on the environment and human health (14)

An important social consequence of the GR was that it often did not directly help to relieve poverty, as it was anticipated that it would. In general, the GR benefited the better-off farmers who could afford the whole GR package of seeds and chemicals and who had access to better quality and irrigated land, and preferential access to finance and credit. Increased harvests increased the incomes of these farmers, despite falling prices due to increased production, and allowed them to take over the lands of their poorer farmer neighbors. The poorer farmers frequently had to go into debt to buy the new seeds and chemicals, which they were unable to repay because of falling commodity prices. They therefore had to sell their land. Better-off farmers might conceivably then employ the newly landless farmers on their expanded farms, but generally they did not, preferring to buy farm machinery instead, (15) sending the newly destitute off to the cities in search of employment. For the better-off farmers, this situation continued favorably for some years, but more recently problems of reduced yields (reduced soil fertility following several years of chemical fertilizer use), pest and disease problems related to weakening plant health due to reduced soil fertility, and human health problems concerned with agricultural chemicals. The need to continue on the proprietary seed and chemical treadmill (increasing cash inputs to crops) despite falling yields has been responsible for a general farmer impoverishment and indebtedness in many developing countries. Individual farmers and farming groups in south and southeast Asia have, over the last 10-15 years, made progress in escaping this vicious circle by converting to organic farming methods.

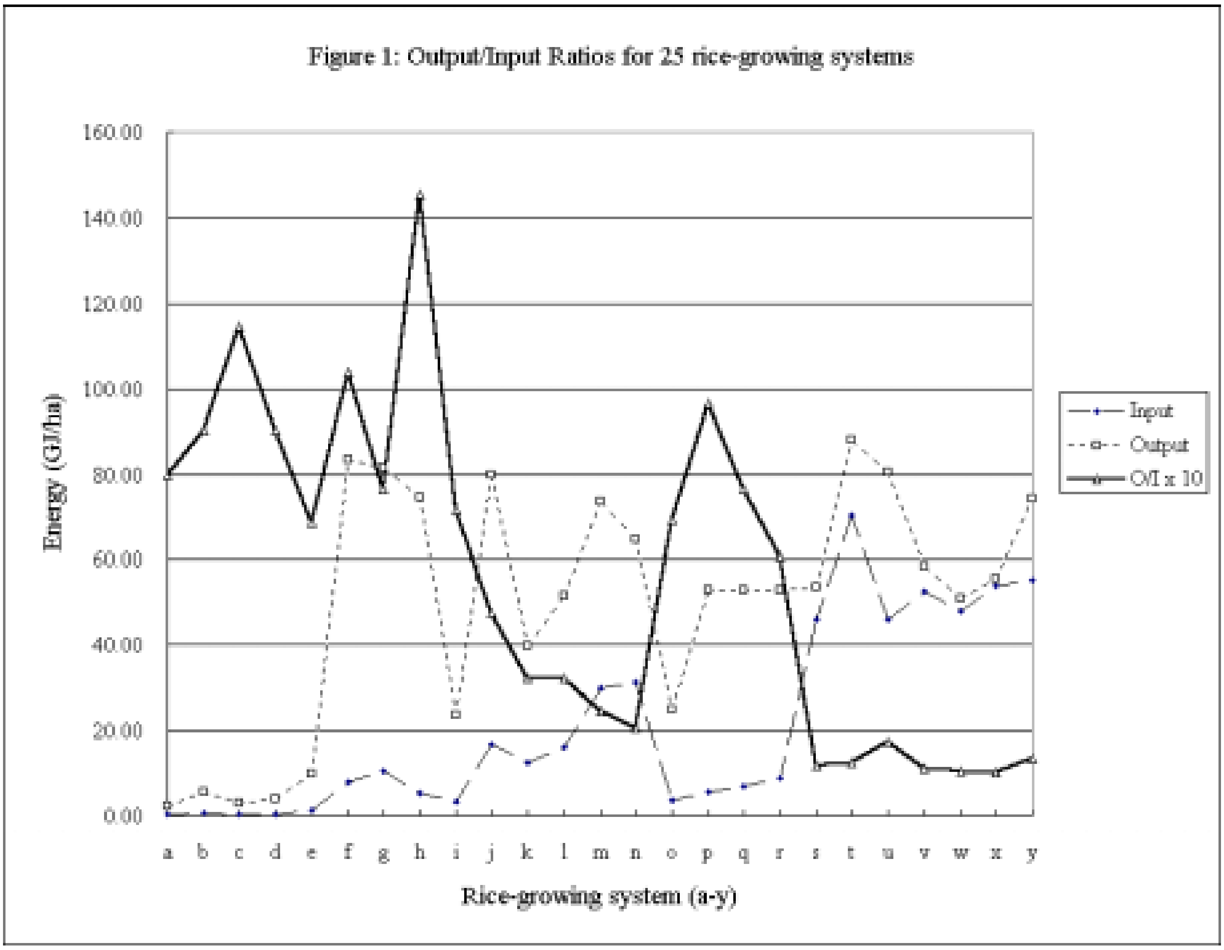

Figure 1: O/I Ratios for 25 Rice Systems a-h = pre-industrial, i-r = semi-industrial, s-y = fully industrial

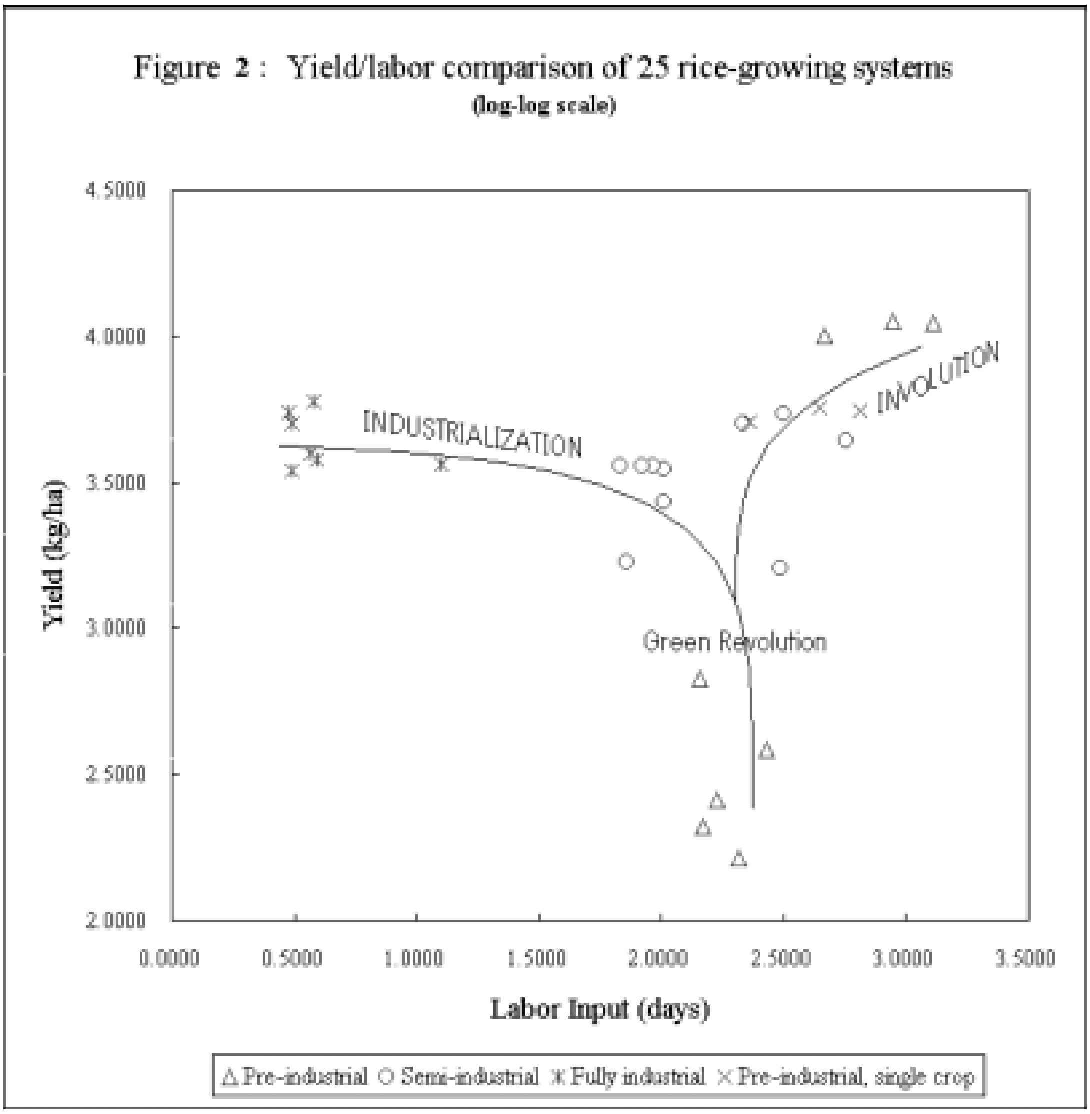

Figure 2: Yield/labor comparisons for 25 rice-growing systems

Shiva (1991) gives a very interesting comparison of labor and energy inputs to 25 rice cultivation systems. What the data show is that energy **output:input** ratios fall as fossil energy inputs increase, despite the increase in yields when compared with traditional pre-industrial agriculture (Figure 1). However, the data suggest that very labor-intensive rice cultivation can also result in high yields. The data become even more interesting when plotted on a log-log scale of labor input against yield. (Figure 2) The plots suggest that there are two developmental "directions" that rice cultivation could follow towards higher yields; the modern, industrial, direction or the direction of pre-industrial, labor- and organic intensification of the GR termed "involution" by Geertz.(16) Note that the yields shown as triangles in top right of Figure 2 are so high that it is possible they are for double-cropped rice. The yield figures have therefore been simply divided in two and plotted separately (as "×" – these values have been used to plot the points for f, g, and h in Figure 1) and show no large quantitative difference. They are similar in value to those from Japan, India, and Hong Kong, marked as "o". These are semi-industrial rice cultivation systems where both labor inputs and energy subsidies are high, resulting in good yields (4.4 to 5.4 tonnes/ha). Fossil energy inputs are supposed to result in labor-saving, but in these cases it seems that they have not. Perhaps the farmer has replaced the water buffalo with a tractor and the buffalo's composted dung with chemical fertilizers, but has continued to spend roughly the same number of hours in his field tending the rice! What this would show is that yields are dependent upon the skill, knowledge, and care of the farmer (other factors being equal), and that higher fossil fuel subsidies will result in a large degree of labor saving, but result in roughly the same level of land productivity (yield, see the cluster of "*" plots on the left-hand side of the graph). In summary, the industrial/chemical intensification "direction" of GR gives higher yields at the cost of sustainability, whereas "involution" – the organic intensification "direction" of GR gives higher yields with sustainability.(17)

3. Direct fossil energy inputs to agriculture

Chemical Fertilizers: Since chemical fertilizers represent a large portion of the fossil energy subsidies to modern farming, it is necessary here to look at them in some detail. Smil(18) has given estimates for global energy inputs into agriculture. For the main chemical fertilizers, nitrogen, phosphorus, and potassium (NPK), nitrogen production is estimated to be at least 35MJ/kg for ammonia, and 70-110 MJ/kg for urea, depending on the process used. Natural gas is now commonly used as both feedstock and fuel source for the synthesis of ammonia by the Haber-Bosch process. Smil(144) estimates that even if all the ammonia for chemical fertilizers were produced in this way, 150 Gm^3, a little less than 7 percent of the world's natural gas production for 2001 would be necessary for this purpose.(19)

Chemical fertilizers are not a renewable, unlimited resource. Future chemical fertilizer production will be affected by the following factors:

- **Nitrogenous fertilizers** require the continued availability of natural gas, now the favored feedstock and fuel for the world manufacture of these fertilizers.
- **Phosphate fertilizers** require the mining of phosphate rock at around 4-5 MJ/kg. The rock is then converted to superphosphate (8-9% P) for about 15-20 MJ/kg, or to diammonium phosphate (up to 23% P) at a rate of 28-33 MJ/kg. Current world consumption of phosphate rock is about 130 m tonnes (2002).(20) World reserves are estimated to be 34 billion tonnes. At current usage, the world's supply of phosphate could last another 250 years. Most of the world's phosphate deposits are in Morocco (almost half the world's known reserves), USA and FSU.(21)
- **Potassium** is far more widely distributed in the world than phosphorus and is not usually a problem in soils and diets. Over half the world's known reserves of potassium are in Saskatchewan Province, Canada.(22) There are also substantial reserves in the FSU and Europe. World potassium fertilizer production in 2002 was about 23 m tonnes.(23) Potassium reserves are thought to be about 50 billion tons.(24). Mining potassium chloride can cost as little as 4-5 MJ/kg, or 15-20 MJ/kg for solution extraction.

However, scarcity of fossil fuels will possibly make mining and manufacturing of both phosphates and potassium ores difficult in the second and third decades of the 21st century.

Unfortunately, up to two-thirds of chemical fertilizer leaches away from agricultural land and into groundwater, lakes and rivers. This results in nitrogen pollution of groundwater and blooms of blue-green algae and eutrophication (de-oxygenation) of surface waters.(25) Worldwide, about 130 million tonnes of atmospheric nitrogen gas is converted by natural processes to ammonia and nitrate, which then circulate throughout the biosphere; the nitrogen cycle. Human activities now match this figure. *At least* another 130 million tonnes of nitrogen is fixed each year through the manufacture of synthetic nitrogen fertilizers, the burning of fossil fuels and forests, the draining of wetlands, and the planting of nitrogen fixing crops such as peas, beans and alfalfa.(26) This is just one example of how the scale of human activities are able to affect the normal functioning of the biosphere.

Further, chemical fertilizers are not beneficial to long-term soil health(27) as they tend to acidify the soil and reduce nutrient availability and uptake.(28) Fields cultivated continuously with chemical fertilizers lose 50-65% of their pre-agricultural amounts of soil carbon and nitrogen, and to regain original carbon and nitrogen levels would take about 200 years by natural succession, or this can be achieved by the use of organic manures in 40-50 years.(29) If fossil inputs are decreased or curtailed, yields fall dramatically, resulting in lower yields than previously because of a decline in soil fertility. Thus, chemical fertilizer inputs have a degrading effect on the soil, making it less fertile that in its original state. The fertility of the soil is artificially bolstered by annual inputs of chemical fertilizers, but if these are withheld, for whatever reason, land productivity is likely to plummet to between a half and a third of previous levels, depending on the state of the soil. This is exactly what happened in North Korea, where the inability to import oil resulted in large declines in chemical fertilizer applications as well as a substantial loss of motive power, leading to severe food shortages within the country.(30) At the same time, we should be aware of how dependent humanity has become on chemical, especially nitrogen fertilizers. Smil estimated in 1997, when the world population was just under 6 billion, that, "Currently at least two billion people are alive because the proteins in their bodies are built with the nitrogen that came – via plant and animal foods – from a factory using this process," namely, the Haber-Bosch process for the synthesis of ammonia. (31) Chemical fertilizers are also know to be inimical to human health, a matter that was made clear by Albert Howard and others in the 1930s and 1940s.(32) This must rate as one of the best-kept secrets of the second half of the 20th century.

Agricultural Chemicals: Generally, agricultural chemicals are produced from petrochemical feedstocks by energy-intensive processes, synthesis of commonly used active ingredients being in the range 100-200 MJ/kg. A total energy cost of 200-300 MJ/kg is generally necessary for manufacturing, packaging and marketing.(33) Heavy reliance on industrial manufacturing and petroleum suggests that, since long-term pesticide availability cannot be guaranteed, alternative methods of preventing crop diseases and pest control should be fairly high on the list of priorities for the transition of agriculture to the post-oil age.(34)

We are now in a position to look at the total fossil energy inputs to agriculture worldwide. Worldwide costs of producing nitrogenous chemical fertilizers (82 m tonnes of N) would be about 5.5 EJ. P and K would add 350 and 250 PJ respectively to that, giving a total world energy use for chemical fertilizer production of about 6.1 EJ. (World crude oil production at 27.3 Gb/yr [2002] = 168 EJ.)(35) Global energy inputs to agricultural chemicals (pesticides) can be estimated to be about 500 PJ. Smil estimates energy inputs to different crops and total energy inputs to various elements in agricultural production as in Table 1.

Table 1: Global Fossil Energy Subsidies to Agriculture

Crop Type	Energy Inputs (GJ/ha)	**Global Energy Subsidies (EJ)**	
Dryland Cereals	8-15	Machinery	5.0
Rice	40-65	Chemical Fertilizers	6.1
Potatoes	40-90	Pesticides	0.5
Vegetables	25-100	Irrigation	0.3
Greenhouse Vegetables	2000-4000	**TOTAL**	**12.0**
Tree Crops	50-150		

Source: Smil, (1991), p.236

The grand total of 12 EJ averages out over the worlds cropland at roughly 8 GJ/ha, 10.5 GJ/ha for rich countries and 7.5 GJ/ha for poor countries. However this still seems a little too low as several factors are not present. Udagawa has shown that a fairly exhaustive account of all energy inputs to agriculture in industrially advanced countries can result in input values about twice as large as those given in Table 1.(36) 12 EJ would be the final energy use equivalent of about 10 percent of the world's crude oil production at 27.3 Gb/yr.

How much energy do residents of the economically advanced countries need to eat? Currently more than 10 J of fossil energy are embodied in each J of food energy consumed. Of that about 20% is used on farms in direct agricultural production of food crops and animal foodstuffs, and about 80% off-farm for food processing, transport, retail, preparation and so on.(37)

To provide the annual average per capita food requirement of about 4 GJ (2617 kcal/day) of food energy for the Japanese population (for example) 4GJ x 127 million = 508 PJ, would require 508 PJ x 10 = about 5.08 EJ (final energy). Final energy averages about ~70% efficiency, so this would be the equivalent of approximately 7.26 EJ in primary energy terms. The 2002 primary energy supply of Japan was approximately 22 EJ. So the equivalent of ~33% of Japan's total primary energy budget was being used to supply food to the Japanese population. However, only 20% of that would have been used directly in agriculture, and then only about 40% of that in-country as Japan's (calorie-base) food self-sufficiency is about 40%.

It is also estimated that approximately 16% of Japan's energy budget is needed for the production and consumption of food.(38) The remaining roughly 17% must then be used outside Japan to provide the 60% of imported food (including the energy for transportation to Japan). Thus, an estimate of energy use for food production, distribution, and consumption for Japan would be as shown in Table 2.

Table 2: Primary energy used to feed current Japanese population

	Direct farm use (20%)	Off-farm use (80%)	Total
Inside Japan	0.70 EJ	2.82 EJ	3.52 EJ
Outside Japan	0.75 EJ	2.99 EJ	3.74 EJ
TOTAL	1.45 EJ	5.81 EJ	7.26 EJ

To summarize, mankind is currently, a) maintaining a dramatically increased world population on limited land resources, while at the same time b) destroying the resource base, fertile soil, with non-renewable fossil energy resources, the depletion of which in the mid-term future is now a matter of common knowledge. This can be called "suicide agriculture".(39) Is it possible to change "direction" to involution of the GR? In other words: Can organic farming (sustainable agriculture) feed the world?(40)

4. Can organic farming feed the world?

Firstly, Drinkwater et al.(41) studied carbon and nitrogen balances in two legume-based (for nitrogen fixing) and one conventional fertilizer-driven agroecosystem. Both of the legume-based systems were managed "organically", avoiding the use of chemical fertilizers and pesticides. One of the legume-based systems simulated a beef operation where biomass was fed to beef cattle and the manure returned to the field as the primary nitrogen source for maize production, which was the main activity carried out on all the fields. The results show that environmentally (less nitrogen leached) and agriculturally (improved soil fertility, especially with the manure system) the legume-based systems were superior. Interestingly, the maize yields were 7140 kg/ha (manure), 7100 kg/ha (legume-based), and 7170 kg/ha (conventional) and these are ten-year averages, making it hard to claim that non-chemical farming results in reduced yields. What matters is the fertility of the soil, something (as discussed above) that is NOT guaranteed by chemical fertilizers.

In an experiment that has run for over 150 years at the Rothamsted Experimental Station in the UK, wheat yields have averaged 3.45 tonnes/ha on manured plots compared with 3.40 tonnes/ha on plots receiving full complements of NPK (nitrogen, phosphorus and potassium) chemical fertilizers. Soil organic matter and soil total nitrogen levels have increased by about 120% over the 150 years in the manured plots, but only about 20% in the plots receiving chemical fertilizers, showing that organic farming is not merely about yields, but also about increasing or improving natural capital.(42)

An article in *Nature*(43) shows how by planting two different varieties of rice in rows in rice fields the incidence of rice blast (a common fungal disease of rice) decreased 94 percent, making the use of fungicides unnecessary. This interesting thing about this experiment, carried out in Yunnan Province in China, is that it was carried out (in the second year) over all 3,342 ha of ten townships in two counties. The system was found to be just as productive, resulting in an 18% yield rise. The important factor here was plant diversity.

Writing in the *Ecologist*(44) Peter Rosset shows how the received wisdom that large farms are more efficient and productive is actually a myth. Measured in terms of total output rather than yield of a certain crop, small, intensive farming is more productive. Small, organic, family farmers will tend to intercrop or multiple-crop because (as in the example above) diseases and pests are far less likely to cause significant damage, and thus yields are better. But then you cannot harvest with a machine. In Yunnan, rice is harvested by hand.(45) Small farmers are also more likely to have livestock on their farm, which provides a variety of animal products to the local economy and manure for improving soil fertility, and to practice a rotation system, again because that helps to keep down unwanted plants (weeds) and reduce disease damage. No chemicals and no fossil fuels are necessary, and the closer a natural ecosystem is imitated, the better productivity will be. Human health will be improved too, because the food that is produced in this way contains no synthetic chemicals, but embodies nutrition from the soil, and so is "healthier". Animals (including humans) in harmony with a diversity of plants equals soil fertility and a balanced, ecological way of living and eating.

On such farms, though the yield per hectare of a single crop might be lower than a large farm, total production per hectare of all the crops and various animal products is much higher than large conventional farms (46). Research on the relationship between total production per unit area to farm size in 15 countries shows in all cases that the smaller farms are much more productive per unit area – 200 to 1000 percent higher – than larger ones.(47) So, the answer to the question, "Can organic farming feed the world?" is "yes," and better than industrial-chemical farming can, with two caveats, 1) the organic farming system must be operated in such a way as to maintain a safe and adequate recycling of nutrients, and 2) human populations should be maintained well within the "carrying capacity" limits of the area.

5. Conclusion

When we are no longer able to rely on fossil energy resources to work the land and maintain its fertility, the only recourse we will have will be to carry out appropriate forms of organic farming (or sustainable agriculture), using human and animal labor, and at the same time reduce and maintain human populations at levels appropriate for the resource base – fertile soil. There is no *a priori* reason why world population should be 6 billion or 10 billion. To know what the "carrying capacity" of the land might be is useful (as we can then arrange to be well within it), but we should not blindly assume that populations will always "automatically" rise to or exceed that figure. The question at the beginning of the 21st century is, "Does mankind have the wisdom necessary to implement the historical lifestyle change (a change in the direction of civilization itself – including a change in the "direction" of agricultural development, involution), whereby populations would be consciously maintained at a level appropriate for the local natural conditions of soil, climate, flora and fauna?"

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