

Fields of Barley, Fields of Gold: Material Intensity in Agriculture

*If heaven was a pie it would be cherry
Cool and sweet and heavy on your tongue
And just one bite would satisfy your hunger
And there'd always be enough for everyone*
Gretchen Peters – 'If Heaven'ⁱ

Agriculture for food and fiber represents another significant category of environmental impact. Before we worry about how to farm, we should consider how much agriculture we need. If you read the technical news, when this subject comes up, it always discusses how to increase food production for a hungry world.

This is completely misleading. If you look at the total food produced world wide, there is enough food produced (including meat and fish) worldwide not just to feed everyone on earth, not just to make everyone fat, but to make everybody morbidly obese. Counting grain, beans, roots, fruits, vegetables, nuts and other plants and fungi (not including animal feed), plus livestock, dairy, fish, eggs and other animal products raised for human consumption we produced nearly 2,800 calories per person per year in 2001⁵² - including 75 grams of protein. 2,200 calories per day are generally accepted, as the average needed to keep a person healthy -neither losing nor gaining weight⁵³. 56 grams of protein is the U.S. RDA for adult men⁵⁴.

Many people have higher requirements than this – most grown men, pregnant and lactating women for example - as well as athletic women. (As one instance, Lucy Lawless used to perform gymnastics and horseback riding in fairly heavy armor ten or more hours per day while starring in "Xena - Warrior Princess", and probably burned 6,000+ calories daily at the peak of her schedule.) Children, and median height adult women mostly need less. Below 2,200 calories, and 56 grams on average is considered an absolute shortage; if we allow a comfort and safety margin that would mean we want at least 2,300 calories on average per person available worldwide.

How big an increase do we need to keep up with population growth? According to the U.S. Census⁵⁵, if you assume the same production with projected increases in population we will still average ~2,500 calories per person per day in 2010, ~2300 per day in 2020. Without cultivation of more acreage or an increase in production per acre, we then approach absolutely scarcity, falling to 1,900 in 2050. We need no increase in total food production before 2020, and only a 21% increase by 2050.

ⁱ "If Heaven" lyric used with permission from songwriter Gretchen Peters, and copyright holder Sony/ATV Music Publishing.

Moreover, in a sense the problem of getting that increase is solved. I'm going to suggest reasons to go beyond plain old organic farming in a moment. But it turns that even conventional organic farming could feed more people than our current industrial system⁵⁶. Normally when people measure land use for organic farming, they look at the rich nations, see that rich nations on average can grow less per acre via organic means than with conventional ones. (It turns out that the difference is smaller than we thought, though - about 20 %.) However, it is a different story in the developing nations. According the Brian Halweil in World Watch Magazine:

...scientists from the University ofMichigan tried to estimate how much food could be raised following a global shift to organic farming. The team combed through the literature for any and all studies comparing crop yields on organic farms with those on nonorganic farms. Based on 293 examples, they came up with a global dataset of yield ratios for the world's major crop for the developed and the developing world. As expected,organic farming yielded less than conventional farming in the developed world for most food categories, while studies from the developing world showed organic farming boosting yields. The team then ran two models. The first was conservative in the sense that it applied the yield ratio for the developed world to the entire planet, i.e., they assumed that every farm regardless of location would get only the lower developed-country yields. The second applied the yield ratio for the developed world to wealthy nations and the yield ratio for the developing world to those countries.

<...>

...The second model [the realistic model - Gar] yielded 4,381 calories per person per day, 75 percent greater than current availability—and a quantity that could theoretically sustain a much larger human population than is currently supported on the world's farmland.

So our problem is NOT how to massively increase food production. We need to make sure everyone has access to the plenty that already exists. Hunger in the world today is due to injustice, not shortagesⁱⁱ. That doesn't mean that injustice is the only problem with the international food system.

Current agricultural production consumes far too much water and contaminates far too many clean water sources. Water is a renewable resource, but not in unlimited quantities. If we contaminate enough of the water cycle, we will have less water available at any given moment. Future clean water does us no good when we need it in the present. If we don't drastically lower agricultural consumption and contamination of water sources, we will eventually suffer a genuine food shortage.

ⁱⁱAs confirmation, most nations with hungry people produce enough for everyone; it is just that not everyone can buy what is produced. Many hungry nations are net food exporters. And many hungry nations devote a large percentage of their agricultural land to producing coffee, flowers, and other non-food or luxury products for export; in others most farmland is owned by a few large families who keep a large portion of it out of production for purposes of real estate speculation.

Similarly, worldwide we erode topsoil every year. Again, we need to reverse this to maintain the ability to feed everybody. There are some questions about mineral sources and soil micronutrients as well.

In addition, the IPCC has pointed out some of the global warming that is already locked in will decrease food production in some of the world's poorest nations. But if we can confine the damage to less than a 2 degree centigrade warming we will actually have an overall 20% **increase**. Of course this increase won't do people in the poorer nations any good if they are not given access to this food. That is a critical problem, probably the most critical problem -- but the point is it is not a technical obstacle to feeding the world.

The technical problem is to maintain food production for the next ten+ years, then increase it slowly, while using far less water, far less energy, eroding less soil, using fewer mineral resources, and releasing fewer toxins into the water table. Conventional organic agriculture is not the limit of how we do this.

A good start would be to reverse the currently trend of destroying farmland that continues every year. This both takes the form of converting croplands to urban uses (roads, buildings and so forth) and destroying suitability of land for farming by erosion, destruction of water sources, mining, and toxic contamination.

Meat production is another example. In 2000 the U.S. used ~27%⁵⁷ of its cropland to grow grain for animal feed; the world used ~18.5% of its production for the same purpose⁵⁸. Yet it turns out that feeding grain to cattle, sheep, goats and other ruminants is not particularly healthy for them or for people who eat them. Forcing animals to spend up to half their lives confined in feedlots causes all sorts of problems. They need hormones to handle grain--far richer food than they are designed to digest. They need antibiotics to stave off the diseases that come from close confinement, and overfeeding - which creates antibiotic resistant strains of bacteria. (Meanwhile hospitals try to minimize antibiotic prescriptions for people.) This still results in occasional e-coli scares. Further, in an effort to increase weight gain, until quite recently we fed animal byproducts to cows and steers - which are really not well designed to be carnivores. This contributed to cases of mad cow in the United States, just as it did in the UK previously.

There is an alternative. Cattle evolved over a long period of time to eat grass. Even today, meat cattle are grass fed in pastures or ranges for around half their lives - and confined to feed lots only during their final months. But there are farmers out there who "grass-finish" their cattle - raise them to their final slaughter weight on plain grass, and produce healthier lower fat, better tasting beef.

Doesn't that lower the tons of beef you raise per acre? It certainly would seem logical. If you pack cattle as tightly as if already dead in steel and concrete feedlots, you can raise more cattle per acre than on pasture. But it takes land to raise the corn and grain and soybeans upon which feedlot cattle subsist. Count this, and grazed cattle have about the same production per acre as feedlot beef⁵⁹.

Will this lead to range and pasture erosion from overgrazing? It won't if we use green grazing (intensively managed rotational grazing) which has a long and honorable history. Instead of eroding pasture or range, land intensively grazed for a short time, then rested, gains topsoil and fertility - just as the Great Plains did when grazed by buffalo instead of cattle. So we can produce as much beef per acre via grazing as we can with feed-lots, without the soil erosion of conventional pasture or range, let alone that of row crops⁵⁹. (Note - we may not produce quite as many pounds of meat, since grass-fed cattle move more, and build muscle. But the protein is likely to be the same, and the taste is better.)

Grass finished beef require between a fifth and a third of the fossil fuel energy needed by feedlot cattle⁶⁰. (Substituting other ruminants - bison, beefalo, sheep and goats can reduce this further.)

How do the economics of this work out? Given an equal playing field, the costs of grass-finished beef (and milk as well) are lower than conventional ranching⁶¹.

Grass-fed beef currently sells for more than feedlot beef. Demand is high relative to supply. Because ranchers who grass-finish cattle tend to raise small herds, they don't have access to the economies of scale that larger ranchers have--facing higher transportation, slaughter and marketing costs per cow than the big guys. Also, regulations tend to favor the giants. For instance, health regulations very strictly enforce exactly what equipment is used in slaughter, whereas actual bacteria present tends not be measured. An opposite approach, one that specified results rather than the means to obtain them would give the little guy a better chance to compete, while protecting consumers better than present rules.

(In one recent case, John Stewart of Creekstone Farms Premium Beef Co., wished to test every animal his company slaughtered for mad cow disease; permission was refused out of fear that if one processor did this, others would be pressured to do the same⁶². [Note: he won his case, and gained the right to test.]

How does green grazing preserve the soil? It avoids root damage; disturbing roots disrupts the growth of key soil micro-organisms--especially the fungi that produce glomalin (one key glue that holds soil in place). Grazing seldom pulls roots; normal grazing weakens plant health by returning to the same spot too often; management intensive grazing gives plants time to heal--and thus completely preserves root structures. The difference compares to that between an annoying cousin who drops by for dinner a few times weekly, and an irritating one who stays over one holiday weekend per year, but leaves you alone the rest of time.

Just as with animal husbandry, we can grow row crops by means that don't disrupt root structure. No-till farming with crop rotation is a first step in this direction. In no-till farming, roots are left undisturbed, and any part of the crop not actually harvested is returned to the soil. This not only cultivates glomalin, but retains soil nutrients. If a legume and a green manure are both included in the rotation, no-till can completely eliminate any need for nitrogen fertilizer, and greatly reduce other fertilizers as well--usually producing slightly greater output than ploughed soil⁶³.

From a global warming perspective, a critical additional factor is that glomalin accounts for 27% of carbon stored in soil⁶⁴; cultivating glomalin actually serve as a significant carbon sink.

The Rodale Institute makes an important point; often, those who promote no-till simply seem to be encouraging the use of Roundup (the world's leading herbicide). Without tilling, weed control appears at first glance to require more herbicide. With all the extra uncomposted plant matter in the soil, it is difficult to avoid attracting insect pests that require pesticide as well. A great deal of grain in the U.S. is grown by no-till methods without crop rotation; this actually increases chemical use. But with proper rotation, cover crops and the use of a chop stalker or roller to convert agricultural residues to an in-place no till mulch, it is possible to reduce herbicide and pesticides by half to two thirds, and water use by 30% to 50%⁶⁵. Because, in a no-till field, pesticides and herbicides remain in the soil until they decompose, pesticide and herbicide run-off is reduced by 90% or more.

Biointensive integrated pest management can reduce chemical pesticides and herbicides further. This includes early pest detection and monitoring, use of predator insects and other biological controls, and least toxic, targeted pesticide and herbicides specific to particular pests as last resorts. This in combination with well designed rotation lets more or less conventional no-till reduce chemical herbicide and pesticides by three quarters. In some case it even allows completely organic methods. For example, Rodale has developed a new cover crop roller that may make no-till without herbicides competitive with herbicide production in yield in per acre⁶⁶. Thus no-till can increase yield per acre, preserve the soil, and reduce or eliminate pesticide, herbicide and artificial fertilizer use - without increasing costs.

How are the economics of no-till farming? Generally you get more production per acre, lower labor costs, and lower capital costs as well. (Thus, while conventional organic agriculture decreases production per acre in rich nations, low input biodiverse no-till increases crops harvested.) There are transition costs. Converting ploughed land to a no-till system takes between three and five years to build the soil enough for increased production. (Lower costs normally increase net profitability even during the transition period.) No-till with fiber crops such as kenaf or hemp can lead to increased compaction - though it has been found that improved drainage, combined with crop rotation will solve this problem.

How much energy does this save? Nitrogen fertilizer use (eliminated in no-till), and farm equipment operations (drastically reduced) are the two biggest energy consumers in row-crop cultivation. Drastic reductions in, (or elimination of), other fertilizers, herbicides and pesticides cut energy use further. So again lowering material intensity indirectly saves energy – in this case by half. Carbon emissions are reduced even more. As with management intensive grazing, building soil structure transforms agriculture from a carbon source to a small carbon sink – providing minor amounts of sequestration.

Beyond this, recent work on charcoal as soil amendments may allow us to go further - sequestering significant amounts of carbon and building soil to a far greater extent⁶⁷. However, there are significant limitations we need to watch out for here, Just as conventional chemical fertilizers add nutrients without building soil structure, charcoal agriculture build soil structure without adding nutrients. So you want to limit the percent and type of agricultural waste you convert to charcoal for this purpose--especially avoiding nitrogen rich materials. Additionally, charcoal making is usually very air polluting. There are charcoal making methods this is not true of, but they are expensive, especially on the small scale you want to use for conversion of agricultural wastes. None of this is insurmountable. Rodale is working on incorporating charcoal agriculture into its no-till farms. It just should not be seen as a quick fix that can avoid the need for emissions reduction.

The following table summarizes some methods of lowering material intensity in agriculture.

Lowering Material Intensity in Agriculture			
Means	Intensity Reduction (%)	Energy Savings (%)	Comments
Green grazing of ruminants ⁵⁹ (Management Intensive Grazing)	78% -90%	66%-80%	(lower cost ⁶¹)
Green grazing non-ruminants (Management Intensive Grazing)	50%	25%	Pigs cost less ⁶⁸ ; chickens more
Rotational No-Till ⁶³ Row Crops, including Legumes, Green Manure, and Biointensive Integrated Pest Management	75%	50%	
Slight or great reduction in meat production depending upon how quickly we move ⁶⁹ .	Meat requires more land per ton of usable complete protein than vegetable sources; to what extent we continue to eat meat depends upon how well we preserve existing agricultural land.		
Sense of location – planting crops appropriate to location. Example: not growing cotton in desert	Cumulates with other means to achieve maximum savings.		
Attention as substitute for inputs. Example: visually inspecting drip irrigation system to verify that it is watering plants as instruments show.	“ “		
Hemp as partial cotton substitute – 100% in some applications, mixes 50/50 in others – overall could substitute for 75% of cotton use. (Most non-clothing use, and clothing that does not touch skin directly such as jeans, and jackets, plus 50/50 mix with cotton in other applications such as T-shirts.	40% ⁷⁰ (given 75% substitution)	15%	Hemp is an excellent crop to include in rotation with grain, legume and green manure. So it can contribute to much larger savings. Advanced cottonization lets hemp be processed in a soft fiber that may be 100% substituted for cotton. However this is water and energy intensive. 75% substitution with organic cotton used for the remaining 25% would be better ecologically.

Because ruminants and row crops account for overwhelming majority of agricultural impact and energy use, very roughly we could expect a 60% reduction in agricultural energy consumption from this. The key point is that we could increase production - per acre and per hour from various near organic techniques, while lowering ecological impacts more than pure organic production can. This is sometimes described as a "middle path", though the non-organic inputs are fairly trivial.

Before we leave the subject of agriculture we may want to examine the current outer limit of low input cultivation.

Biointensive farming is many steps beyond no-till. Generally through double digging and the use of compost, aerated soil is provided to a depth of 24 inches, either in raised or sunken beds. A variety of crops, not just one or two plants but a multiplicity, are grown closely spaced. The close spacing shuts out weeds, as does the filling of all available niches by multiple crop plants. The biodiversity also discourages pests, since very few insects, diseases or fungi are generalist enough to attack all the species grown.

It produces far more food per acre than other form of agriculture, excluding some forms of hydroponics. It is so land efficient that 100% of a vegan diet may be produced on less than 3,200 square feet - fertilized only by compost from the person the garden feeds⁷¹.

Now this is also a very labor intensive form of agriculture, perhaps slightly less labor intensive than the traditional pre-industrial farming, but much harder work than modern no-till farming. It is not something to implement on a large scale, in its present form, in the long run. But a large part of the world lives on less than two dollars a day; this type of system certainly makes sense in places where people are starving and without work. It is undesirable, though, that people stay poor. Hopefully any nation poor enough that this makes sense for a large part of it's people would use it as a stepping stone to improve their lives, and not leave them with subsistence agriculture (no matter how ecologically correct the type) as all that held off starvation.

The main point of bringing it up in the context of the U.S., where we don't live on two dollars a day, and hopefully won't in the future, is to show that we have by no means begun to tap the potential of what sustainable agriculture will do. While current sustainable low-labor no-till techniques will meet our needs in the long run it is important to gain resource efficiency in agriculture comparable to that of biointensive techniques without the waste of valuable human labor.

End Notes

⁵² Food and Agriculture Organization of the United Nations (FAO), "Food Balance Sheet," *FAOSTAT Online Database 2004. Commodity Balances Database - Production*. Aug 2004, Food and Agriculture Organization of the United Nations (FAO), 10/Sep/2005

<<http://faostat.fao.org/faostat/servlet/XteServlet3?OutputLanguage=english&Areas=ALL&Items=2901&Years=2001&Years=2000&Domain=FBS&ItemTypes=FBS&language=EN&Codes=ShowCodes>>.

⁵³ Economic Research Unit United States Department of Agriculture, *ERS/USDA Briefing Room - Global Food Security: Questions and Answers*. 11/May 2005, Economic Research Unit United States Department of Agriculture, 10/Sep/2005 <<http://www.ers.usda.gov/Briefing/GlobalFoodSecurity/questions/>>.

⁵⁴ Institute of Medicine of the National Academies, *Dietary Reference Intakes: Macronutrients*. May 2005, National Academy of Sciences, 10/Sep/2005 <<http://www.iom.edu/Object.File/Master/7/300/0.pdf>>.p4.

⁵⁵ U.S. Census Bureau, "World Population: Total Midyear Population," *Intenational Data Base*, 30/April 2004, U.S. Census Bureau, 25/May/2004 <<http://www.census.gov/ipc/www/worldpop.html>>.

⁵⁶ Brian Halweil, "Can Organic Farming Feed Us All?". *World Watch Magazine* 19, no. 3 May/June 2006 *The Organic Center*, Worldwatch Institute, Jan-03-2007 <<http://www.organic-center.org/reportfiles/EP193A.Halweil.pdf>>.

⁵⁷ Food and Agriculture Organization of the United Nations (FAO), *FAOSTAT Online Database 2004 - Crops Primary*. Aug 2004, Food and Agriculture Organization of the United Nations (FAO), 10/Sep/2005 <<http://faostat.fao.org/faostat/servlet/XteServlet3?Areas=231&Items=%3E1714&Elements=31&Years=2000&Format=Table&Xaxis=Countries&Yaxis=Items&Aggregate=&Calculate=&Domain=SUA&ItemTypes=Production.Crops.Primary&language=EN>>.

U.S. Grain harvest in 2000 in hectares equal

58,497,083

U.S. agricultural harvest from cropland in 2000 equals

136,057,883

So ~43% of total cropland harvested in 2000 was grain.

World Resources Institute, "Meat Consumption: Grain Fed to Livestock as a Percent of Total Grain Consumed," *EarthTrends Environmental Portal - Environmental Information Database*, 2004, World Resources Institute, 10/Sep/2005 <http://earthtrends.wri.org/searchable_db/results.cfm?years=1999-2000,2000-2001,2001-2002,2002-2003,2003-2004&variable_ID=348&theme=8&cID=190&ccID=0>. From 60% to 65% of U.S. grain is fed to animals, So around 27% of U.S. cropland used to grow food for animals

⁵⁸ Food and Agriculture Organization of the United Nations (FAO), *FAOSTAT Online Database 2003 - Crops Primary*. Aug 2004, Food and Agriculture Organization of the United Nations (FAO), 10/Sep/2005 <<http://faostat.fao.org/faostat/servlet/XteServlet3?Areas=862&Items=%3E1714&Elements=31&Years=2000&Format=Table&Xaxis=Years&Yaxis=Countries&Aggregate=&Calculate=&Domain=SUA&ItemTypes=Production.Crops.Primary&language=EN>>.

Total Crops Worldwide 2000 (Ha)

1,348,840,594

Total Crops World Wide Grain (Ha)

674,247,980

So ~50% of harvested primary crop acreage used for grain in 2000

World Resources Institute, "Meat Consumption: Grain Fed to Livestock as a Percent of Total Grain Consumed," *EarthTrends Environmental Portal - Environmental Information Database*, 2004, World Resources Institute, 10/Sep/2005 <http://earthtrends.wri.org/searchable_db/results.cfm?years=1999-2000,2000-2001,2001-2002,2002-2003,2003-2004&variable_ID=348&theme=8&cID=190&ccID=0>. Around 37% of grain crops worldwide fed to animals.

~37% of ~50% ~18.5% of total cropland worldwide used to grow grain for animals.

⁵⁹Joel Salatin, a grass-fed beef pioneer and author makes the point from a stockman's viewpoint:

Roughly speaking, land that will produce 100 bushel-per-acre corn, will produce 400 cow-day[s] forage (one cow day is what one cow will eat in one day--cow-days are to graziers what inches are to carpenters and board-feet are to lumberjacks). If 100 bushels (average 60 pounds per bushel, weight 6,000 pounds), that will produce about 857 pounds of beef.

At 400 cow-days we can carry 600 stocker calves (400-800 lb.) gaining at least 1.5 pounds per day, yielding 900 lbs. (600 X 1.5 = 900) of beef per acre.

..... The point is to move the stock to mimic grazing patterns of native herbivores...

... Under good controlled grazing, we allow the grass to recuperate through its "blaze of growth" period before being regrazed... ..By keeping 98% of the farm at rest and in the fast growth period, not letting the forage get grazed too early or too late after growth slows down, we can see tremendous increases in forage growth...

.... Most parasites lose strength dramatically after being denied a host for three weeks. Since most paddock shifts occur at least three weeks apart..., this depletes parasite virility and reduces the need for wormers..

.... Because the animals lounge in different paddocks every day, they spread their manure more evenly over the pasture...

Joel Salatin, "Joel Salatin Introduces Livestock Grazing... 'Salad Bar Beef,'". *Acres USA - A Voice for Eco-Agriculture* March 1996 *Eco-Friendly Foods*, 10/Sep/2005
<<http://www.ecofriendly.com/index.cfm?section=4&page=20>>.

⁶⁰Cutler J. Cleveland and Charles A. S. Hall, "Climate Change Human Driving Forces, Biophysical Basis, and Likely Impacts," *Climate Change - Socioeconomic Dimensions and Consequences of Mitigation*, ed. Pentti Vartia, 2000). Oct 1999. *Fortum*, Boston University, 11/Sep/2005
<<http://www.bu.edu/cees/research/workingp/pdfs/9910.pdf>>.p9.

⁶¹Jimmy Henning et al., *Rotational Grazing*, 2000), ID-143. 2000. *Cooperative Extension Service - University of Kentucky, Department of Agriculture*, 13/Sep/2005
<<http://www.ca.uky.edu/agc/pubs/id/id143/id143.pdf>>.

State of Illinois Department of Agriculture Illinois Sustainable Agriculture Committee, "S/A 98-18 Sustainable Beef Production - Management Intensive Grazing Vs Corn Silage Program for Beef Stocker Calves.," *Sustainable Agriculture Grant Review Committee C2000 Sustainable Agriculture Grant Projects - ON-FARM RESEARCH AND DEMONSTRATION*. Oct 2001. *State of Illinois Department of Agriculture Illinois Sustainable Agriculture Committee*, State of Illinois Department of Agriculture Illinois Sustainable Agriculture Committee, 13/Sep/2005
<<http://www.agr.state.il.us/C2000/fy00/FY00Report.pdf>>.pp6-17

(*Note: total beef production over the three year period was about one third the per acre production from corn.. However this was an experimental program grazing basically two forages - alfalfa /orchard grass during warm weather, and small grain cereal rye during cool. A more experienced grazer with a wider variety of forages could expect better results - especially if drought resistant varieties were used. Also the cattle tested were largely bred as feedlot animals. Forage animals in pasture compared to feedlot breeds on grain would be a better test. However, even with the lower production per acre, cost per pound of beef, and especially labor per pound of beef was lower with grass raised.)

Center for Integrated Agricultural Systems of the University of Wisconsin's College of Agricultural and Life Sciences, *CIAS: Management Intensive Rotational Grazing's Sense..and Dollars*. April 1996, Center for Integrated Agricultural Systems of the University of Wisconsin's College of Agricultural and Life

Sciences, 13/Sep/2005

<http://www.cias.wisc.edu/archives/2000/01/04/dairy_grazing_can_provide_good_financial_return/index.php>.

(The milk per acre is slightly lower, but labor costs are MUCH lower, as are feed costs and capital costs. So even with no price premium the farmer would make higher profits.)

Also, Ibid 59

⁶²Richard Cowan, "U.S. Group Blasts Creekstone Mad Cow Testing Plan," *Reuters Via Forbes.Com* 19/Apr 2004, Forbes, 14/May/2004
<<http://www.forbes.com/markets/newswire/2004/04/19/rtr1336959.html>>.

⁶³Donald Lobb, "No-Till Success Hinges on Developing a Complete Crop Production 'System,'" *Sustainable Farming*, no. Winter 94 (1994)*Ecological Agriculture Projects, McGill University (Macdonald Campus)*, Resource Efficient Agricultural Production - Canada (REAP-CANADA), 17/Sep/2005
<<http://www.eap.mcgill.ca/MagRack/SF/Winter%2094%20I.htm>>.

⁶⁴Sara Wright, *Glomalin: A Manageable Soil Glue*. 2004, USDA Sustainable Agricultural Systems Laboratory, 26/May/2004 <<http://www.ba.ars.usda.gov/sasl/research/glomalin/brochure.pdf>>.

⁶⁵Preston Sullivan, *Conservation Tillage*, Jul-2003). *Appropriate Technology Transfer For Rural Areas*. Aug 2003. *National Center for Appropriate Technology*, 26/May/2004 <<http://attra.ncat.org/attra-pub/PDF/consertill.pdf>>.Pp2-3.

Corliss Karasov, "No-Till Farming on Comeback Trail," *Environmental Health Perspectives* 110, no. 2 Feb 2002, 1/Jun/2004 <<http://www.greennature.com/article833.html>>.

⁶⁶Laura Sayre, "New Farm Research: Cover Crop Roller," *The New Farm*, 20/Nov 2003, The Rodale Institute, 7/May/2005 <http://www.newfarm.org/depts/NFfield_trials/1103/notillroller.shtml>.

⁶⁷ Emma Marris, "Black is the New Green," *Nature* 442, no. 10 Aug 2006, Charcoal Sequestering Carbon in Soil, Nature Publishing Group, Jan-03-2007
<http://www.bestenergies.com/downloads/naturemag_200604.pdf>.

⁶⁸Greg Gunthorp and Lei Gunthorp, *Grassfarmer.Com - PASTURED PIGS ON THE GUNTORP FARM*. 24/Feb 2004, American Farmland Trust, 13/Sep/2005 <<http://grassfarmer.com/pigs/gun1.html>>.

Sustainable Agriculture Network, *Profitable Pork:Strategies for Hog Producers. Livestock Alternatives*. Jul 2003. *Sustainable Agriculture Network*, Sustainable Agriculture Research and Education Program, 31/May/2004 <<http://www.sare.org/publications/hogs/profpork.pdf>>.

⁶⁹Roger Segelken (ED), "U.S. Could Feed 800 Million People with Grain That Livestock Eat, Cornell Ecologist Advises Animal Scientists," *Cornell University Science News*, 7/Aug 1997, Cornell University, 13/Sep/2005 <<http://www.news.cornell.edu/science/Aug97/livestock.hrs.html>>.

⁷⁰Hempopotamus, *All About Hemp*. 2004, Industrial Hemp, Hempopotamus, 22/Jun/2004
<<http://www.hemphouse.com/docs/hempinfo.html>>.

⁷¹John Jeavons, "Cultivating Our Garden: Biointensive Farming Uses Less Water, Land, Machinery, and Fertilizer - and More Human Labor," *In Context*, no. 42/Fall 1995 - A Good Harvest (1995), Context Institute, 17/Sep/2005 <<http://www.context.org/ICLIB/IC42/Jeavons.htm>>.p34.