RESEARCH EDITORIAL

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Spending our water and soils for food security

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While the farmer holds the title to the land, actually it belongs to all the people because civilization itself rests upon the soil. —Thomas Jefferson

For the most part, food security is dependent on our soil and water resources. Recent food security studies in economics, geology, and anthropology (Diamond 2005; Montgomery 2007; Rosen et al. 2008) have concluded that soil and water resources will reach critical levels and, before long, fail to feed us. Among the causes of the crisis is the expected dramatic rise over the next few decades in world population and the stress it will put on resources (FAO 2008; Janzen et al. 2011). The crisis is predicted to cause anything from increased starvation to societal collapse. Our challenge is to secure food supplies through the proper use of soil and water. And, in this endeavor, energy plays no small role.

Over time, in many developing countries, food security cannot be maintained (FAO 2008); yet, in developed countries, where food stores peaked in the middle 1980s, it is more than satisfied. As in other times of plenty (Mazoyer and Roudart 2006), to eliminate excessive overhead, stores were reduced and production curtailed. In recent lean years, reduced stores caused riots and deaths because prices and scarcity put food beyond the reach of the poor. Despite the decrease in food prices after the 2008 spike, it is still more expensive than before to obtain food (FAO 2012a); people are still starving (Alston et al. 2009); and local conflicts are still raging over resources, including (but not limited to) food and water (Diamond 2005; Arezki and Brückner 2011). Shortages will invariably happen again. And so with this inevitability in mind, we work toward food security for our country. We work toward food security for others as well—if not for humanitarian reasons, at least to protect ourselves from external turbulence.

Food security is threatened by both nature and man. Common natural threats are those that damage the plant, kill it, or prevent planting/harvest, such as floods, droughts, and hail. Another natural threat, exacerbated by man, is global warming. It is expected to affect some areas positively and some areas negatively. Unfortunately, the areas expecting negative effects are those that can afford it least, developing countries (FAO 2009). Food security is also threatened by man. Hungry environmental refugees can threaten the security of others (Montgomery 2007), or food can be used as a weapon or deterrent during sieges or embargos (Time 1941).

Food security is threatened by more than droughts, conflicts, and global climate change. Though some projections expect world population to plateau soon, most do not (United Nations 2007). More people are added to the planet than lost. World population will grow by 50 mouths as you read this paragraph and another 500 before you finish reading the article. The immediate problem we face is feeding ourselves and an additional 2 billion people by the middle of the century (World Hunger Education Services 2012). These people are added to a world where today over 900 million people are undernourished (figure 1) and another billion face food security issues (Rosen et al. 2008). Added to the number of food insecure people are other stresses: houses replacing farmland, crops needed for biofuel, and developing countries aspiring to better standards of living. The result is increasing competition for soil and water resources while the soil's carrying capacity is degrading (FAO 2012a) and water resources are drying up. We are spending our soil and our water resources in an unsustainable manner.

Spending Our Soil

Soil (USDA NRCS 2012) is the thin unconsolidated mantle of earth that serves as a medium for plant growth, the source of 95% of our food. According to archeologists (Mazoyer and Roudart 2006), we started farming when we needed more food than we could hunt or forage, about 8,000 to 10,000 years ago. We cleared the land and cultivated it to plant crops and graze livestock. Although soils naturally degrade, cultivation and grazing exposed them to a greater degree, beyond their ability to rebuild. Archeologists found evidence of degradation/erosion in places like Southeast Asia, the Levant, and Mesoamerica—places where cultivation and grazing first began (Lowdermilk 1953; Montgomery 2007). In the Mediterranean, though erosion may have helped the Nile valley with deposition, it damaged soil in Greece and around Rome; then, it continued into the rest of Europe and North Africa. Soil produced food and fiber, but the cost was loss of soil. And the process continues today with soil that makes the Yellow River yellow and carries nutrients into the Gulf of Mexico. Of course, agriculture is not the only cause of soil erosion. Deforestation and its ensuing erosion was also the result of making ships out of Cedars of Lebanon (Kuniholm 1997), moving statues on Easter Island, and using wood for building and fuel (Olson 1981; Diamond 2005). Erosion can be the sensational phenomena of mud slides and dust storms. It can just as easily be slow and silent as it accrues soil, almost imperceptibly, from millions of hectares to add sediment loads that color rivers and kill civilizations (figure 2).

In the US, concern about erosion from the dust bowl of the 1930s sparked research and conservation measures that significantly reduced soil loss. For example, sediment in the Mississippi River averaged 56 Mg y^{-1} (123 million tn yr^{-1}) from 1999 to 2008 (Filippo 2010), only 3% of its average of 1.8 Gg y^{-1} (4 billion tn yr^{-1}) in the 1950s. Successes like this made our soils more sustainable and bought us time to reach equilibrium between soil loss and regeneration.

Though a host of factors affects soil loss and regeneration, it is evident that soil is

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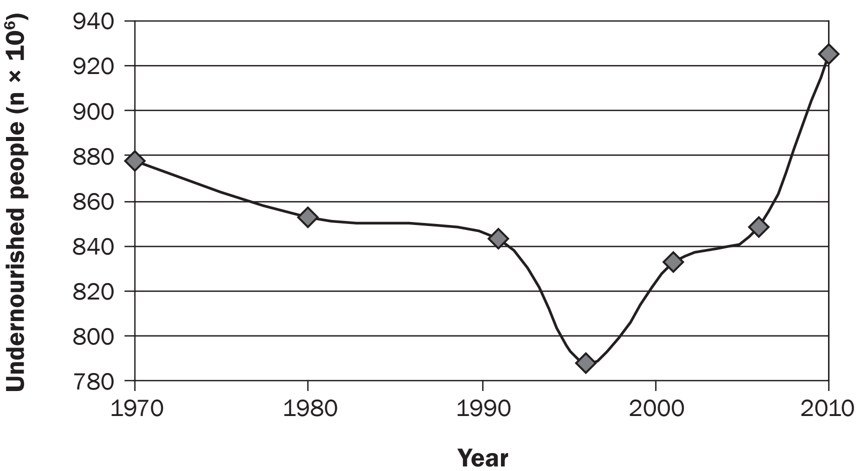
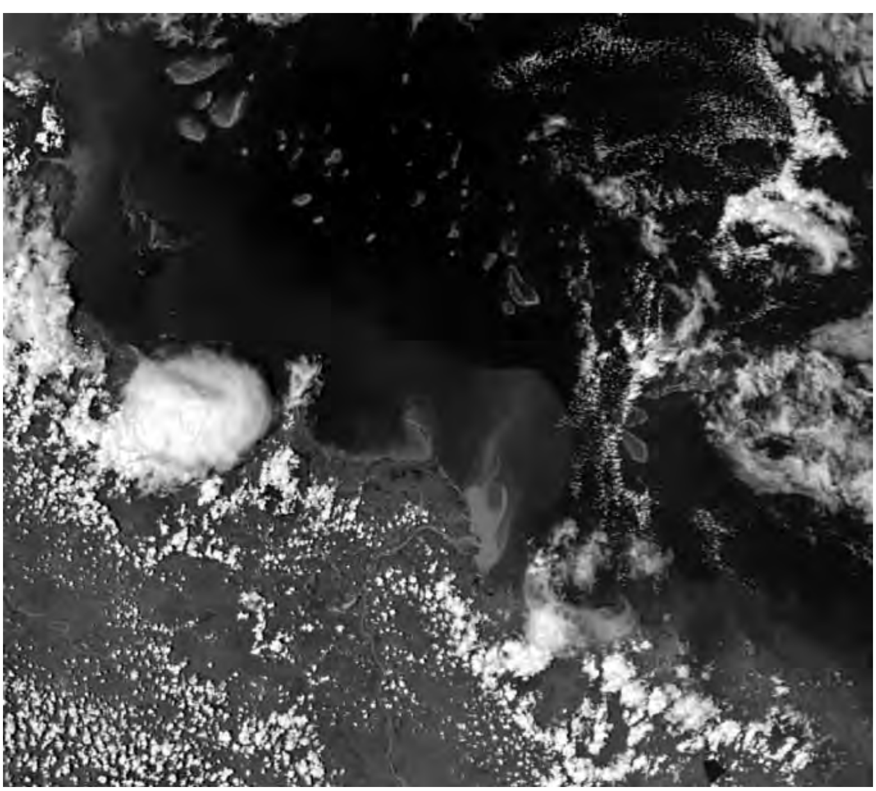
Figure 1
Number of undernourished people in the world. Hunger has increased because of high food prices, lower incomes, and increasing unemployment from the recent economic crisis (FAO 2012b).



being lost significantly faster than it is being regenerated. As a rule of thumb, soil forms from parent material below it at about 0.25 mm y^{-1} (0.01 in yr^{-1}). Another general estimate based on concentration of elements in soils, in their parent materials, and in rivers is that soil forms at 0.056 mm y^{-1} (0.0022 in yr^{-1}). Other estimates of regeneration rate, based on more local conditions (Buol et al. 2003), range from 100 mm y^{-1} (4 in yr^{-1}) in a mud flow to 0.01 mm y^{-1} (0.0005 in yr^{-1}) in a tropical soil.

Figure 2
Flooding in Queensland, Australia, sends turbid water toward the Great Barrier Reef. (NASA 2011.)



And how fast is soil lost? Estimates range from 6 to over 40 t ha^{-1} y^{-1} (2.7 to over 16.2 tn ac^{-1} yr^{-1}). Estimates for the US and Europe range from 6 to 13 t ha^{-1} y^{-1} (2.7 to 7 tn ac^{-1} yr^{-1}). Using a standard acre furrow foot, this translates to depths of soil loss for the United States and Europe from 0.4 to 1 mm y^{-1} (0.02 to 0.04 in yr^{-1}), well above the regeneration rates. Estimated losses for Asia, Africa, and South America are about twice as high (Pimentel et al. 1995a; Pimentel et al. 1995b; USDA NRCS 2009). To maintain the medium that is the source of 95% of our food, we need to reduce losses down to the level at which soil regenerates, worldwide.

Erosion is not the only form of soil degradation. Other forms include salinization, physical compaction, and loss of nutrients. Like erosion, salinization is another suspected killer of civilizations (Cowen 2010). In salinization, evaporating water (usually irrigation) accumulates salts in soils, and the salts prevent plant water uptake. To destroy Carthage, the Romans salted soils, though they later tried to reverse the treatment to feed themselves. Compaction is becoming more common because of our heavy machinery (Mazoyer and Roudart 2006), and nutrients are lost as soils use them to grow crops. While some degradation is caused by climate or other natural causes, most is caused by man's activity (Montgomery 2007).

According to FAO (FAO 2012a), the area of degraded land in the world today is 19.6 million km^2 (7.6 million mi^2) (table 1) and climbing by 5 to 6 million ha (12 to 15 million ac) annually; it is now larger than the United States and China combined. The amount of land that is degraded beyond any functionality is 3.05 million km^2 (1.18 million mi^2), an area larger than Argentina. In the past when an area was degraded, producers might have moved to new lands and abandoned the old lands or let them rest/recover, if they could. But today, we don't move because we need all our developed land to produce food, fiber, and fuel. And, even if we want to move, productive new land is not easy to find. Most idle lands are marginal—inaccessible, sloping, compacted, infertile, saline, too dry, or too wet. To produce food, fiber, and fuel, we spend our soil.

Table 1
Estimates of global land degradation in km² × 10⁶* (Oldeman et al. 1991).

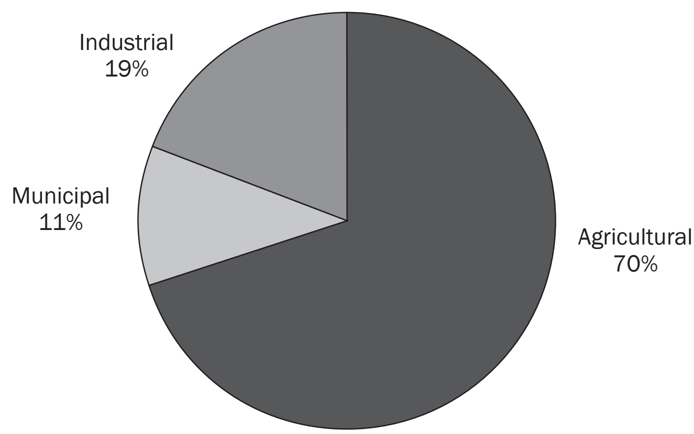
Degradation	Light	Moderate	Strong/extreme	Total
Water erosion	3.43	5.27	2.24	10.94
Wind erosion	2.69	2.54	0.26	5.49
Chemical†	0.93	1.03	0.43	2.39
Physical‡	0.44	0.27	0.12	0.83
Total	7.49	9.11	3.05	19.65

* 1 km^2 = 100 ha = 247 ac.

† Includes salinization, loss of fertility, acidification, and pollution.

‡ Includes compaction, crusting, waterlogging, and subsidence.

Figure 3
Global water withdrawls (Aquastat 2010).



Spending Our Water

Soils do not produce food in a sterile environment; they need fertility, microflora/fauna, and water—lots of water. On a planet that is three-quarters ocean, one would think that we have enough water for human use; unfortunately, over 99% of the water is too saline or tied up as ice. Less than 1% is available from lakes, rivers, and groundwater (FAO 2001), and not all of that will be available to agriculture. Competition for water's use comes from others who can pay more, like industry, municipalities, and energy producers.

In the United States, 48% of fresh and saline water withdrawals are used for thermoelectric power generation (Hutson et al. 2000). Through evaporation, only 2% to 3% of this water is consumed during power generation (Solley et al. 1995), an average of 2.1 L MJ^{-1} (2 gal kWh^{-1}) (Torcellini et al. 2003); the rest is returned for reuse. Eleven percent of freshwater withdrawals are used by municipalities (figure 3), but 90% of that can be returned as waste water to be treated and reused (FAO 2001). Nineteen percent of freshwater withdrawals are used by industry; its returns vary widely in quantity and quality that may or may not be reusable.

In contrast, most agricultural water is consumed through evapotranspiration or soil management. On a country-by-country basis, agriculture uses anywhere from less than 20% to more than 90% of freshwater withdrawals (Aquastat 2012). The wide range depends on climate, productivity, and water use efficiency (Hamdy 2007; Boutraa 2010). On a worldwide average, 70% of our water withdrawals are used for agriculture (Aquastat 2010).

Fortunately, water is renewable; it precipitates from the atmosphere and evaporates back to it. Unfortunately, groundwater can be used faster than it is replenished; it can be mined. Mined water for agriculture accounts for 43% of groundwater use (Siebert et al. 2010). Current groundwater sources are dwindling and new sources are more difficult to find and/or develop. Examples of mined water can be seen in the dropping levels of the Ogallala Aquifer in the central United States (Colaizzi et al. 2009), conservative groundwater use of only supplemental irrigation by many small farmers (International Bank for Reconstruction and Development 2005), and dropping aquifer levels for wheat and cotton production in the Hebei Plain in China (Yang et al. 2010). For industry, food, and drink, we are also spending our nonrenewable water.

Spending Energy

We cannot ignore agriculture's benefit from (and its dependence on) low-cost, nonrenewable energy. It helped spur the development of machinery and low cost fuel to run it. Machinery freed animals and us from much of the burden of agricultural production, processing, and transportation; fewer draft animals also meant less food for them, more for us. Low-cost energy stimulated a chemical industry with pesticides that reduced production losses. It also increased production through fertilizers, many of which are energy expensive to produce. Energy is used in most aspects of food production, from planting seeds to transporting food to the consumer. On average, in developed countries, 7 to 10 kcal of nonrenewable energy are used to produce every kilocalorie of food (Horrigan et al. 2002). Unfortunately, the era of inexpensive energy from nonrenewable sources appears to be coming to an end, and new sources will be expensive to develop (Rubin 2009). Nevertheless, especially in developed countries, we spend energy to produce inexpensive food.

Some Optimism

Not all the news is bad. For the past century, agricultural productivity has kept pace with or exceeded population growth through innovations like the Haber-Bosch process, soil management/machinery improvements, increased fertilizer use, and new varieties of the Green Revolution. Improved productivity has increased our average daily caloric intake consistently since the mid-1960s (FAOSTAT 2010), even with an increasing world population (figure 4). And, though future population increases are expected to press the limits of our agricultural output, human ingenuity is always changing the future.

Solutions

Three potential ways to feed our growing population include opening up millions of hectares of new cropland, developing better

Figure 4
Increase in food amount per person between 1965 and 2015 (FAO 2002). Note that an average does not mean that everyone shares in the increase.

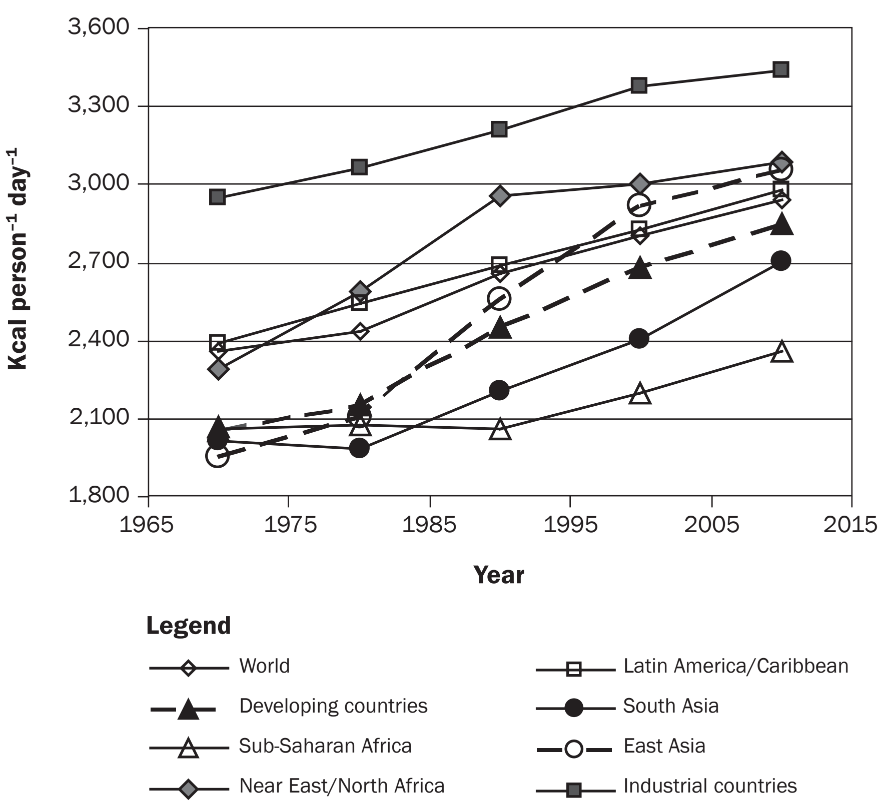
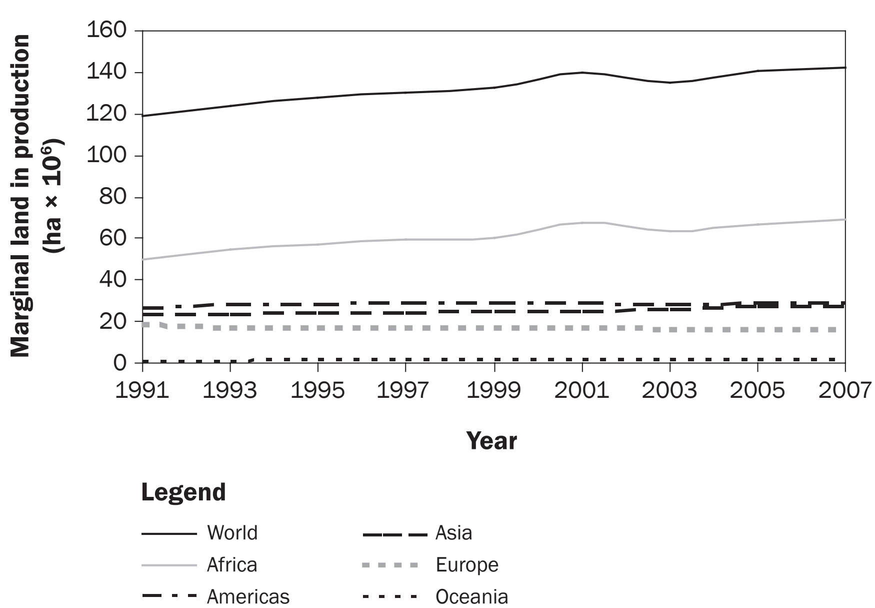


Figure 5
Increase of marginal lands in production (Terrastat 2010).



eating habits, and improving the efficiency of farming (Pimentel and Pimentel 2003; Pimentel et al. 2008). To some extent, we will probably do all three but none in excess. Opening up too much land would damage ecosystems and biodiversity (Royal Society 2009), but countries will continue to develop and can do so in an ecologically responsible manner. Better eating habits would help some by freeing up resources and others by improving health. Better farming (better use of soil and water resources) is an area where research and societal involvement can have its most significant impact.

Opening Up New Lands. Opening additional lands for development has other problems than ecosystem and biodiversity shock. Though governments list large tracts of land available for development, sometimes these lands only appear to be available because they are being used by people marginalized from formal law, institutions, and land rights/claims (Cotula et al. 2009). Additionally, much of the area of expansion is not prime farmland. Worldwide, the extent of prime farmland, land with no constraint to plant growth, is 1.4 to 1.7 billion ha (3.5 to 4.2 billion ac) (FAOSTAT 2010; TERRASTAT 2010). Most of that land is already in use; the 1.4 billion ha (3.5 billion ac) in production today is mostly prime farmland (FAOSTAT 2010). This leaves degraded or marginal land to be improved and put into (or put back into) production (figure 5). For example, the World Bank project to reclaim soils turned saline from irrigation by improving drainage is aimed mainly at improving the lot of small/subsistence farmers (International Bank for Reconstruction and Development 2005).

Eating Habits. Meat production can have a high cost in terms of fuel, grain, and water (Pimentel and Pimentel 2003; Rifkin 1992). Meat can cost up to 43,000 L of water kg^{-1} (5,000 gal lb^{-1}). Humans certainly need protein for a proper diet, but in listening to the health officials, it might not be a bad idea to increase the amount of whole grains and fruits in developed-country diets. Whole grains use 500 to 4,000 L of water kg^{-1} (60 to 480 gal lb^{-1}) (Molden 2007), and apples use 700 L of water kg^{-1} (85 gal lb^{-1}) (Hoekstra et al. 2011). And, with increasing fuel and related transportation costs, whatever we eat will probably be grown closer to home (Rubin 2009).

More Efficient Soil Use. Marginal or degraded land can be improved. Land improvement has been occurring for millennia. Marginally dry land in the Nile Valley was irrigated by the Egyptians (Mazoyer and Roudart 2006), infertile soils in the Amazon basin were amended with biochar by Pre-Columbian South Americans (Mann 2005), and sloping soils were terraced by Southeast Asians two to three millennia ago (Warkentin 2006; Mazoyer and Roudart 2006). To prevent degradation, soils also used to be maintained (and in some places still are) through the use of manures: a practice more widely used before energy-expensive commercial fertilizers became common.

We have an assortment of ways to improve lands that are marginal or degraded, as well as ways to maintain lands for more sustainable development (Matson et al. 1997; Lal and Pimentel 2007). We have terraces, windbreaks (figure 6), and conservation tillage that conserve soil, water, and nutrients by promoting infiltration and preventing runoff. We have cover crops that act in a similar manner while also preventing nutrient leaching and adding much-needed organic matter. We have green manures and other sources of increased organic matter that provide a host of services to the soil: sites for nutrient storage, energy for biological activity, soil-to-soil links that improve aggregation, cushions that ease compaction, buffers for pH changes, and increased water retention and infiltration. The list continues with new or rediscovered methods, such as tillage reduction, spatial applications of nutrients or pesticides, and soils amended with polyacrylamide or biochar. Though we have a number of ways to slow degradation, more research and development are necessary to make production profitable and sustainable.

More Efficient Water Use. Floods cause more destruction (Munich Re Group 1999) than any other natural disaster. Though a certain amount of water is needed to promote stream health, we lose valuable excess fresh water to the saline oceans. Water is lost in other ways as well. In developing countries, even though irrigation efficiency has doubled over the past 50 years, more water destined for crop irrigation is lost than used (FAO 2001). Additional improvements are expected to produce more crop per amount of irrigation water, to deliver more water to the field/lose less in transit, and to more efficiently use rainfall/lose less to floods (Mehari et al. 2011) and to the ocean (International Bank for Reconstruction and Development 2005).

Figure 6

Windbreaks in North Dakota to protect the soil against erosion. Picture by Erwin Cole, National Resources Conservation Service, USDA, 1997.

More production for the amount of water irrigated can be achieved through drip or bubbler irrigation though it can be expensive. More water delivered to the field can be achieved with lined, covered, or locally developed water delivery systems. More efficient use of rainfall can be achieved through increased storage or supplemental irrigation of rain fed systems. These and a number of other systems are in use or proposed by the World Bank and FAO (International Bank for Reconstruction and Development 2005; FAO 2001).

Optimism exists on the amount of food that can be grown with irrigation, not because more water will be available but because water can be used more efficiently, because older saline systems can be renovated, and because political systems can be altered for more effective water use (International Bank for Reconstruction and Development 2005). Improvements affecting productivity can also be made by including input from more marginalized farmers whose ideas and actions substantially affect local management (FAO 2001).

Changing water use will be difficult because of current laws, regulations, and expectations. But, in some cases, changes will have to be made to improve management and prevent overuse. The World Bank (International Bank for Reconstruction and Development 2005) recognized the need for water policy reforms by promoting reform and adjusting loan structures to be compatible with national policy and budget cycles.

Energy in Agriculture. With recent increases in energy costs, new practices are being developed to reduce our dependence on nonrenewable resources, to use them more efficiently, and to replace them with renewable sources. As technology improves, renewable resources, such as already-developed hydroelectric power and less-developed wind, solar, geothermal, and biomass, show more potential to supply our energy needs,. From 2004 to 2008, renewable energy (REN21 2009) increased 75%, excluding large hydroelectric, to 280 GW. When biomass is used as a fuel, researchers will have to determine how much can be removed for fuel and how much has to be retained to assure food production and soil health (Lal 2009). Research will also have to assure that biomass for fuel does not consume water needed for crop growth or biodiversity (Janzen et al. 2011).

Improvement, Remediation, and Conservation. We have many ways to improve the use of soil, energy, and water. But improvement is not enough; we need research and development to revitalize and sustain soils to the point that we are not losing them faster than they are developing—to the point that centimeters or inches of soils are lost over centuries or millennia rather than decades or centuries. We need to remediate degraded soils and use water and energy at sustainable rates. In short, we need to appreciate the land and resources that feed us (Miller 2008) rather than depreciate them.

On an individual scale, we can waste less food, recalling that we are not just wasting the food but also the items needed to make it (Jones 2005)—energy, fertilizer, pesticides, subsidies, eroded soil, human labor, transportation, and possibly other food because meat can take several kilocalories of grain per kilocalorie to produce (Horrigan et al. 2002). We can become aware of world problems and their relationship to renewable resources and food security. Additionally, we can join the conversation about current problems and future needs related to soil, water, and food production (Janzen et al. 2011; Reganold et al. 2011).

On a societal scale, FAO, the World Bank, the Soil and Water Conservation Society, and other organizations have been exceptional advocates. They helped farmers adopt conservation practices, strove to educate the public about their natural resources, and lobbied for or funded sustainable research and development. Although we need to continue to do all of these things, we need to do more:

- Recognize/reward producers who maintain sustainable rates of production.
- Develop better methods and more stringent standards for soil retention/nondegradation.
- Set targets for remediation of degraded soils.
- Press for higher value of soil and water resources.
- Research the real value of food, fiber, and fuel based on the soil and water needed to produce it.
- Encourage research that conserves energy, water, and soil.
- Stress the importance of long-term goals and the impending losses if we do not start now.

Collectively, we can work to reduce soil and water losses to renewable levels; we can develop more sustainable agricultural practices; we can produce enough food for a reasonably sized population. But we cannot accomplish these goals alone. The soil and water community needs help from society as a whole. Without them, complacency will reign, and profits will continue to undervalue soil and nonrenewable water. We can give future generations a legacy of degrading soils and disappearing water that will eventually fail to feed them, or we can start to develop their food security now.

References

Alston, J.M., J.M. Beddow, and P.G. Pardey. 2009. Agricultural research, productivity, and food prices in the long run. Science 325:1209-1210.

Aquastat. 2010. FAO's Information System on Water and Agriculture. Rome, Italy: Food and Agriculture Organization of the United Nations, Aquastat. http://www.fao.org/nr/water/aquastat/main/index.stm.

Aquastat. 2012. Review of global agriculture water use per country. Rome, Italy: Food and Agriculture Organization of the United Nations, Aquastat. http://www.fao.org/nr/water/aquastat/water_use_agr/index5.stm.

Arezki, R., and M. Brückner. 2011. Food prices and political instability. International Monetary Fund Working Paper 11/62. Washington, DC: International Monetary Fund.

Boutraa, T. 2010. Improvement of water use efficiency in irrigated agriculture: A review. Journal of Agronomy 9:1-8.

Buol, S.W., R.J. Southard, R.C. Graham, and P.A. McDaniel. 2003. Soil Genesis and Classification, 5th Ed. Ames, IA: Iowa State Press.

Colaizzi, P.D., P.H. Gowda, T.H. Marek, and D.O. Porter. 2009. Irrigation in the Texas High Plains: A brief history and potential reductions in demand. Irrigation and Drainage 58:257-274.

Cotula, L., S. Vermeulen, R. Leonard, and J. Keeley. 2009. Land grab or development opportunity? Agricultural investment and international land deals in Africa. London and Rome: IIED/FAO/IFAD.

Cowen, R. 2010. Exploiting the Earth. Essays on Geology, History, and People. http://mygeologypage.ucdavis.edu/cowen/~GEL115/index.html.

Diamond, J. 2005. Collapse: How Societies Choose to Fail or Succeed. New York: Penguin Group.

FAO (Food and Agriculture Organization of the United Nations). 2001. Crops and drops: Making the best use of water for irrigation. Rome, Italy: Food and Agriculture Organization of the United Nations.

FAO. 2002. World Agriculture: Towards 2015/2030, an FAO Study. Rome, Italy: Food and Agriculture Organization of the United Nations.

FAO. 2008. The state of food insecurity in the world. Rome, Italy: Food and Agriculture Organization of the United Nations.

FAO. 2009. How to feed the world in 2050. Rome, Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/wsfs/forum2050/wsfs-background-documents/hlef-issues-briefs/en/.

FAO. 2012a. Rome, Italy: Food and Agriculture Organization of the United Nations. www.fao.org.

FAO. 2012b. Hunger. Rome, Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/hunger/en/.

FAOSTAT. 2010. Food Balance Sheets. Rome, Italy: Food and Agriculture Organization of the United Nations. http://faostat.fao.org/site/345/default.aspx.

Filippo, S. 2010. Mississippi river sediment availability study: Summary of available data. Army Corps of Engineers, ERDC/CHL CHETN-IX-22. Vicksburg, MS: Army Corps of Engineers.

Hamdy, A. 2007. Water use efficiency in irrigated agriculture. *In* Proceedings of 4th WASAMED (Water Saving in Mediterranean Agriculture) Workshop, Amman, Jordan, September 30, 2007, 9-19. Bari, Italy: International Centre for Advanced Mediterranean Agronomic Studies.

Hoekstra, A.Y., A.K. Chapagain, M.M. Aldaya, and M.M. Mekonnen. 2011. The Water Footprint Assessment Manual: Setting the Global Standard. London: Earthscan.

Horrigan, L., R.S. Lawrence, and P. Walker. 2002. How sustainable agriculture can address the environmental and human health harms of industrial agriculture. Environmental Health Perspectives 110:445-456.

Hutson, S.S., N.L. Barber, J.F. Kenny, K.S. Linsey, D.S. Lumia, and M.A. Maupin. 2000. Estimated use of water in the United States. USGS Circular 1268. Reston, VA: US Geological Survey. http://pubs.er.usgs.gov/.

International Bank for Reconstruction and Development. 2005. Shaping the future of water for agriculture. Washington, DC: World Bank.

Janzen, H.H., P.E. Fixen, A.J. Franzluebbers, J. Hattey, R.C. Izaurralde, A.M. Ketterings, D.A. Lobb, and W.H. Schlesinger. 2011. Global prospects rooted in soil science. Soil Science Society of America Journal 75:1-8.

Jones, T.W. 2005. The corner on food loss. Biocycle 46(7):25.

Kuniholm, P.I. 1997. Wood. *In* The Oxford Encyclopedia of Archaeology in the Near East, E.M. Meyers, ed, 347-349. New York: Oxford University Press.

Lal, R. 2009. Soil quality impacts of residue removal for bioethanol production. Soil and Tillage Research 102:233-241.

Lal, R., and D. Pimentel. 2007. Biofuels from crop residues. Soil and Tillage Research 93:237-238.

Lowdermilk, W.C. 1953. Conquest of the land through seven thousand years. Agriculture Information Bulletin No. 99. Washington, DC: USDA, Soil Conservation Service.

Mann, C.C. 2005. 1491: New Revelations of the Americas before Columbus. New York: Vintage and Anchor Books.

Matson, P.A., W.J. Parton, A.G. Power, and M.J. Swift. 1997. Agricultural intensification and ecosystem properties. Science 277:504-509.

Mazoyer, M., and L. Roudart (translated by J.H. Membrez). 2006. A History of World Agriculture: From the Neolithic Age to the Current Crisis. New York: Monthly Review Press.

Mehari, A., F. van Steenbergen, and B. Schultz. 2011. Modernization of spate irrigated agriculture: A new approach. Irrigation and Drainage 60:163-173.

Miller F.P. 2008. After 10,000 years of agriculture, whither agronomy? Agronomy Journal 100:22-34.

Molden, D., ed. 2007. Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. Earthscan, London: International Water Management Institute.

Montgomery, D. 2007. Dirt—The Erosion of Civilization. Los Angeles, CA: University of California Press.

Munich Re Group. 1999. Annual report on natural catastrophes, Munich, Germany: Munich Re Group.

NASA (National Aeronautics and Space Administration). 2011. Aqua-MODIS image. http://modis.gsfc.nasa.gov/.

Oldeman, L.R., R.T.A. Hakkeling, and W.G. Sombroek. 1991. World map of the status of human-induced soil degradation: an explanatory note. Wageningen, The Netherlands: International Soil Reference and Information Centre.

Olson, G.W. 1981. Archaeology: Lessons on future soil use. Journal of Soil and Water Conservation 36(5):261-64.

Pimentel, D., C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Shpritz, L. Fitton, R. Saffouri, and R. Blair. 1995a. Environmental and economic costs of soil erosion and conservation benefits. Science 267:1117-1123.

Pimentel, D., C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Shpritz, L. Fitton, R. Saffouri, and R. Blair. 1995b. Response. Science 269:464-465.

Pimentel, D., and M. Pimentel. 2003. Sustainability of meat-based and plant-based diets and the environment. American Journal of Clinical Nutrition 78:660S–663S.

Pimentel, D., S. Williamson, C.E. Alexander, O. Gonzalez-Pagan, C. Kontak, and S.E. Mulkey. 2008. Reducing energy inputs in the US food system. Human Ecology 36:459–471.

Reganold, J.P., D. Jackson-Smith, S.S. Batie, R.R. Harwood, J.L. Kornegay, D. Bucks, C.B. Flora, J.C. Hanson, W.A. Jury, D. Meyer, A. Schumacher Jr., H. Sehmsdorf, C. Shennan, L.A. Thrupp, P. Willis. 2011. Transforming US agriculture. Science 332:670-671.

REN21 (Renewable Energy Policy Network for the 21st Century). 2009. Renewables global status report: 2009 update. Paris, France: Renewable Energy Policy Network for the 21st Century Secretariat.

Rifkin, J. 1992. Beyond Beef. New York: Dutton Books.

Rosen, S., S. Shapouri, K. Quanbeck, and B. Meade. 2008. Food security assessment. 2007. USDA, Economic Research Service, Report GFA-19. Washington, DC: USDA.

Royal Society. 2009. Reaping the benefits: Science and the sustainable intensification of global agriculture. London: The Royal Society. http://royalsociety.org/Reapingthebenefits/.

Rubin, J. 2009. Why Your World is About to Get a Whole Lot Smaller: Oil and the End of Globalization. Canada: Random House.

Siebert, S., J. Burke, J.M. Faures, K. Frenken, J. Hoogeveen, P.D. Döll, and F.T. Portmann. 2010. Groundwater use for irrigation—a global inventory. Hydrology and Earth System Sciences 14:1863–1880.

Solley, W.B., R.R. Pierce, and H.A. Perlman. 1995. Estimated use of water in the United States. US Geological Survey Circular 1200. Denver, CO: US Geological Survey.

TERRASTAT. 2010. Land resource potential and constraints statistics at country and regional level. Rome, Italy: Food and Agriculture Organization of the United Nations, TERRASTAT. http://www.fao.org/ag/agl/agll/terrastat/.

Time Magazine Staff. 1941. WAR AND PEACE: Food: A Weapon. New York: Time Magazine.

Torcellini, P., N. Long, and R. Judkoff. 2003. Consumptive water use for US power production. National Renewable Energy Laboratory/TP-550-33905. Golden, CO: National Renewable Energy Laboratory.

United Nations. 2007. World population prospects: The 2006 Revision. Department of Economic and Social Affairs, Population Division, Working Paper No. ESA/P/WP.202. New York: United Nations Department of Economic and Social Affairs.

USDA NRCS (Natural Resources Conservation Service). 2009. National Resources Inventory—2007 NRI. Washington, DC: USDA Natural Resources Conservation Service. http://www.nrcs.usda.gov/technical/nri/2007/nri07erosion.html.

USDA NRCS. 2012. What Is Soil? Washington, DC: USDA Natural Resources Conservation Service. http://soils.usda.gov/education/facts/soil.html.

Warkentin, B.P. 2006. Footprints in the Soil: People and Ideas in Soil History. Amsterdam: Elsevier.

World Hunger Education Service. 2012. 2012 World Hunger and Poverty Facts and Statistics. Washington, DC: World Hunger Education Service. www.worldhunger.org/articles/Learn/world hunger facts 2002.htm#Number_of_hungry_people_in_the_world.

Yang, Y., Y. Yang, J. P. Moiwo, and Y. Hu. 2010. Estimation of irrigation requirement for sustainable water resources reallocation in North China. Agricultural Water Management 97:1711-1721.