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Comparing 20th Century Trends in U.S. and Global Agricultural Water and Land Use

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Abstract: *Globally and in the United States, agriculture is the major user not only of water but also of land. This paper compares trends in aggregate and per capita water and land use by the agricultural sector in the United States and the world during the 20th century. It finds that although cropland use per capita has been declining in both areas since the early 1900s, agricultural water use per capita only began declining in the latter half of that century. That the increases in efficiencies of agricultural water use lagged behind the increases in the efficiency of cropland use is consistent with the fact that farmers (and farming communities) have traditionally had stronger property rights to their land than to their water. As a result, through much of the 20th century, farmers had a greater incentive to improve the efficiency of land use than that of water use and to substitute water for land (or irrigated land for dryland) in producing crops.*

Keywords: *Water use, agriculture, cropland, trends, land use, property rights, environmental transition.*

Introduction

Land and water are probably the two most critical natural resource inputs for agriculture. Predictably, no other human activity uses more land and water than agriculture. Worldwide, agriculture accounts for 38 percent of land use, 66 percent of freshwater withdrawals, and 85 percent of freshwater consumption (FAO, 2001; Shiklomanov, 2000). Not surprisingly, agriculture can have a critical impact on terrestrial and freshwater habitats, ecosystems, and biological diversity (Wilson, 1992; Goklany, 1998; 1999a; IUCN, 2000).

It is generally recognized that conversion of land to agricultural uses is probably the single most important threat to terrestrial biodiversity. According to the IUCN (2000), habitat loss and degradation, to which agriculture is a major contributor, affect 89 percent of all threatened birds, 83 percent of threatened mammals, and 91 percent of threatened plants that the organization assessed.

Similarly, the diversions of water for agriculture and the pollution generated by agricultural practices contribute significantly to the threats facing many freshwater species (IUCN, 2000; Wilson, 1992). Although global information is poor, it is estimated that about 20 percent of freshwater species are threatened, endangered, or extinct due to a variety of causes, including agricultural demand (IUCN, 1999).

In the following, I will compare trends in agricultural land and water use in the United States and worldwide during the 20th century, and discuss why these trends might not run in parallel.

U.S. Trends: 1910 to 1998

In the U.S., as in the rest of the world, agriculture is the predominant user of water and land. In the U.S., it accounts for one-third of surface water withdrawals and two-thirds of groundwater withdrawals (Solley et al., 1998). More significantly, it is responsible for 85 percent of consumptive water use (Solley et al., 1998). With respect to land, cropland accounts for 17 percent of the land area outside of Alaska (which has very little agricultural potential), and land in farms accounts for three times that (U.S. Bureau of the Census, 2000; U.S. Department of Agriculture, 2001a).

Between 1910 and 1995, the U.S. population increased by 184 percent. Despite the increase in food demand, cropland harvested declined 7 percent; on the other hand, total water withdrawn (used) for irrigation increased by 243 percent (Figure 1) (U.S. Bureau of the Census, 1975; 2000; Gleick, 1998; Solley et al., 1998; U.S. Department of Agriculture, 2001b). Over the same period, yields per unit of land increased substantially for many of the major crops. For instance, corn and wheat yields increased by 307 and 162 percent, respectively (U.S. Bureau of the Census, 1975; U.S. Department of Agriculture, 2000).

Figure 1 also shows that the amount of irrigated land increased by 353 percent from 1910 to 1995. However, a

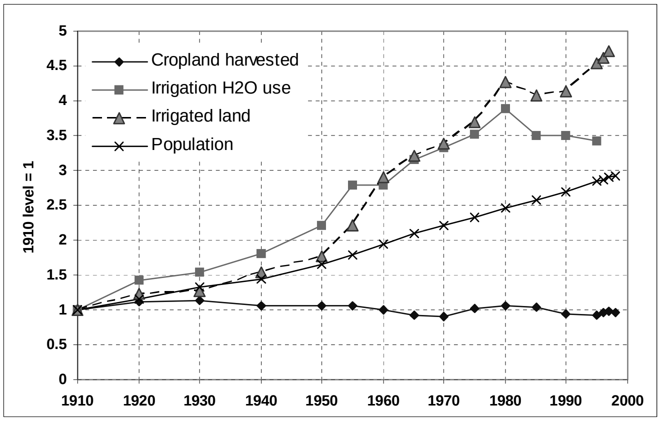

Figure 1. U.S. cropland and irrigation water use, 1910 to 1998. Sources: USBC (1975, various years); Solley et al. (1998); Gleick (1998); USDA (2001a).

word of caution is needed regarding these data which are interpolated from data provided in the periodic Censuses of Agriculture gathered until 1997 by the Department of Commerce (U.S. Bureau of the Census, 1975; U.S. Department of Agriculture, 2001b). The latest (1997) Census which, for the first time, was gathered by the U.S. Department of Agriculture shows a very rapid increase since the early 1990s in the amount of irrigated land, but another data set collected by the U.S. Geological Survey (Solley et al., 1998) shows a much smaller increase. A comparison of the Census of Agriculture (interpolated) estimates with the USGS's estimates from 1960 through 1995 show that the latter's figures are consistently higher by 10 to 25 percent.

The contrast in U.S. trends in per-capita cropland, irrigation water use and irrigated land is illustrated in Figure 2. As noted elsewhere, per-capita indicators (like per-GDP indicators) are *leading indicators* in societies where population (or GDP) is growing (Goklany, 1999b). That is, one cannot, for such societies, expect to see a downturn in aggregate indicators unless they are preceded by or, at the latest, concurrent with downturns in their corresponding per-capita (or per-GDP) indicators. And, in fact, comparing Figures 1 and 2, we see that cropland per capita has been declining at least since 1910, while aggregate cropland has remained more or less stable with perhaps a minor peak around 1930. With respect to irrigation water, both aggregate and per-capita levels have been declining since around 1980. Notably, between 1910 and 1995, cropland per capita declined by 67 percent while irrigation water use per capita and irrigated land per capita increased 20 and 59 percent, respectively.

Figures 1 and 2 show that between 1910 and 1950 U.S. irrigation water use grew more rapidly than irrigated land, but this trend was reversed in the 1950s. Currently, irrigated land seems to be increasing at a faster rate than irrigated water use.

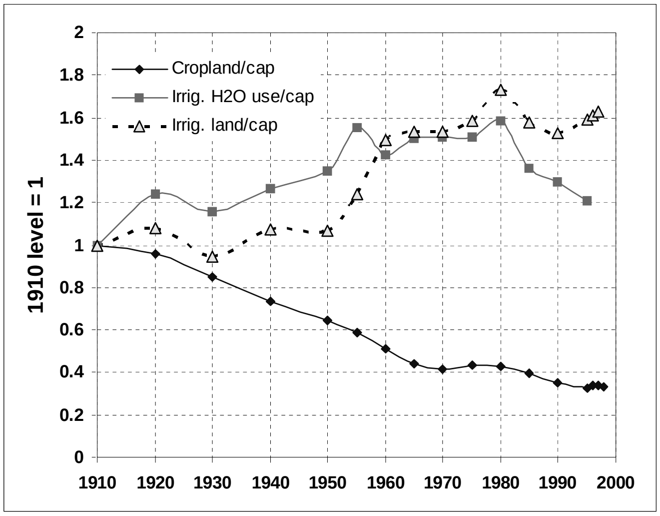

Figure 2. U.S. per capita cropland and irrigation water use, 1910 to 1998. Sources: USBC (1975, various years); Solley et al. (1998); Gleick (1998); USDA (2001a).

Global Trends: 1900 to 1997

Figure 3, which shows global trends in aggregate land and water use and consumption by agriculture between 1900 and 1997, suggests that they are on paths similar to that of the United States, except they are not as far along. This figure is based on water and irrigated land data from Shiklomanov (2000), population data from McEvedy and Jones (1978) and FAO (2000), and cropland data from Goklany (1999a) and FAO (2000). Since the FAO's data for cropland began in 1961, cropland for 1960 is extrapolated using 1961 and 1962 data. This figure also shows that while cropland seems to be leveling off (Goklany, 2001a), agricultural water use and consumption, and irrigated land area continue to increase, although much less rapidly than in the past. Moreover, during this period, rela-

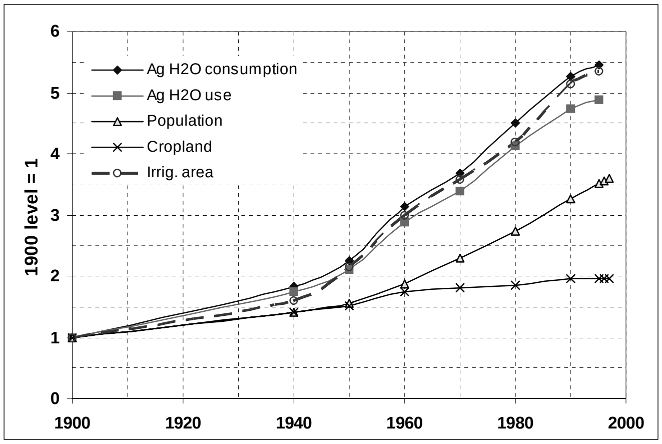

Figure 3. Global cropland and agricultural water use, 1900 to 1997. Sources: Shiklomanov (2000); McEvedy and Jones (1978); Goklany (1999a); FAO (2000; 2001).

tive to population growth, water use and consumption have increased much more than has cropland. Between 1900 and 1995, the population increased 251 percent, cropland increased 95 percent, and agricultural water use increased 388 percent. Agricultural water consumption and irrigated land area increased even faster — by 446 and 435 percent, respectively. Not surprisingly, the amount of irrigated land tracks relatively closely with agricultural water consumption because the two sets of data are related and come from the same source (i.e., Shiklomanov, 2000).

Figure 4 provides the same information, but on a per-capita basis, i.e., using leading indicators. This shows that cropland per capita has been declining since around the 1930s. Between 1900 and 1995, it dropped by 44 percent. On the other hand, per-capita agricultural water use and consumption both peaked around 1960. Although they have declined since then, per-capita withdrawals, per-capita water consumption due to agriculture and per-capita irrigated land were higher in 1995 than in 1900 (by 39, 56, and 52 percent , respectively).

Just as for the United States, Figures 3 and 4 shows that global agricultural water withdrawals and consumption grew more rapidly than irrigated land in the first four decades of the 20th century, but this trend has since reversed. Since 1980, irrigated land has increased at a faster rate than either agricultural water withdrawals or consumption. Between 1980 and 1995, irrigated land area increased 28 percent while water withdrawals and consumption increased by 19 and 21 percent, respectively.

Discussion

What accounts for the large differences in the trends for agricultural water and land use in both the U.S. and worldwide? Why has agricultural water use increased much more rapidly than land use? Why did increases in the efficiency of cropland use precede those of agricultural water use?

The Environmental Transition Hypothesis

The trends displayed in Figures 1 through 4 are consistent with the "environmental transition hypothesis" (Goklany, 1998; 1999b). This hypothesis is depicted graphically in Figure 5, where the y-axis indicates the environmental impact (EI) on or by a society as measured by a particular indicator. For example, it could be the air quality with respect to a specific pollutant. With respect to water resources, one measure of EI could be the irrigation water withdrawn or consumed; similarly, cropland use could serve as a measure of the human impact on the land (Goklany, 1996). The amount of irrigated land, however, does not fit neatly as a measure of EI solely for either land or water, although it might help explain some of the trends in both land and water use.

The x-axis in Figure 5 represents time, which serves as a surrogate for technological change (Goklany, 1999b). In most countries of the world, time has also brought with it affluence or economic development, (as measured by the gross domestic product per capita (Maddison, 2001). For the United States, for example, the correlation between affluence and time between 1900 and 1994 is 0.96 (Goklany, 1999b). Therefore, for most countries the x-axis could just as well be affluence.

Figure 5 shows that EI first goes up, then it goes through an "environmental transition" (ET) after which EI declines, at least until society deems that the indicator has been sufficiently reduced to a level corresponding to an environmental standard (i.e., society determines that it

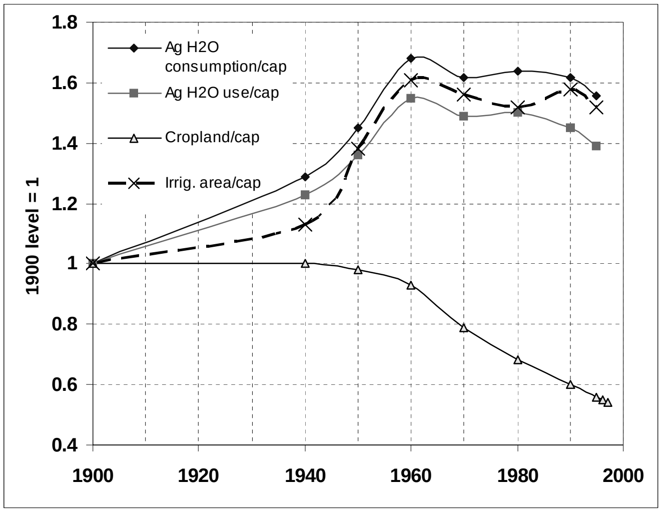

Figure 4. Global agricultural land and water use per capita, 1900 to 1997. Sources: Shiklomanov (2000); McEvedy and Jones (1978); Goklany (1999a); FAO (2000; 2001).

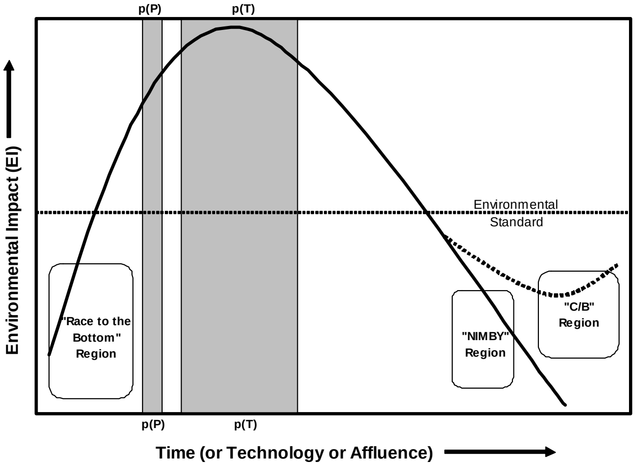

Figure 5. The Environmental Transition. Note: p(P) = period of perception; p(T) = period of transition; NIMBY region = "not in my back yard" region (EI enters this region if benefits far exceed costs borne by beneficiaries); C/B region = EI enters this region if costs and benefits have to be more carefully balanced. Source: Goklany (1999b).

is clean enough (Goklany, 1999b). Until that point, the trajectory for EI is shaped like an inverted-U (IU). For some indicators (e.g., sanitation or safe water), the transitions have historically occurred earlier in a country's developmental history (Goklany, 1995). For others, because the problem has yet to be addressed successfully (e.g., carbon emissions), a transition may not be evident, i.e., the country may still be on the upward slope of the ET.

In addition to the trends plotted in Figures 1 through 4 for cropland and irrigation water use and consumption, historical trends in many of the richer countries of the world for a variety of other environmental indicators also follow a path stylistically shown in Figure 5. These include various air quality related indicators for traditional air pollutants (such as lead, sulfur dioxide, particulate matter, and carbon monoxide (Goklany, 1999b), as well as indicators of water quality (e.g., dissolved oxygen levels, lead, and DDT (Goklany, 1994; 1998; European Environment Agency, 1998). However, data from developing countries often shows that their pollution levels are currently increasing, that is, they are on the ascendant part of the ET curve (Goklany, 1994).

An explanation offered for an environmental transition is that society is on a continual quest to improve its quality of life which is determined by numerous social, economic, and environmental factors (Goklany, 1995; 1998; 1999b). The weight given to each determinant is constantly changing with society's precise circumstances and perceptions. In the early stages of economic and technological development, which go hand-in-hand, society places a higher priority upon increasing affluence than on other determinants, even if that means tolerating some environmental deterioration because it provides the means for obtaining basic needs and amenities (e.g., food, shelter, water, and electricity) and for reducing the most significant risks to public health and safety (e.g., malnutrition, infectious and parasitic diseases, and child and maternal mortality). Also, in these early stages, society may be unaware of the risk posed by the environmental impact represented by EI. However, as society becomes wealthier, tackles the other, more significant problems and, possibly, gains more knowledge, reducing EI automatically rises higher on its priority list (even if EI does not worsen). But because economic activity frequently increases EI, lowering EI becomes even more urgent. Thus, the perception rises that environmental quality needs to be upgraded as a more important determinant of the overall quality of life. This stage is represented in Figure 5 as the period of perception or p(P) (Goklany, 1999b).

Prior to p(P) one should not expect society to require, or private parties to volunteer, to reduce EI, although reductions may occur due to secular improvements in technology or other reasons (Goklany, 1995;1996). For example, for SO_2 in the U.S., p(P) probably did not begin earlier than October 1948 when an air pollution episode in Donora, Pennsylvania, was associated with the 18 excess deaths in a population of 14,000, but indoor SO_2 levels had begun to improve before the 1940s (Goklany, 1999b). From p(P) onward, a democratic society will often translate its desire for a cleaner (or improved) environment into laws, either because improvements are not forthcoming voluntarily or rapidly enough, or because of sheer symbolism. The wealthier such a society, the more affordable –and more demanding – its laws.

At the same time, with increasing affluence and the secular march of technology, society is better able to improve its environmental quality. Affluence also makes research and development targeted on cleaner technologies more affordable, as it does the purchase and use of new or existing-but-unused cleaner technologies, especially if their up-front costs are higher. Thus, EI undergoes a period of transition. Ultimately, greater affluence and technological change should result in a decline in EI (Goklany, 1995; 1999b).

Note that the timing, height, and width of an ET curve for a specific indicator is unlikely to be the same for all countries. In general, all else being equal, latecomers to industrialization should have ETs occur at lower levels of affluence because they can learn and adapt technologies from early industrializers. And, indeed this seems to be the case worldwide since, by comparison with developed countries, many of today's developing countries have started to address environmental issues (such as safe water and sanitation, and lead, sulfur dioxide, and other air pollutants) at much lower levels of economic development and sometimes are actually cleaner (or better off) than developed countries were at equivalent levels of economic development (Goklany, 1995; 1999b; 2001a).

Other factors can also affect the timing of an ET and the level of affluence at which an ET occurs for a country. First, they depend on the precise indicator used to characterize EI and how closely it is tied to the perceived quality of life. This helps explain why in the U.S., for example, the transitions occurred earlier for indoor air pollution than for outdoor air quality, and for sulfur dioxide and particulate matter — pollutants most directly related to killer air pollution episodes of the 1940s and 1950s — than for less powerful pollutants such as nitrogen oxides and ozone (Goklany, 1999b). Similarly, we see that worldwide, countries attack problems of the lack of safe water and poor sanitation ahead of other forms of water pollution. Second, the timing, height, and width also depend upon the responsiveness of the government to the perceived needs and desires of the general public; thus, democracies are more likely to see earlier ETs. In addition, the political power of the sectors contributing to EI can affect the timing, height and width of the transition because that affects stringency of laws directed at them. Fourth, ETs are affected by the natural resource endowment of the country. The period of perception is more likely to be delayed for a country with plenty of water, for instance. Finally, the height and width will depend on the fiscal resources and human capital available and devoted to bringing about the environmental transition. The costlier or more difficult it is to bring about a transition, the more likely that its transition will be delayed, the width — the period of transition — might be wider, and the height at which the transition occurs will be greater. This helps explain why developing countries are still on the upward slope for many pollutants for which the richer countries have gone past their transitions. It also helps explain why greenhouse gas emissions, for example, continue to rise worldwide (Goklany, 1999b).

Notably, cross-country data for some pollutants also result in inverted-U (IU) shaped curves (called Environmental Kuznets Curves, EKCs) when EI is plotted against affluence (GDP per capita). Despite the superficial resemblance between the ET and EKC hypotheses, the two have significant differences. In the former, the environmental indicator is plotted for one country (or political group) at a time, and the x-axis represents time, a good proxy for both affluence and technological development (at least for the past two centuries; Goklany, 1999a; 1999b). However, for the EKC, the data are generally plotted for a set of countries, and the x-axis represents only affluence. In fact, Goklany (1999b) has shown that a set of single-country IU-shaped ETs does not necessarily result in an IU-shaped cross-country EI verses affluence curve, instead it could be N- or even U-shaped (Goklany, 1999b).

U.S. Situation

Figures 1 and 2 show that for the U.S., aggregate as well as per capita irrigation water use have gone beyond their environmental transitions (or peaks). Aggregate cropland is close to, and, perhaps, also past, the transition while cropland per capita is clearly past its environmental transition. These figures also indicate that although aggregate cropland has stayed more or less static for the 20th century, the increase in the productivity of agricultural land use substantially exceeds the increase in water use productivity. One possible reason as to why the decline in cropland per capita commenced earlier than agricultural water use per capita might be that land, in contrast to water, has often been privately owned. While there are several reasons why this has traditionally been the case (e.g., water supplies are uncertain and variable, not all its uses are rival, and water use can result in externalities; Livingston, 1998), private property rights to land provides its owner with powerful incentives to maximize long term productivity per unit of land, which will be discussed further. These incentives are less compelling where, as is the case for water, private property rights are either absent or unclear.

Notably, if U.S. agricultural technology and its penetration been frozen at 1910 levels, i.e., if cropland per capita stayed at 1910 levels, then in 1998 the U.S. would have needed to harvest 951 million acres rather than the 311 million acres that were actually harvested that year.

This calculation is based on three relatively optimistic assumptions. First, sufficient new cropland would be available, but this is unlikely since the total amount of potential cropland in the U.S. is estimated to be only 647 million acres (Goklany, 2001a, based on NRCS, 2001). Second, the additional cropland would be just as productive as existing cropland. Third, the productivity of existing cropland would be maintained without any new technologies. Clearly the increase in land productivity averted a potential catastrophe for biodiversity in the U.S. One can obtain another perspective on the amount of land saved from conversion when one considers that the total amount of land and habitat under special protection in the U.S. was 217 million acres in 1999. This includes National Parks, National Wildlife Refuges, and National Wilderness Areas.

By contrast, water use per capita increased between 1910 and 1995, possibly because water use is more dependent on political muscle and machinations than on economics. Once access to water has been secured, in the absence of the ability to sell excess water or transfer it to other users for compensation, the incentive to increase the productivity of water used in agricultural activities is limited. However, even where *de facto* water “rights” are not fully transferrable, there is an incentive to optimize water use within such constraints as exist. One method of doing this is to improve irrigation efficiency which, in turn, would allow more land to be irrigated. Let’s examine the U.S. experience more closely.

In the early part of this century, farmers and the agricultural sector had their way with water. However, throughout the 20th century, the demographic and economic power of the agricultural sector declined, while that of urban, suburban, and environmental interests – interests with broad overlap in membership – increased. Agriculture’s share of national income dropped from 18.9 percent in 1899 to 1903 to 7.2 percent in 1948 to 1953 and 3.1 percent in 1970 (U.S. Bureau of the Census, 1975). In 1899, agriculture accounted for 36.9 percent of the population engaged in production; by 1948 to 1953 that had declined to 10.6 percent before dropping to 4.3 percent in 1970 (U.S. Bureau of the Census, 1975). Concurrently, the percentage of the population in rural areas declined from 60 percent in 1900 to 41 percent in 1950 and 26 percent in 1970 (U.S. Bureau of the Census, 1975). Also by 1970, the demand for water and the costs of tapping new sources of water had gone up for all sectors. Thus, the politics and economics came together to enable the urban-suburban-environmental groups to often challenge agriculture’s claims to water. While all these challenges might not have been fully successful, they did serve by the 1980s to reduce the amount of water diverted as well as irrigation water use per capita (Solley et al., 1998; Postel, 1999). One of the adjustments made to cope with the difficulty of obtaining additional water for agriculture is to increase irrigation efficiency and expand the amount of land under irrigation. This would help account for the decline in the amount of irrigation water applied per acre of land from about 2.5 acre-feet in 1980 to 2.1 acre-feet in 1995 (Solley et al., 1998), and explain the rapid increase in irrigated land during this period even as irrigation water use declined.

Global Situation

Figure 3 shows that while aggregate cropland seems to be leveling off, i.e., approaching an environmental transition (Goklany, 2001a), aggregate water use and consumption as well as irrigated land use continue to increase, albeit less rapidly than previously. Moreover, except for cropland, they have all increased faster than population.

On a per-capita basis, however, cropland and irrigation water use and consumption have all gone past their environmental transitions. But these levels have not yet dropped off as much as the levels for the U.S.

Despite the pressures agriculture has brought to bear on global biological resources, similar to the situation in the U.S., those pressures could have been much worse had global agricultural productivity, and therefore yields, been frozen at, say, 1961 levels. This is equivalent to freezing technology, and its penetration, at 1961 levels. In that case, agricultural land area would have had to more-than-double its actual 1998 level of 12.2 billion acres to at least 26.3 billion in order to produce as much food as was actually produced in 1998 (Goklany, 2001b). Thus, agricultural land area would have had to increase from its current 38 percent to 82 percent of global land area (FAO, 2001a; Goklany, 2001b). Cropland would also have had to more-than-double, from 3.7 to 7.9 billion acres. In effect, an additional area the size of South America-minus-Chile would have to be plowed under. Thus increased land productivity forestalled further increases in threats to terrestrial habitats and biodiversity.

However, these improvements were not matched by similar increases in efficiencies of irrigation water use. Not surprisingly, some analysts now believe that the major resource constraint for being able to satisfy future global demand for food is likely to be water rather than, as Malthus and others had traditionally thought, land (FAO, 1996; Postel et al., 1996; Pimentel et al., 1997; Postel, 2000).

A similar rationale as was suggested for the U.S. also helps explain the global lag in the increase in water use efficiency relative to the increase in cropland efficiency, namely, in most areas of the world, farmers have some property rights to their land but often not to water; nor is water usually treated as an economic commodity in other ways. In fact, the tremendous increase in irrigation worldwide over the past few centuries (L'Vovich et al., 1990; Goklany, 1998) and the U.S. (Gleick, 1998) could be viewed, at least in part, as the substitution of often-subsidized water for land, proving Anderson's (1995) statement that when water is cheaper than dirt, it will be treated that way.

Property rights include long-term tenure to land, the right to trade, and the right to profits from selling products and improving productivity (Goklany and Sprague, 1991; IPCC, 1991; Taylor, 1997). Farmers would not invest – a euphemism for risk-taking – their time, money, and effort to increase productivity and efficiency without such rights, which include their right to profit from such investments. Property rights also provide an incentive for the farmer to engage in long term sustainable practices.

A good example of the beneficial effects of property rights comes from China's experience in improving agricultural productivity in the early 1980s, and its subsequent slowdown in improving yields (Prosterman et al., 1996). In the early 1980s, Chinese farmers were given an albeit imperfect measure of property rights to a portion of their produce. The rate at which agriculture productivity increased annually soared, only to decline again because when it became clear that long term tenure was not yet forthcoming, farmers held back further investments in "their" plots.

Not surprisingly, Gwartney et al. (1998) find cereal yields increasing across countries with their degree of economic freedom, which Norton (1998) has argued, serves as an aggregate measure for the deference given by a country to property rights since it includes components for the security given to property rights under law as well as components which would diminish those rights indirectly through inflation or through limitations on the freedom to trade or exchange. Norton also finds that rates of deforestation decline with increased property rights. These two sets of results — increased yields and lowered deforestation — are consistent with the notion that higher agricultural productivity leads to greater land conservation (Goklany and Sprague, 1991; IPCC, 1991; Goklany, 1998; 1999a).

On the other hand, the failure to develop and assign property rights to water only encourages waste and reduces incentives to adopt existing or develop new conservation, re-use, or recycling technologies. To make matters worse, on the basis that water is crucial to mankind, most societies subsidize its use, particularly in agriculture (Anderson, 1995; Pimentel et al., 1997). But, perversely, such subsidies further reduce the incentive for conservation. Predictably, water conservation technologies remain under-utilized and under-researched. Yet another perverse consequence of these subsidies is that in many urban areas in the developing world, the poor pay more for water than do the middle and upper classes that are connected to subsidized municipal water systems (Serageldin, 1995). Ironically, many in these subsidized groups are happy enough to pay larger sums for Coca Cola or Pepsi even when they are not needed to quench their thirst.

If institutions and policies are modified to price water, and private entities are assigned transferrable property rights to water (which would encourage markets and trading in water), then it might be possible to replicate for water the almost universal historical experience with land which shows the latter's use being made progressively more efficient. The success of such policies has been demonstrated in cultures as diverse as the U.S., Chile, Jordan, India, Pakistan, and Indonesia (Anderson 1995; Rosegrant et al., 1995; Serageldin, 1995; Easter et al., 1998). For example, in Chile water trading increased efficiency of water use by 22 to 26 percent between 1976 and 1992, effectively expanding irrigated area by that much (Rosegrant et al., 1995). The experience in India and Pakistan shows that gains in efficiency can be obtained even where markets are based on informal and imperfect property rights (Saleth, 1998; Meinzen-Dicks, 1998).

The environmental benefits of property rights are also evident in other arenas. For example, with respect to air pollution, the initial major improvements in air quality came in the first half of the 20th century when households and businesses began switching from coal and wood burning stoves and fireplaces to oil and gas, while others adopted more efficient combustion equipment and practices (Goklany, 1996; 1999b). By and large, homeowners and businesses undertook these measures willingly because they were cleaning up their own private property and were confident that their investments would result in direct benefits by reducing smoke, dust, and grit to themselves, their families, and, in the case of businesses, their employees and customers. No less important was the fact that the use of newer, more efficient technology reduced their fuel costs. Thus, by virtue of the institution of property rights, they had an economic as well as an environmental incentive for cleaning up.

The ability of property owners to capture the economic benefits associated with greater efficiency also provided much of the impetus behind the secular improvements in technology which helped reduce emissions per GDP for sulfur dioxide, volatile organic compounds, nitrogen oxide pollutants, and long before any of these substances were generally recognized to be environmental problems or, for that matter before the Federal government got involved in air pollution control (Goklany 1999b). SO_2 was not perceived to be a public health problem until after the Donora, Pennsylvania episode in 1948 and the London episode of December, 1952, yet SO_2 emissions per GDP have been in decline since the early 1920s. Similarly, VOC and NO_x emissions per GNP have been dropping nationwide since the 1930s, decades before these substances were either implicated (in the 1950s) as being responsible for the formation of photochemical smog or recognized (in the late1960s and early 1970s) to be nationwide air quality problems (Goklany 1999b). Likewise, CO_2 emissions per GDP have been declining at the rate of 1.3 percent per year for the past century and a half, long before global warming hit the public consciousness in the late 1980s.

Summary

Agricultural land and water use in the U.S. and worldwide are currently among the primary pressures on terrestrial and freshwater habitats, ecosystems, and biodiversity. These pressures could be much worse but for the increased productivity of land in agriculture over the past century. But this increase in land productivity has not been matched by a similar increase in agricultural water productivity. This leads to one of the most interesting conundrums in natural resource use, namely, why have the spectacular decades-long increases in agricultural productivity per unit of land in the U.S. and worldwide not been matched by comparable increases in productivity per unit of water?

If anything, it seems that water was substituted for land in order to boost productivity. As a result the availability of water might well become the major impediment to resolving the dilemma inherent in satisfying global food and fiber needs while conserving habitat and maintaining biodiversity.

The differences in the trends for agricultural land and water use could partly be due, if not substantially due, to the almost universal differences in the institutional arrangements for the use and management of these two critical natural resources around the world. Establishing and conferring well-defined property rights for water similar to those for land would harness the forces unleashed by the marketplace, including the force of human ingenuity, in the service of agricultural water use efficiency. The resulting improvements in water use efficiency might help defuse one of the most critical natural resource challenges looming in our future: namely how to meet human needs for food and fiber while sparing not only enough land but also enough water for the rest of nature.

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Discussions open until March 1, 2003.

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