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Energy in Agriculture: Lessons from the Sunshine Farm Project

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Abstract: To explore the reduction of fossil fuel use in its Sunshine Farm Project during 1991-2001, The Land Institute conducted energy accounting of its 85-ha organic farm powered by commercial biodiesel, draft horses, and a photovoltaic array. Legume crops provided nitrogen, and no nutrients were imported except some purchased feed amounting to only a few kg/ha of elemental nutrients annually. Three-fourths of the consumed animal feed was produced on the Sunshine Farm for a team of draft horses, beef cattle, and poultry. The proportion of cropland area planted in legumes was 40%, of which one-fourth was green manure, and the other three-fourths were also devoted to feed, marketed products, and oil for biodiesel. About 34 and 26% of the cropland was devoted to feed and marketed products, respectively. Based on published process energy values for farm inputs, the Sunshine Farm could meet 90% of the embodied energy in its yearly inputs through leguminous nitrogen fixation, animal feed, oilseeds for biodiesel, and electricity from its array. If the embodied energy in amortized capital such as farm equipment, vehicles, physical facilities, and the photovoltaic array is included with the yearly inputs, then half of the overall embodied energy was provided by the farm. On a net energy basis including oilseed production, processing, and meal cake credit, 30% of the cropland area was devoted to soybeans and sunflowers for biodiesel fuel that could be commercially produced to power the field operations and off-farm transportation. The ratio of gross energy content in marketed products to embodied energy in purchased inputs and capital was 2.4. Inclusion of lifestyle support energy for average American rural labor dropped this ratio to 1.5, and for austere Amish labor, 2.0.

1. INTRODUCTION

Food security dictates that the dependence of farming on fossil fuels should be reduced by substitution of on-farm resources for commercial farm inputs and by adoption of renewable energy technologies. Energy analyses related to this endeavor have shown in various countries that organic production generally requires less energy than conventional production for crops [1,2] and dairy farms [3-5]. The same was also found to be true for organic treatments compared to conventional ones in long-term cropping experiments [6-9]. Energy consumption per hectare was less on mixed crop and livestock farms in six Amish communities compared to nearby conventional production [10,11]. Amish farms are biologically integrated because of their use of draft horses and livestock manure, but they often employ stationary tractors to run threshing machines and generators for milking equipment.

At least several national programs have been conducted on a small group of energy-integrated farm systems, but with little energy analysis of the overall systems. The US Dept. of Energy conducted its Energy Integrated Farm System program during 1980-1987 with biogas digesters on six swine and dairy operations and a fluidized-bed gasifier on a cotton farm [12]. Design requirements and economic performance were reported for the technologies and some farms, but an integrated energy analysis was published for only one farm, which showed that energy conservation practices and alternative fuel sources should reduce fossil fuel input into this farm by 60-70% [13]. Some of the farms were able to reduce their annual purchased energy requirements by 20-60% [12]. The other national program of energy-integrated farm systems was initiated in the early 1980s by EMBRAPA, the agricultural research system in Brazil [14]. Pilot demonstration projects were set up at eight research centers, employing biogas digesters, gasifiers, small ethanol stills, and alternative energy crops, but there appears to have been no reported energy analysis.

To explore the reduction of fossil fuel use in farming, The Land Institute conducted its Sunshine Farm Project during 1991-2001. A feasibility study was done during the first year to integrate the cropping system, animal production practices, and power sources with respect to demands for crop nitrogen, animal feed, biodiesel fuel, and electricity. The amount of fuel, materials, and labor were recorded during the next nine years for every farm task and for farm capital in order to construct energy budgets for the crops, animals, power sources, and the farm.

2. METHODS

2.1 Farm and power sources

The mixed crop and livestock research farm was located near Salina, Kansas (N 38°52'30", W 97°35'30") with its cropland on level, coarse-silty Fluventic Haplustoll soil. The animal enterprises were small-scale production of broilers and eggs and short-rotation grazing of a cow-calf herd of Texas longhorn beef cattle on 65 ha of mostly native pasture. Unirrigated, organic crops were grown on 20 ha in narrow crop strips with different entry points in some five-year crop rotations. To fix nitrogen, about 40% of the cropland was in legumes, of which one-fourth was green manure and three-fourths, forage and soybeans. No phosphorus or potassium was imported except a few kg per ha of cropland annually in the form of manure from some purchased feed. The three nutrients were adequate as indicated by soil tests and plant tissue analysis conducted by the Kansas State University Soil Testing Laboratory. Yields of wheat, oats, soybeans, alfalfa, and sweet sorghum averaged over 1993-2001 were comparable to conventional dryland yields averaged over the same years [15], but not grain sorghum and sunflowers as a result of weed pressure and seed predation by birds, respectively (Student's t-test, $P<0.05$).

A 4.5-kilowatt photovoltaic array provided electricity for workshop tools, electric fencing, water pumping, and farmhouse. Traction was provided by a pair of 450-kg Percheron draft horses and a 50-kw (70-hp) direct-injection diesel tractor run on biodiesel, namely purchased soybean methyl ester fuel. In the analysis, we assumed that the biodiesel was a 50:50 mixture of soybean and sunflower methyl esters on a gross energy basis, with the oil mechanically presumably extracted by a local farmers' co-operative in efficiencies of 50 and 75%, respectively [16,17]. We ignored our use of some purchased high-protein feeds and assumed that we would have fed byproduct meal cake from the co-operative, but still owned by the farm.

Although soybeans have a low oil yield, we did not consider biodiesel consisting solely of sunflower, rapeseed, or canola methyl ester because of agronomic limitations specific to the US. Future expansion of organic production of sunflowers will be severely limited by insect pests and diseases associated with its weedy ancestor, *Helianthus annuus*, widespread in the US. Rapeseed and canola have been introduced to the eastern and central US only in the past several decades and will require genetic breeding and selection to overcome problems such as pests and diseases, winterkill, vulnerability to drought, uneven maturity, and excessive shattering [18-20].

2.2 Energy analysis
Embodied energy of farm inputs was based on weight-based process energy values [21], except dollar-based energy intensities for electronic materials [22] and medicines [23]. Process energy values for metal products were increased 25% to include energy used in fabrication [24, 25]. Energy budgets included fuel to deliver farm inputs from factories to dealers, based on national statistics for transportation of freight [26]. Primary energy displaced by electricity from the array was 10.55 MJ (10,000 Btu) per kWh [27].

Embodied energy of purchased vehicles and farm machinery was determined according to Doering [28]. Embodied energy of facilities constructed on the farm was obtained from our energy budgets. Next, embodied energy in a purchased or constructed capital item was amortized over its estimated lifetime to obtain an annual value that was prorated among its uses within a given year on the farm in our annual energy budgets.

Process energy values for purchased livestock, feed, and seed were national or Midwestern estimates [26, 29]. For feed or animal breeding replacements produced on our farm, the embodied energy was determined from our energy budgets. Energy requirement was 75 and 25 MJ per hour for human labor as a portion of the average lifestyle support energy in the US and in Amish communities, respectively [11, 30]. Gross energy content of farm outputs was based on the following sources: crops [31], beef [32, 33], and broilers and eggs [34].

3. RESULTS AND DISCUSSION

About 90% of the embodied energy in annual inputs not counting capital or labor was in the form of on-farm production of inputs, the latter in the following proportions: feed, 35%; biodiesel fuel, 36%; leguminous nitrogen fixation, 24%; and electricity from the array, 5% (Table 1). The other 10% was purchased seed and phosphorus and potassium fertilizer, the latter not actually used, but simulated in the energy budget to offset nutrients removed in marketed products. Amortized capital constituted about 40% of the total embodied energy in annual and amortized inputs, not counting labor. On-farm production of inputs met only 53% of the embodied energy in annual and amortized inputs, and this dropped to 41 and 48% with the inclusion of labor as a portion of average US and Amish lifestyle support energy, respectively.

Annual production from 20 ha of cropland on the farm amounted to 1,065 GJ of gross caloric energy in the following proportions: oil for biodiesel, 8%; fed meal, 4%; marketed meal, 22%; fed crops, 34%; marketed crops, 19%; and green manure legumes, 13%, the latter not harvested (Table 2). In other words, almost 85% of the byproduct meal was marketed, and of the crops fed or marketed, nearly two-thirds were fed. The following proportions of cropland area devoted to this production were fairly similar to the respective proportions in gross energy: biodiesel and byproduct meal, 30%; feed, 34%; marketed crops, 26%; and green manure legumes, 10%.

The Sunshine Farm is compared with other mixed farms in terms of outputs relative to inputs. If a boundary is drawn around the farm, then marketed outputs should be compared with purchased inputs. The farm sold 440 GJ of marketed meal and crops, or 22 GJ per ha of cropland, very much greater than most mixed crop and livestock farms (Table 3). The reason for the great difference is that these farms feed most of their crops, but the Sunshine Farm could feed only 15% of the byproduct meal from its substantial biodiesel output and thus sold the remainder (Table 2). The only exception to this pattern was the large crop output in the group of conventional Illinois farms for which crops constituted nearly 60% of the gross energy in marketed outputs (Table 3).

In addition to the marketed meal and crops from the Sunshine Farm, the 19 GJ in animal products and the primary-energy equivalent of 42 GJ in marketed electricity resulted in a total 501 GJ of marketed outputs, or 25 GJ per ha of cropland, not as different from the other mixed farms as when crops alone were compared (Table 3). The reason for the less pronounced difference is that crops made up almost 90% of the gross energy in marketed outputs on the Sunshine Farm, but only 14-29% on the other farms, except for the group of conventional Illinois farms (Table 3). In other words, much greater animal production on the other farms brought them closer to the Sunshine Farm in total marketed outputs.

Gross energy in marketed outputs on the Sunshine Farm was 2.4, 2.0, and 1.5 times the embodied energy in purchased inputs, including no labor, Amish-supported labor, and US-supported labor (Table 3). The former energy ratio is the one most appropriate for comparison to the other mixed farms because they contain charges for human labor that are small as a result of considering only food consumption instead of lifestyle support energy. This ratio of 2.4 is greater than the energy ratios for most of the other mixed farms for two reasons. First, the purchased inputs per ha for the Sunshine Farm are less than the values for all conventional farms and some Amish farms in Table 3 despite the fact that purchased inputs included all amortized capital on the Sunshine Farm but only equipment, machinery, and sometimes building repair for the other farms. Second, proportionally less crops, including meal from the oilseeds, were fed on the Sunshine Farm than the other farms, thus incurring less energy losses in animal metabolism and allowing greater marketed output (Table 3). The greater energy ratio for the Sunshine Farm was not a result of the photovoltaic array since its energy ratio was only 1.6, i.e., (11+42)÷34 (Table 1, and 42 GJ noted above). These results are corroborated in 15 hypothetical farm energy budgets computed by Leach [35], in which larger farm energy ratios were clearly associated with fewer purchased inputs and greater proportion of outputs arising from crops. For the same two reasons, national agricultural energy ratios are generally higher in less developed countries than industrialized nations that can afford energy-intensive inputs and diets based heavily on animal products [36].

It will be a challenge to provide society with considerable energy from agriculture, let alone food, since the energy returns for various energy technologies have generally been greater than the above ratios for mixed crop and livestock farms. Fossil fuels usually have ratios in the range of 10-30, and solar and wind technologies, typically 3-10, but renewable liquid or gaseous fuels from agricultural production, mostly 5 or less [37, 38]. Solar and wind technologies have greater power densities than energy crops and thus require less land area [24]. Although the US exports one-fourth of its grain production [39], diversion of this grain for conversion into useful energy would meet less than one-half of the embodied energy in annual farm inputs used by US agriculture [40].

Energy ratios in agricultural production could be raised by reducing purchased inputs and by increasing marketed outputs. However, in a future era of resources declining in quantity and quality, the latter will be achieved less by increased yields than by diverting cropland from supplemental animal feed to crops for direct human consumption. The infrastructure and research needed to develop an agriculture based on renewable power sources should be established now while we have the luxury of high energy ratios from fossil fuels.

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