Economics and Energetics of Organic and Conventional Farming

DAVID PIMENTEL

College of Agriculture and Life Sciences
Cornell University
Ithaca, NY 14853

Abstract *The use of organic farming technologies has certain advantages in some situations and for certain crops such as maize; however, with other crops such as vegetables and fruits, yields under organic production may be substantially reduced compared with conventional production. In most cases, the use of organic technologies requires higher labor inputs than conventional technologies. Some major advantages of organic production are the conservation of soil and water resources and the effective recycling of livestock wastes when they are available.*

Keywords: Agriculture, organic, energy, economics, environment.

Introduction

Throughout the world, genuine concern exists over the increased use of fertilizer and pesticide chemicals in agriculture because of the public health and environmental problems associated with their use. In Denmark, Sweden, the Netherlands, and the province of Ontario, Canada, government programs have been developed to reduce pesticide use by 50% over relatively short periods of time. Other nations, including the United States, are also trying to reduce the use of pesticide, fertilizer and other chemicals to make agriculture environmentally sound and sustainable for the future (Edwards et al., 1989; National Academy of Sciences (NAS), 1989; Paoletti et al., 1989; Pettersson, 1993; Surgeoner, 1993). Because the major objective of organic farming is to produce crops and livestock with few or no added chemicals and to protect soil, water, and biological resources, several organic farming practices are now being utilized in commercial U.S. agriculture (NAS, 1989).

Definitions of organic farming range from no use of synthetic chemicals in crop and livestock production to the judicious use of agrochemicals. In this analysis, however, organic farming is defined as production systems that exclude the use of synthetic chemical fertilizers, pesticides, and growth regulators.

Journal of Agricultural and Environmental Ethics 1993

Included in this assessment are the economic, labor, and energy inputs of organic agricultural technologies compared with those of conventional agricultural production. Two crops, maize (corn) and potatoes were selected because, worldwide, they are major crops and both receive heavy applications of commercial fertilizers and pesticides.

Methods

The data used in this study are from published information on the production of U.S. maize and potatoes employing different technologies and energy inputs. Commercial fertilizers were used for the conventional farming system to provide the essential crop nutrients of N, P, and K, whereas for the organic system they were provided by crop residues, livestock manure, legumes and other soil amendments [glauconite (K) and rock phosphate (P)]. It was assumed that the manure sources were located reasonably close to the crop area, because manure, with about 85% water, cannot be efficiently transported more than about 10 km. For this analysis, it was assumed that the cattle manure was about 3 km distant and that it was transported and spread by tractor. An input of 15,000 kcal (about 1.9 liters of fuel) was required to apply 1 tonne of manure to the land. Note that only about one-half of the livestock manure produced in the United States is collected. This half has the N equivalent equal to the amount of commercial N that was applied to U.S. agriculture (Pimentel, 1990). Most U.S. livestock manures, however, are underutilized and many pollute surface and ground water resources (NAS, 1989).

In the organic system, only readily available, nonchemical pest controls were used in the analysis. For weed control both mechanical cultivation and crop rotations were employed. For insect control, only crop rotation was used to control the corn rootworm complex and to provide limited control of the Colorado potato beetle (Pimentel et al., 1991). It was assumed that other than the benefits of crop rotation to control plant pathogens, no additional nonchemical controls for diseases were available for the organic systems.

Relying on crop rotation as the only alternative nonchemical pest control is a conservative approach for both crops because, in fact, several additional nonchemical pest control technologies are available for use against pests of both maize and potatoes (Pimentel et al., 1991). These include: host plant resistance; planting short-season varieties; time of planting; density of plantings; and trap crops.

About 20% more labor was needed in the organic farming systems to transport and apply the cattle manure and to cultivate for weed control than was needed in the conventional system (Pimentel, 1990).

Organic and Conventional Maize Production

For the analysis of maize produced under organic and conventional agricultural production technologies, energy, labor, yield data, and economics were based on average U.S. maize production (Table 1). In addition, for organic maize production, the technologies examined were the use of livestock manure, natural mineral P and K, and use of crop rotations.

Table 1

Energy and economic inputs per hectare for conventional and organic maize production systems

	Conventional			Organic		
	Qty.	10^3 kcal	Economic	Qty.	10^3 kcal	Economic
Labor (h)	10[a]	7[f]	50[r]	12[cc]	9[f]	60[r]
Machinery (kg)	55[b]	1,485[g]	91[s]	55	1,485[g]	75[s]
Fuel (L)	115[b]	1,255[h]	58[t]	135[dd]	1,472[h]	67[t]
N (kg)	152[b]	3,192[i]	81[u]	(27t)[ee]	559[kk]	26[ll]
P (kg)	75[b]	473[j]	53[v]	34[ff]	214[j]	17[v]
K (kg)	96[b]	240[k]	26[w]	15[gg]	38[k]	4[w]
Limestone (kg)	426[b]	134[l]	64[x]	426[hh]	134[l]	64[x]
Corn Seeds (kg)	21[b]	520[m]	45[y]	21[b,ii]	520[m]	45[y]
Insecticides (kg)	1.5[c]	150[n]	15[z]	0	0	0
Herbicides (kg)	2[c]	200[n]	20[z]	0[jj]	0	0
Electricity (10^3 kcal)	100[b]	100[o]	8[aa]	100[b]	100[o]	8[aa]
Transport (kg)	322[d]	89[p]	32[bb]	190[d]	53[p]	19[bb]
Total		7,845	$543		4,584	$385
Yield (kg)	7,000[e]	24,746[q]		7,650	27,044[q]	
Output/input ratio		3.21			5.90	

Sources

[a] Labor input was estimated to be 10 h because of the extra time required for tillage and cultivation compared with no-till, which required 7 h (USDA, 1984).

[b] Pimentel and Wen (1990).

[c] Mueller et al. (1985).

[d] Transport of machinery, fuel, and nitrogen fertilizer (Pimentel and Wen, 1990).

[e] Three-year running average yield (USDA, 1989).

[f] Food energy consumed per laborer per day was assumed to be 3,500 kcal.

[g] The energy input per kilogram of steel in tools and other machinery was 18,500 kcal (Doering, 1980) plus 46% added input (Fluck and Baird, 1980) for repairs.

[h] Fuel includes a combination of gasoline and diesel. A liter of gasoline and diesel fuel were calculated to contain 10,000 and 11,400 kcal, respectively (Pimentel, 1980). Weighted average value of 10,900 used in calculations. These values include the energy input for mining and refining.

[i] Nitrogen = 21,000 kcal/kg (Dovring and McDowell, 1980).

[j] Phosphorus = 6,300 kcal/kg (Dovring and McDowell, 1980).

[k] Potassium = 2,500 kcal/kg (Dovring and McDowell, 1980).

[l] Limestone = 315 kcal/kg (Terhune, 1980).

[m] Hybrid seed = 24,750 kcal/kg (Heichel, 1980).

[n] Energy input for insecticides and herbicides was calculated to be 100,000 kcal/kg (Pimentel 1980).

[o] Includes energy input required to produce the electricity.

[p] For the goods transported to the farm, an input of 275 kcal/kg was included (Pimentel, 1980).

[q] A kilogram of corn was calculated to have 4,000 kcal.

[r] Labor = $5/h.

[s] (USDA, 1984)

[t] Liter = $0.50

[u] Nitrogen = $0.53.

[v] Phosphorus = $0.51.

[w] Potassium = $0.27

[x] Limestone = $0.15.

[y] (USDA, 1984)

[z] Insecticide and herbicide treatments = $10/kg for both the material and application costs.

[aa] kwh = $0.07.

[bb] Transport = $0.10/kg.

[cc] Five additional hours were necessary for collecting and spreading 27 t of manure (Pimentel, 1980).

[dd] 20 L more fuel for mechanical cultivation.

[ee] A total of 27 t of cattle manure was applied to provide 152 kg of N.

[ff] A total of 41 kg of P was provided by the manure.

[gg] A total of 81 kg of K was provided by the manure.

[hh] Assumed that same amount of N, P, K, and Ca required in no-till.

[ii] About 10 kg of cover crop seeds were used (Heichel, 1980).

[jj] No herbicide used, weed control carried out by cultivation and rotation.

[kk] About 1.9 L of fuel was required to collect and apply 1 t of manure (Pimentel et al., 1984).

[ll] The value of manure was given for the fuel required to transport and spread.

The yield of maize grown by conventional (continuous) technology was 7,000 kg/ha (USDA, 1989), with a fossil energy input of 7,845 million kcal and labor input of 10 h/ha (Table 1). Thus, the energy production ratio, i.e., the ratio of kcal output of maize/kcal input, was 3.21 and the labor productivity was 700 kg maize/h of labor. The cost of producing a kilogram of maize was $0.08.

The maize grown organically was assumed to be planted after soybeans so that rootworm pest was not a problem. However, no credit was given for the N carryover from soybeans to maize. By using crop rotation without insecticides, crop losses to insects were assumed to be 3.5% in contrast to 12% for conventionally grown corn (USDA, 1965; Pimentel et al., 1991).

Although at present 96% of U.S. maize acreage is treated with herbicides, 91% of the maize acreage also receives mechanical cultivation for weed control (Duffy, 1982; Schweizer, 1989). Weed and disease losses were assumed to be the same for both organic and conventional maize production (Pimentel et al., 1991). For organic production, herbicide use was replaced by two additional cultivations, with a labor input of 1 h/ha, and an energy input of 5 L of fuel/ha per cultivation for a total of 91,300 kcal.

Raising organic maize using cattle manure as the major source of nutrients is calculated to produce 7,650 kg/ha of maize with an energy input of 4,584 million kcal and labor input of 12 h/ha (Table 1). The higher yield of maize under organic production compared with conventional production was due to more effective pest control with crop rotations than with insecticides (Pimentel et al., 1991). Thus, with a higher yield and lower energy input, the energy production ratio is 5.90 or 184% higher than that of conventional maize production. However, the labor productivity was 638 kg maize per hour of labor, or 9% less than conventional maize production. Overall, the production cost of organic maize was $0.05/kg or 38% lower than conventional maize.

In summary, the organic production of maize resulted in a higher yield, lower fossil energy input, and overall lower costs of production. However, with 20% more labor expended, less maize was produced per labor-hour of input compared with conventional production. Considering all the factors, there are some advantages to the production of organic maize compared with conventional maize production.

Organic and Conventional Potato Production

The yield of potatoes grown employing conventional U.S. agricultural technology was 30,000 kg/ha, with a fossil energy input of 18,420 million kcal/ha and a labor input of 35 h/ha (Table 2). This resulted in an energy output/input ratio of 1.06 and a labor productivity of 857 kg/h. The cost of production was $0.06/kg of potato.

Synthetic insecticides, fungicides, and herbicides were not used in the organic production of potatoes (Table 2). For organic potato production, synthetic fertilizers were replaced with cattle manure and mineral P and K. For alternative weed control, it was assumed that 2 additional tractor cultivations were made, requiring an additional 10 L of fuel/ha.

Table 2

Energy and economic inputs per hectare for conventional and organic potato production systems

	Conventional			Organic		
	Qty.	10^3 kcal	Economic	Qty.	10^3 kcal	Economic
Labor (h)	35[a]	25[c]	175[m]	42[u]	29[c]	210[m]
Machinery (kg)	14[a]	378[d]	23[i]	14[dd]	378[d]	23[i]
Fuel (L)	413[a]	4,502[e]	207[n]	423[v]	4,610[e]	207[n]
N (kg)	229[a]	4,809[f]	122[o]	(41t)[w]	849[aa]	39[bb]
P (kg)	390[a]	1,170[g]	276[p]	328[x]	984[g]	232[p]
K (kg)	222[a]	355[h]	60[q]	99[y]	158[h]	27[q]
Seed (kg)	2,134[a]	1,309[i]	512[i]	2,134[b]	1,309[i]	512[i]
Cover crop seeds (kg)	—	—	—	—	—	—
Insecticides (kg)	31.4[a]	2,678[j]	310[r]	0	0	0
Herbicides (kg)	18[a]	1,798[j]	180[r]	0[z]	0	0
Electricity (10^3 kcal)	131[a]	131[a]	10[s]	100[cc]	100[cc]	8
Transport (kg)	656[a]	181[k]	66[t]	427[a]	118[k]	43[c]
Total		17,336	$1,941		8,535	$1,301
Yield (kg)	30,000[b]	18,420[l]		15,000[dd]	9,210[l]	
Output/input ratio		1.06			1.08	

Sources

[a] Pimentel and Pimentel (1979).

[b] USDA (1989).

[c] Food energy consumed per laborer per day was assumed to be 3,500 kcal.

[d] The energy input per kilogram of steel in tools and other machinery was 18,500 kcal (Doering, 1980) plus 46% added input (Fluck and Baird, 1980) for repairs.

[e] Fuel includes a combination of gasoline and diesel. A liter of gasoline and diesel fuel were calculated to contain 10,000 and 11,400 kcal, respectively (Pimentel, 1980). Weighted average value of 10,900 used in calculations. These values include the energy input for mining and refining.

[f] Nitrogen = 21,000 kcal/kg (Dovring and McDowell, 1980).

[g] Phosphorus = 6,300 kcal/kg (Dovring and McDowell, 1980).

[h] Potassium = 2,500 kcal/kg (Dovring and McDowell, 1980).

[i] Estimated.

[j] Energy input for insecticides and herbicides was calculated to be 100,000 kcal/kg (Pimentel, 1980).

[k] For the goods transported to the farm, an input of 275 kcal/kg was included (Pimentel, 1980).

[l] A kilogram of potato was calculated to have 614 kcal.

[m] Labor = $5/hr.

[n] Liter = $0.50.

[o] Nitrogen = $0.53.

[p] Phosphorus = $0.51.

[q] Potassium = $0.27.

[r] Insecticide and herbicide treatments = $10/kg for both the material and application costs.

[s] kw/h = $0.07

[t] Transport = $0.10/kg.

[u] Seven additional hours were necessary for collecting and spreading 27 t of manure and cultivation (Pimentel et al., 1984).

[v] 20 L more fuel for mechanical cultivation.

[w] A total of 41 t of cattle manure was applied to provide 229 kg of N.

[x] A total of 62 kg of P was provided by the manure.

[y] A total of 123 kg of K was provided by the manure.

[z] No herbicide used; weed control carried out by cultivation and rotation.

[aa] About 1.9 L of fuel was required to collect and apply 1 t of manure (Pimentel et al., 1984).

[bb] The value of manure was given for the fuel required to transport and spread.

[cc] Less electricity was used because of fewer inputs and 50% lower yield.

[dd] See text.

The potatoes were assumed to be grown in rotation, providing some control of the Colorado potato beetle and a reduction of the plant pathogen and weed problems. However, based on published data, crop rotations are generally ineffective for control of the major insects and diseases of potatoes. Thus, without pesticides, insect losses were estimated to be 20% and disease losses 30% (Oelhaf, 1978; Pimentel et al., 1991). Although these losses are not necessarily additive, the 50% loss figure does agree with the data of Oelhaf (1978). Thus, it was assumed that total yields of organically produced potatoes were one-half those of conventionally produced potatoes (Table 2).

Based on the diminished yields, raising organic potatoes using cattle manure produced only 15,000 kg/ha of potatoes with an energy input of 8,535 million kcal/ha and labor input of 42 h/ha (Table 2). The energy output/input ratio for organic potatoes was 1.08 or 2% better than conventional potato production. However, the yield of potatoes per labor hour was only 357 kg/h or 58% poorer than the conventional system. The cost of production was $0.09/kg or 50% higher than conventional potato production (Table 2).

In summary, the assumed 50% losses caused by insects and plant pathogens in organic potato production lowered yield per labor hour compared with the conventional system. In addition, the total cost per kilogram of potatoes was significantly higher than conventional production. Interestingly, the overall energy output/input ratios were similar because the fossil energy inputs in the organic system were about half those of the conventional system.

Conclusion

The organic production of grains, such as maize, requires less fossil energy than conventional crop production. For some crops, the organic production system may also produce higher crop yields, as demonstrated with the organic maize system. Under organic conditions, however, crop production per unit of labor can be expected to be lower than crop production in conventional systems.

However, yields of other crops, such as vegetables and fruits, under organic production may be substantially reduced because pests cannot always be effectively controlled by nonchemical means. For instance, the available data on organic potato production suggest a 50% higher loss to insects and diseases than conventional potato production.

If the judicious use of agrochemicals is included in the definition of organic, then it would be entirely possible to maintain similarly high yields of fruit and vegetable crops as obtained in conventional systems but with significantly reduced commercial fertilizer and pesticide inputs (Pimentel et al., 1989, 1991). With fewer fossil energy and other inputs and employing environmentally sound technologies, agricultural systems can be made more sustainable. At the same time, farmers can maintain high yields and realize greater profits. Combining low inputs with environmentally sound technologies clearly requires that farmers have greater knowledge of the management strategies used in the agroecosystem than farmers who employ the more simplistic heavy-chemical use systems (NAS, 1989). For this reason those countries that have active plans to reduce pesticides and commercial fertilizers in agriculture are investing heavily in research and supporting extension education.

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