American Journal of Alternative Agriculture, Volume 16, Number 1, 2001, pp. 2-15.

An Economic Comparison of Traditional and Conventional Agricultural Systems at a County Level: Appendices and Expanded References

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Appendix A - Supplemental feed and harvested crop production

Production of harvested crops in corn-equivalent feed units (CFU) was compared with consumption of supplemental feed by cattle, swine, sheep and poultry in Ohio counties, Ohio, and the US in 1997 and 1920 (Table 1). CFU is the substitution value of feeds for corn (13.5% moisture), or corn-equivalent weight per unit weight of feed, as determined in feeding trials (Hodges, 1964). The accuracy of the method below was tested on a national scale with a calculation of 488 million t CFU consumed in 1992 based on marketed and inventoried animals reported by USDA (1994b), only 10% larger than the 442 million t CFU reported by USDA (1996a) for that year.

Calculations for crops and animals were based on the convenient table of county summary highlights in the federal agricultural census (USDA, 1999a). The table lists only six or seven major crops, which vary according to the state containing the reported counties. Nonetheless, the short list closely approximates the total crop production because it covers most of the cropland acreage that is not idle or used solely for pasture (e.g., nearly 100% in Holmes and Wayne counties and 98% for Ohio). In the case of Ohio, the total crop production in each county was obtained from the air-dry harvest in the list and the CFU factor (Hodges, 1964, in parentheses) for corn (1.0), wheat (1.05), oats (0.9), soybeans (1.7), and all hay including small grain hay and grass silage or green chop (0.5) except corn silage and green chop in fresh weight (0.15). The total in 1997 was 150 and 370 million kg CFU in Holmes and Wayne counties, respectively. Across the 35,600 and 72,000 ha of cropland devoted to these crops in the respective counties, this averaged 4.3 and 5.1 t CFU/ha (Table 1).

The same table provides the Dec. 31 inventory of milk cows, beef cows, swine, sheep and lambs, and layers and 13-week pullets or older. Number of bulls were calculated as 5 percent of milk and beef cow inventory, and sows and boars as 11 and 2 percent of the swine inventory, respectively (USDA, 1996a). Since the national feed consumption (including pasture) by sheep is small compared to other animals, little error is introduced by assuming that rams, ewes, and other sheep and lambs have the same average consumption per head, the sole feed amount reported by USDA (1996a) for sheep. The breeding populations for poultry are negligible due to the large annual number of progeny per hen. The table also contains the marketed number of cattle and calves, swine, and broilers.

Average kg CFU per head (includes pasture) in a year's time, or less than two months in the case of broilers, are: sheep or lamb, 590; layer or pullet, 59; broiler, 5.2; milk cow, 5,900; and other dairy and all beef cattle, 2,700 (USDA, 1996a). Calculations based on data reported by Crampton and Harris (1969) show the kg CFU per head to be 1,800 for sows and 900 for boars in a year's time, and 680 for 105-kg pigs marketed six months or less after birth (market weight from USDA, 1996a).

Total feed for a regional or national cattle population in this method is a full year's feed for the cows, bulls, and marketed cattle and calves. Since marketed cattle includes culled cows and bulls, the Dec. 31 inventory of cows and bulls in the federal census includes the replacement heifers and bulls so that it represents the full breeding population for the next year. The number of replacement and culled individuals are not reported in the federal census and do not need to be known anyway. This is because they are about equal for the populations concerned, thus resulting in feed imbalances that roughly cancel out when the above rates of 2,700 and 5,900 kg per head, respectively, are applied to the categories of marketed cattle and dairy cows that do include culled and replacement cows. Also, the partial year of feed for weaned calves is included in the full year's feed for marketed yearlings because the latter live for only part of a year. This is a result of the facts that the period from weaning to market is approximately one year and that a large cattle population has a roughly stable age distribution.

Similar logic applies to swine, with offsetting feed imbalances between the categories of marketed pigs and breeding population (the Dec. 31 inventory of sows and boars). This is a result of culled and replacement individuals in the two categories and the different feeding rates for sows, boars, and marketed pigs, with a full year's feed for the latter being the above six months or less. With a roughly stable age distribution for regional or national populations, the calculated feed will apply to the surveyed swine population despite having some litters born in the latter part of one calendar year and marketed in the early part of the next calendar year, one of them being the surveyed year. Calculations are not altered by the inclusion of replacement sows in the category of sows. This is because replacement sows generally give birth to their first litter in about a year after their own birth, a duration in concordance with annual census.

By this method, animal consumption of supplemental feed and grazed pasture forage in Holmes and Wayne counties in 1997 was 350 and 510 million kg CFU, respectively. In the former county, cattle, swine and poultry accounted for 51, 26 and 23%, and in the latter, 67, 20 and 13%, while sheep were negligible. Then, an average consumption of 4.5 t/ha (2.0 tons/acre) of air-dry forage was assumed for all pasture including grazed woodland and cropland used only for pasture (USDA, 1999a). Subtraction of the resulting pasture production left the consumption of supplemental feed as 310 and 480 million kg CFU in the respective counties, or an average of 8.8 and 6.7 t CFU per ha of cropland indicated above for the crops. Hence, supplemental feed was 2.0 and 1.3 times harvested crop production (almost all feed) in Holmes and Wayne counties, respectively (Table 1). Similar calculations were done for Ohio from the first column in the table on county summary highlights in the federal census.

Calculations for the above crops plus rye, barley, and grain sorghum show that harvested crop production in the US for 1997 was 540 million t CFU (USDA, 1996a), or 5.1 t CFU/ha across 107 million ha of cropland devoted to these crops (Table 1). Domestic supplemental feed was reported as 295 million t CFU (USDA, 1996a), or 2.8 t CFU/ha over the same harvested cropland (Table 1). Likewise, harvested crop production in the nation during 1920 was 170 million t CFU for the above crops with the exception of very little soybean acreage (USDA, 1922; USBC, 1960). This was a yield of 1.5 t CFU/ha on the 115 million ha of cropland for these crops (Table 1). Domestic supplemental feed at that time was 104 million t CFU (Jennings, 1949), which was an average of 0.90 t CFU/ha over the same cropland (Table 1).

Appendix B - Number of horses and mules relative to cropland area

The average number of horses and mules owned per given area of cropland was compared between Amish agriculture in Holmes County during 1997 and US agriculture in 1920. In the former situation, there were 7,050 horses on 850 farms (USDA, 1999a), mostly Amish since about half of the 1,400 farms in Holmes County are Amish (pers. comm., Dean Slates, OSU Extension Service, Millersberg, Ohio). Amish farms studied by Craumer (1977) in central Pennsylvania averaged 22 ha of cropland, which can also be assumed for the farms in Holmes County. This is because the mean size of 39 ha for the Pennsylvania farms was found to be consistent with farm sizes in Holmes, Wayne, and surrounding Ohio counties (see results section on conventional charge for Amish labor). With the above facts, the assumed cropland area would imply an ownership of 38 horses per 100 ha of cropland on Amish farms in Holmes County (Table 2).

Nationally in 1920, there were 25.7 million work and replacement stock, the latter younger than the working age of 2 (USBC, 1960). Almost all fieldwork and off-farm hauling was done with work stock because only 3.6 and 2.0% of US farms had tractors and trucks at that time, respectively (USDA, 1922). From an annual data series maintained since 1910, Anderson et al. (1957) reported that 22% of US cropland acreage in 1920 was devoted to feed for horses and mules on farms and 3% for those in cities and mines. Since the latter received more grain and hay per head than the former due to less pasture (Anderson et al., 1957), this implies that about 10% of the nation's horses and mules were in cities and mines, leaving 90% on farms, or nearly 23 million work and replacement stock. Across 151 million ha of cropland harvested, failed, and fallowed in the US during 1920 (Anderson et al., 1957), this was an average of 15 head owned per 100 ha (Table 2).

The cropland harvested, failed, fallowed, and in the Conservation Reserve Program during 1997 in the US was 147 million ha, slightly less than the above figure for 1920 and used often in Apps. C and D. Hence, this area could be farmed with the same national population of 23 million horses and mules as in 1920, if there were appropriate field implements, manageable farm sizes, and nearby markets and grain elevators. This gives an average ownership of 16 head per 100 ha of cropland (Table 2).

Appendix C - Cropland requirement for horse and mule feed

In terms of feed demand, the 23 million work and replacement stock required for the current US cropland area (App. B) are almost equivalent to 23 million work stock. This is because each replacement horse is roughly equivalent to a work horse if the feed requirement of the former also includes the indirect feed consumption of the brood mare for bearing and nursing the replacement foal (Morrison, 1950, pp. 924-929).

Annual supplemental feed for a work horse typically consists of 1,300 kg corn grain, 1,600 kg alfalfa, and 500 kg harvested roughage (Anderson et al., 1957; Jasny, 1938). National yields for corn grain and alfalfa during the past decade were 7.7 t/ha (123 bu/ac) and 7.3 t/ha (3.3 tons/ac), respectively (USDA, 1999c). With no additional land for roughage from corn stubble, the crop yields imply 0.39 ha of corn and alfalfa for one work horse. Hence, the 23 million horses and mules would thus require 9.0 million ha of feed, or 6% of US cropland. This would increase to 7% if the roughage were instead obtained from cereal hay at 7.5 t/ha. Based on the crop yields and gross energy contents (Crampton and Harris, 1969), the weighted gross energy yield of the grain, stubble, and alfalfa is 146 GJ/ha. Also, corn and alfalfa are an adequate supplemental diet for horses and mules (Morrison, 1950). Hence, unless ethanol was also made from oats, it would be unfair to insist that work stock be fed oats, which requires more cropland due to its national yield being less than 30% of corn yield (USDA, 1999c).

To derive the supplemental feed entirely from cropland, power must be produced from crops to meet the energy required for factory manufacture of the farm inputs in feed production, otherwise known as embodied energy. In other words, this would put feed on a net energy basis in which the devoted cropland is split between feed and its production inputs, similar to net energy in ethanol production (App. D). While there are various crop-based energy sources that could power the inputs, corn-based ethanol is chosen because the mechanical traction in our comparison is powered by it (App. D).

Since our comparison is in terms of cropland requirements, the above 6% of US cropland must be increased by the land area of corn-based ethanol required for the embodied energy of the feed inputs. The inputs in conventional feed production must be decreased for displacement of all traction fuel and self-propelled machinery by the 23 million horses and mules. The embodied energy (GJ/ha) of the adjusted inputs is: corn, 16.2; alfalfa, 8.8; and harvest of corn stubble, 0.9 (Table 3). Based on the above annual supplemental feed and crop yields, this gives a weighted requirement of 12.4 GJ/ha, or 112 million GJ of embodied energy in the inputs for producing 9 million ha of feed.

Return of manure from the 23 million horses and mules is credited according to the embodied energy of the nitrogen, phosphate and potash fertilizer thus displaced. This was computed from embodied energy factors for the fertilizers in the USDA review of ethanol production that App. D is based on. The credit was also based on 9 t of fresh manure annually per horse, containing 6.3 kg nitrogen, 2.1 kg phosphate, and 6.5 kg potash per tonne (Ensminger, 1991). It was assumed that only 20% of the manure is returned to cropland in droppings and field applications, both with subsequent nutrient losses of 50%. The calculated manure credit of 8 million GJ leaves 104 million GJ of embodied energy in the inputs for 9 million ha of feed, or 11.6 GJ/ha.

Next, the land area devoted to corn-based ethanol for this embodied energy must be calculated by means of the net ethanol yield, again traction-powered by horses and mules. In the USDA review of ethanol, the net ethanol yield is 8.9 GJ/ha (App. D). For horse-driven corn production, this must be increased by 4.3 and 1.1 GJ/ha, respectively, for displacement of fuel and machinery (Table 3). Likewise, the above manure credit of 8 million GJ across 9 million ha represents an increase of 0.9 GJ/ha in net ethanol yield.

The net ethanol yield including the three modifications becomes 15.2 GJ/ha. Hence, the 104 million GJ of embodied energy in inputs for horse feed production requires 7 million ha of corn grain devoted to net ethanol. As a result, the supplemental feed for 23 million horses and mules would require a total of 9 + 7, or 16 million ha, which is 11% of US cropland on a net energy basis. From the above gross energy yield of 146 GJ/ha, the effective net energy yield of the feed is (9/16)(146), or 82 GJ/ha.

Appendix D - Cropland requirement for biofueled mechanical traction

The national cropland area needed to produce sufficient ethanol was computed for all fieldwork and transportation in US crop production, which required 763 PJ (E15 joules) of fuel in 1981 (Torgerson et al. 1987). From then until 1990, direct fuel use in US agriculture declined about one-third (Cleveland 1995) and has changed little since then (USDA, 1999c). This decline, applied to 763 PJ, suggests a current rough estimate of 500 PJ. Averaged across 147 million ha of cropland (App. B), this is 87 l/ha (9.3 gal/ac) of diesel-equivalent fuel. This appears to be a conservative estimate, compared to the value of 111 l/ha for corn given below.

In a USDA review of ethanol, Shapouri et al. (1995) found that a nine-state Midwest corn yield of 7.7 t/ha (122 bu/ac) resulted in a gross ethanol yield of 68 GJ/ha of corn land. This was based on a conversion rate of 0.375 l/kg (2.525 gal/bu) and a gross energy content of 23.4 MJ/l (84,000 Btu/gal) according to its higher heating value. Hence, 500 PJ of ethanol for all traction in US crop production would require 7.4 million ha, or 5% of US cropland.

To derive ethanol entirely from cropland, like boot-strapping, some of the ethanol must provide the energy required for factory manufacture of inputs in corn production and its processing into more ethanol. In other words, the net energy yield of ethanol is determined by decreasing its gross yield by charges for inputs in corn production and its processing into ethanol and increasing it by credits for process byproducts. In the USDA review of ethanol, the byproducts were credited by the embodied energy of protein- and oil-equivalent amounts of soybean meal and oil, respectively.

In the USDA review, the net energy content of ethanol is 3.1 MJ/l (11,100 Btu/gal), containing our inclusion of machinery input for conventional corn production (footnote d in Table 3). The latter should be included because the ethanol-based embodied energy of the two tractors, truck, and self-propelled combine (among other machinery) would be the mechanical analog of the feed requirement of the replacement stock for horses and mules (App. C). By the above corn yield and conversion rate, the net energy content translates into a net ethanol yield of 8.9 GJ/ha, which must modified as follows.

Since the ethanol would be produced specifically for traction in crop production, no further input of fuel would be required. Hence, the net ethanol yield must not include the input of 4.3 GJ/ha in traction fuel for corn production (Table 3). Otherwise, the fuel requirement for traction would be double-counted in calculations. In more familiar units, the fuel consumption averaged 111 l/ha (11.9 gal/ac) of diesel-equivalent across nine states in the Midwest, two-thirds for fieldwork and one-third for transportation (Shapouri et al., 1995).

This raises the net ethanol yield to 8.9 + 4.3, or 13.2 GJ/ha, corresponding to a net energy content of 4.6 MJ/l (16,500 Btu/gal). Thus, 500 PJ of ethanol for all traction in US crop production would then require 38 million ha, or 26% of US cropland. This effectively results in 30.6 million ha for inputs and byproduct credits, in addition to the 7.4 million ha for all traction in US crop production.

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