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Agricultural technology and its societal implications

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Abstract

Although the refinement of laboresque technologies that save farm labor continues, its boom (in terms of sheer number of machines) passed during the quarter-century lifetime of *Technology in Society*. Instead, landesque technology, which spares land, holds the spotlight. Landesque is exemplified by high-yielding varieties, the Green Revolution, and genetically modified organisms. The contribution of landesque technologies to national performance can be charted on a plane with the dual dimensions of sustainability: 1) present need and 2) environmental impact. In the dimension of need, national crop production has increased. In the dimension of environmental impact, landesque technology plus consumption that increases more slowly than income has countered population and wealth to steer national journeys toward sustainability. On the sustainability plane, the genius to discover new landesque technology and the courage to apply it can steer nations toward still greater production without veering toward higher impact.

Keywords: Green Revolution; Sustainability plane; Genetically modified organisms; Cropland; Irrigation; Landesque; Laboresque

1. Introduction

Farm technology freed people from spading, hoeing, and stooping in a hot sun. It freed them from gleaning skimpy seed, enabling them to reflect and invent. Thus, despite its prehistoric origins and hayseed caricature, farming is the Mother of Invention of all technology. Within the quarter-century lifetime of *Technology in*

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Society, one spotlight has been cast on the high yields of the Green Revolution, another on genetically modified organisms (GMO).

Agriculture's characteristics impart peculiarities to the nature and implications of farm technology. For example, the utter dependence on food from farming ties societal failure to agricultural failure, absolutely. Agriculture characteristically deals almost wholly with living things. At its core the agricultural business captures solar energy in green foliage, photosynthesizes the energy into food, sometimes transforms the food into meat or milk from animals, and finally harvests the food for another living organism—ourselves. Farmers capture the fundamental energy in sunlight by spreading green crops further across the landscape than any factory spreads its work. Because farm crops alone occupy 11% of global land and 20% of US land, agriculture is outdoorsy and thus intimately linked to the natural environment. Agriculture depends on the environment, and the environment depends on farming. Agriculture's peculiarities make its technology irreplaceable for society, make its technology biological as well as mechanical, and place it at the crossroad where demand for human well-being meets demand for environmental well-being.

Some technology saves labor and can be called *laboresque*. Other saves land and can be called *landesque* [1]. Emphasizing crops, I shall describe both sorts of technology and then their societal implications.

2. The technologies: Laboresque

A reader might well equate farm technology with the mechanical inventions that began with a pointed stick and curved sickle and continued with Jefferson's moldboard plow and McCormick's reaper. Mechanical invention has accelerated until the present day when it is exemplified by combine harvesters driven by operators cooled by air-conditioning, or fertilizer applicators tuned to square meters of field by global positioning systems.

The acceleration of invention enabled me to witness a transformation. As a boy, I toted a jug cooled by a wrapper of wet burlap past a shaking thresher joined to a chugging engine by a flapping belt. I carried water to men pitchforking oat sheaves onto wagons drawn to the quaking thresher by teams of horses. Luckily, the women who cooked the meal for threshers gave the water-boy a pass to sit at the table among grown men, and thus I heard them compare the virtues of old horses burning oats from the farm versus new tractors burning petroleum from Texas. The tractors won and multiplied five-fold from 1930 to 1955. By 1955, however, their heyday of expansion was past in the US.

On the other hand, in a developing nation such as India, the heyday was just beginning as tractors spread at 10% per year or faster from 1975 to 1985. After that decade, just as earlier in the US, the increase of tractors in India decelerated to only 5% per year during the final decade of the century. No doubt horsepower continued growing after the number of tractors stopped rising. As happens with technology generally [2], tractors rose from 10 to 90% of their maximum number

faster in the late adopter, India, than in the earlier adopter, the US. Surprisingly, the number of US grain combines also leveled and after 1960 actually decreased. Thus, although the refinement of mechanical technology on the farm has continued, the boom of sheer number of agricultural machines passed during the lifetime of *Technology in Society* [3,4].

The refinement of machinery is exemplified by modern equipment guided by GPS to deliver fertilizer prescriptions to each square meter of a field. *Precision agriculture* captures the promise of increasing productivity while minimizing production costs and environmental impacts. Precision agriculture conjures up images of farmers applying intensive care with detailed maps, soil analyses, and then computerized machinery that is precisely controlled via satellites, local sensors, and software [5].

3. The technologies: Landesque

3.1. High-yielding varieties

During the lifetime of *Technology in Society,* the high yields of the Green Revolution and the GMOs of biotechnology have taken center stage.

The Green Revolution traces its roots to about 1940 when Vice President Wallace of the US attended the inauguration of President Camacho of Mexico. Then the Rockefeller Foundation commissioned three scientists to visit Mexico. In their satchels they carried a wealth of knowledge about agronomy, plant breeding, plant protection—and about 75 years of experience, largely at US land-grant colleges [6]. The establishment of the International Rice Research Institute in 1960 and the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) in 1966 were other notable occurrences. From the seed that had been planted earlier, high-yielding varieties, such as wheat, diffused across the developing world during the final quarter-century of the millennium. The shining success of high-yielding varieties came to be known by the name "Green Revolution," and the 1970 Nobel Peace Prize bestowed on Norman Borlaug, a leader of the Revolution, may blind us to the broader, deeper, and later penetration of the varieties [7].

Early success with wheat and rice rested on extensive breeding experience and rich genetic resources in developed countries. Unlike former varieties that put much energy into straw and foliage, early high-yielding varieties channeled more energy into grain, and the new varieties benefited from fertilizer and prospered under irrigation.

During the following decades, extension of breeding to other crops took more time. Uncovering genetic stocks and building experience with crops like cassava and tropical beans took time. Extending into diverse crops required the development of partnerships among international and national experiment stations. Varieties had to be attuned to a wide spectrum of climates and soils encountered by real farmers. Surprisingly, the Green Revolution's high-yielding varieties boosted yields more during the period 1981 to 2000 than from 1961 to 1980.

A century earlier, another event had a major effect on the Green Revolution. In 1840 Justus Von Liebig published his *Law of the Minimum*: whatever is limiting will continue limiting, no matter what else is added (such as high-yielding varieties). So, while Green Revolution varieties raised the botanical limit, they could not raise yields until farmers also raised the limits imposed by fertilizer and water. Thus, while new varieties might contribute half the improved growth of Asian crops from 1981 to 2000, for example, the technology of nitrogen fertilizer was crucial. In the past, farmers depended on clearing new land and mining its nitrogen supply. They depended on manure, shoveled from the barn or imported from natural deposits. Or they depended on legumes fixing nitrogen from the air. When synthetic nitrogen fertilizer became economical after World War II, farmers applied it, displacing nitrogen from manure or from land-using legumes. They did less land clearing because synthetic fertilizer allowed them to plant the same fields year after year. Although the exponential rise in fertilizer use sparked alarm among environmentalists, real use soon leveled off. After 1975, the nitrogen applied per crop production often declined, demonstrating improved efficiency as the lifting of limits let high-yielding varieties produce improved outputs [8].

Irrigation lifts the limitations imposed by water. While building dams and channeling water results in more irrigation water, technology that conserves water also makes the water go farther. Although gravity spreads water across about half of the irrigated fields in the US, the acreage that is irrigated that way declined 20% from 1979 to 1998. In absolute acreage, more efficient sprinkler irrigation expanded most. In relative terms, however, trickle and drip irrigation expanded the most, quintupling from negligible in 1979 to 4% in 1998. By wetting less soil surface and decreasing evaporation, trickle and drip methods conserve water [9].

High-yielding varieties that put more photosynthate into grain and fruit and less into stems and pests conserve more water per crop because a bumper crop may evaporate and transpire little more water than a skimpy or pest-ridden one. Also, when a valuable crop and a cheap crop evaporate similarly, the valuable crop yields more social value per liter of water than the cheap crop does. The 15% of irrigated area in the US West, which grows valuable orchards and nurseries, vegetables and berries grew 60% of the dollar income [10]—far more dollars per liter of water.

3.2. Biotechnology

Today the spotlight shines brightly on genetic engineering or recombinant DNA technology. All organisms contain a blueprint of molecules in their cells called DNA, which determines development and growth. Genetic engineering manipulates DNA to change hereditary traits or produce biological products. Unlike conventional breeding, which is limited by barriers between species, genetic engineering allows DNA exchange even across kingdoms. Genetic engineers cut up DNA strands and transfer genes from one organism to another across the barriers between species and even between microorganisms and crops. The resulting GMO might be a plant that produces a natural pesticide for insect control; it might be

herbicide tolerant and so enable more environmentally friendly weed control. These pest-control characteristics have dominated practical GMOs thus far.

Farmers have adopted GMOs at amazing rates. GM soybeans that tolerate herbicides have expanded from 2% of US acreage in 1996 to fully 74% in 2002. Insecticide-producing GM cotton expanded to 70% and corn to 32% of US acreage in 2002. The global area of GM crops of all species increased an average 60% per year from 1996 to 2002, attaining 59 million ha in 2002, which can be visualized as one-fourth of the global area of corn plus cotton plus soybeans [11,12]. Farmers are adopting GMOs as fast as Iowa farmers took up hybrid corn six decades ago [13].

4. Societal implications: Laboresque

Cotton pickers exemplify laboresque machines that affected society. An index of cotton output per man-hour rose forty-fold from 1939 to 1986, the last year of the data series [14]. Although the northbound migration of workers is associated with World War II, the index of output per man-hour rose most rapidly in the 1970s. Did cheaper mechanical cotton harvesters drive out workers, or did better jobs elsewhere draw them away? One scholar concluded that falling demand for labor propelled the workers; another that the mechanized cotton picker emancipated workers from backbreaking labor and emancipated the South from its dependence on cotton and sharecropping [15,16]. Either way, machinery surely cut the number of laborers in cotton fields, they went elsewhere, and society felt the impact. Similar stories might be told about milking machines, automated feeders, and hired hands who squeezed teats and scooped feed. Inevitably, farms grew larger.

Another way to examine the societal implications of laboresque equipment is to ask why farmers choose a technology. Although a more efficient machine might seem irresistible, Hayami and Ruttan [17] argued that a change in the relative endowments of resources induces technical change, and updated data support their argument [18]. Imagine a labor-land map with output per laborer increasing eastward and output per land area increasing northward. On those labor-land coordinates in 1880, greater output per manpower in labor-poor US put it east of Japan and European nations, which had more abundant labor. Higher output per area in land-poor nations, on the other hand, put them north of the US on the labor-land map. During the century since 1880, the agriculture of all nations moved northeast toward better land and labor efficiency on the labor-land map. Nevertheless, the labor-poor US stayed further east in the labor-efficient longitudes than the other nations,[1] and as expected, the land-poor nations stayed further north in the land-efficient latitudes than the US.

Hayami and Ruttan carried their reasoning further. They argued that, in addition to prompting farmers' choice of technology, shortages and costs induce

[1] Improvement of labor productivity in nations other than the US, especially European but not sub-Saharan Africa, can be seen in the labor-land map [18].

scientists and engineers to develop more appropriate technology over time. The invention of the reaper and cotton picker in the labor-poor US illustrates induction.

In the US from 1910 to 1940, labor input changed little. Then from 1940 to 1975 it plummeted. Then since 1975 labor input again remained stagnant, indicating that US farmers made their awesome labor savings before the birth of *Technology in Society* [14,17].

5. Societal implications: Landesque and the sustainability plane

5.1. High-yielding varieties

Near the beginning of *Technology in Society*, agricultural shortages and widespread hunger made plain that freedom from hunger outranks freedom from drudgery in the scale of societal implication. Russian wheat deals, Indian hunger, and American soybean prices fueled fears that the world could not feed itself. At the millennium a quarter century later, two examples made it clear that high-yielding varieties not only fed more people, they fed them better. While India's population rose 1.9% per year from 1975 to 2000, a price-weighted index of food production, which rose 2.6%, outdistanced it,feeding people better.[2] In the US, a 1.6% per year increase in food production outdistanced a 1.0% per year population increase, and the first societal implication of agricultural technology—a well-fed humanity—turned out to be a happy one. However, the environmental worries marking the first Earth Day about a quarter-century ago, and deepening even further since then, add a second societal implication for agricultural technology: at what cost to man's natural surroundings were more people fed better?

Despite growing environmental worry, in 1982 when the United Nations started the World Commission on Environment and Development, which took Chairman Bruntland's name, the planners decided that considering environment *alone* would be a grave mistake [19]. Humanity's needs persist on a par with environmental sensibility, thus confronting society with a dilemma of dual anxieties.

The Bruntland Commission responded to the dilemma by seeking ways to achieve *sustainability*. Sustainability's dual goals were (1) meeting our needs now, and (2) not compromising future generations' ability to meet their needs. With the dual dimensions of need and environment, Bruntland moved beyond one-dimensional economic development and one-dimensional environmental control. By stipulating two dimensions, Bruntland made humanity's common journey to sustainability[3] into an odyssey across a two-dimensional plane. One dimension—line;

[2] Both the US Department of Agriculture and FAO report price-weighted indices of crop production [3,4]. Unlike, say, tons of cereal, the indices give credit for growing what society demands. Tons of cereal that rose as fast as 4% per year in the 1960s has slowed to less than 1% per year recently. Because the index credits improvement in value as well as quantity, the indices have consistently risen 2–3% per year since 1961.

[3] Using the analogy of a journey, the US National Research Council entitled its 1999 study of sustainability, *Our Common Journey* [20].

three dimensions—volume; but two dimensions—sustainability. On the planes charted in Fig. 1, tangible longitude represents the need for food, and concrete latitude shows hectares of environmental impact. From left to right, food production increases from scarce to abundant. From bottom to top of the plane, impact rises from unused and pristine to cropped and impacted. In the northwest lies the plowed-hungry shoal. In the southeast lies the pristine-plump haven.

As a nation navigates on the sustainability plane, many grasp the tiller. Naming them and assigning responsibility reveals what has been done. An identity links the national latitude of hectares cropped to five variables:

$$\text{Cropland} = \text{Population} \times \text{GDP/Person} \times \text{Food/GDP} \times \text{Crop/Food} \times \text{Land/Crop}$$

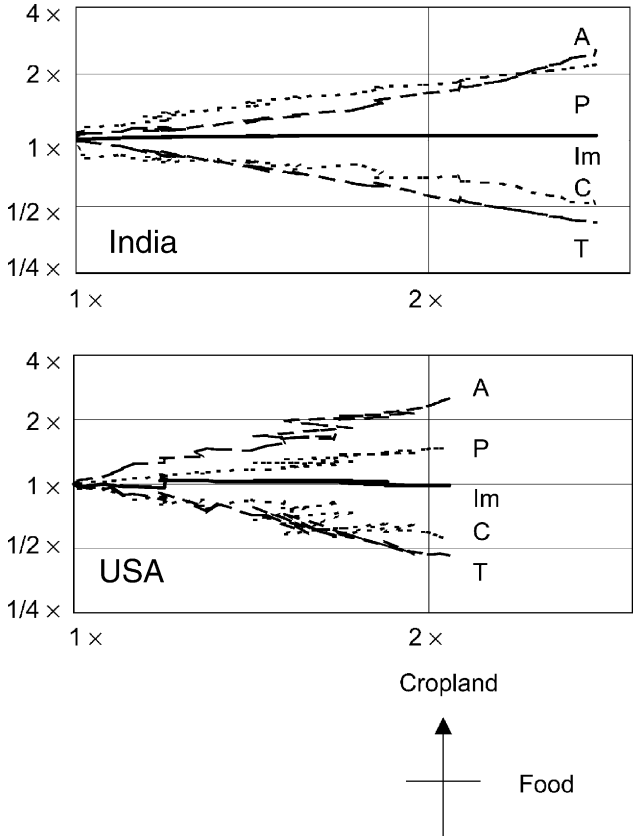

Fig. 1. Indian and US journeys on a sustainability plane where longitude is food production. Latitude is the impact Im of cropland area, which is the net of the leverages P population, A income, C food per GDP and T cropland per crop. The logarithmic scales are marked in multiples. Year-to-year decreases of production caused westward zigs in the curves. Sources: FAO [4] and World Bank *World Development Indicators.*

Call cropland expanse the impact *Im*. Omit the ratio *Crop/Food*, which changes little. Taking Bunyan's *Pilgrim's Progress* as a model, name four actors: Parent, Worker, Consumer, and Farmer. Let P be Parent's population and A the affluence or *GDP/Person* which Worker produces. Make C the *Food/GDP* showing how much income Consumer spends on food. Last is T for *Land/Crop*, the technology Farmer uses to lift yield and shrinks the land needed to grow the crop. The ImPACT identity follows [21]:

$$\mathrm{Im} = \mathrm{P} \times \mathrm{A} \times \mathrm{C} \times \mathrm{T}$$

India's journey on the plane in the upper portion of Fig. 1 began in 1961, the first year of the FAO record [4]. The nation moved eastward across longitude measured as the logarithm of increasing food production; the scale is marked in multiples of one and two times 1961 production. At first, less Indian food production put some early years west of the 1 × 1961-production axis, but then India moved eastward toward more food. Up and down the latitude of impact, the actors traced paths labeled P, A, C, and T. Year-to-year decreases of production caused westward zigs in the curves. On the logarithmic ordinate of the chart, the four leverages P, A, C, and T are added and subtracted to achieve a net impact *Im* that scarcely changed.

One can easily backslide into writing about rates per year and neglect headings on the sustainability plane. That is a mistake, because plotting impact on a timeline relates environmental cost to the passage of years—a goal only a child could love. Instead, mapping impact on the sustainability plane relates the environmental cost to food production—a goal all enjoy. The slopes, tangents, or headings measured relative to a straight-east path of unchanging impact show the four actors' leverage on the Indian and US tillers during their journeys of rising food production.

The ratio of the percent change of a leverage to the percent change of food could be called its *food elasticity*. The sum of the headings P, A, C, and T equals the heading of impact *Im*. Although Indian P contributed a more northward direction to its heading than did its A, its rising income is now outdistancing its population change on the plane. The sustainability challenge posed by combined P plus A was much the same from 1961 to 2000 in developing India and developed US.

Economists have Engels Law which says more income will increase food consumption but decrease the fraction of income spent on food. As food production increases eastward on the sustainability plane, a southward movement of C, the ratio of food to GDP, manifests Engels Law.[4] Nevertheless, the net of Parents, Workers, and Consumers would have expanded the impact of cropland, steering *Im* northward toward the higher latitude and impact of expanding cropland.

Fortunately, Farmer's technology T almost exactly countered the net leverages of P, A, and C. In both India and the US, the land to grow a unit of crop shrank

[4] Although I neglected change in crop/food in assigning symbols to the ratios, a slight decrease in crop/food caused by improving food quality reinforced C's decline in both nations.

about 2% per year, steering T southward on the plane. On the sustainability plane, of course, the heading rather than rate per year matters. Roughly, doubling crop yields halved the land to produce a unit of food, steering T southeast with a heading of −1 on the plane.

The near-zero net leverage of P, A, C, and T headed the sustainability journeys of both nations nearly straight east as cropland stayed nearly constant. In fact, Indian food production increased twenty times as much as cropland *Im* expanded, and US cropland actually shrank somewhat as food production increased. The societal implication of these journeys on the sustainability plane was a gratifying trip.

5.2. Irrigation

The use of irrigation water by farmers, like their use of cropland, affects the environment. In 1987, farmers used one-third of all water withdrawn in the US to irrigate 15% of all cropland, which grew 38% of all crop value [22]. Fig. 2 charts

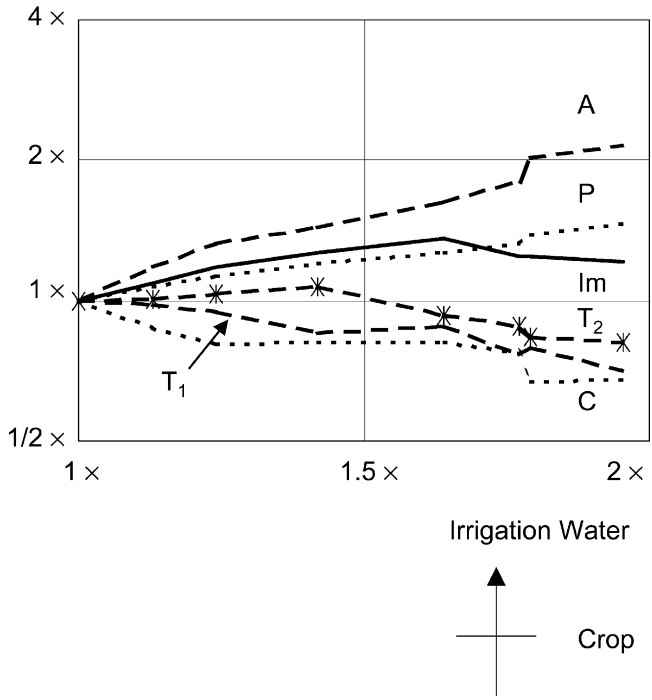

Fig. 2. The US journey on a sustainability plane where longitude is crop production. Latitude is the impact *Im* of irrigation water withdrawal, which is the net of the leverages P population, A income, C crop per GDP, T_1 irrigated area per US crop production index, and T_2 water per irrigated area. Because reports of water withdrawal are at five-year intervals, this figure uses average population, GDP, etc. for five-year intervals. The logarithmic scales are marked in multiples. A slow increase of crop production placed data points close together longitudinally. Sources: [2],9] and US Bureau of Economic Analysis.

the US journey from 1960 to 1995 on a sustainability plane, where longitude is crop production and latitude the impact *Im* of water withdrawal. Population P, income A and consumption C of crop production travel similar to the charts of land use for the longer period 1961 to 2000.

Leverages T_1 and T_2 are new. T_1 is the ratio of all crop production per irrigated area. The small decline or slightly southerly heading of T_1 as crop production increased indicates that sheer expansion of irrigated area did not propel increasing crop production. T_2 is the ratio of irrigation water withdrawn per irrigated area. Its slightly southerly heading can be viewed as improving efficiency per hectare. This improved efficiency can be partly attributed to increasing irrigation in moister climates where evaporation is less. Improved technology, including drip rather than flood irrigation, have also improved water efficiency.

With C obeying Engels Law, coupled with T_1 and T_2, together they countered the leverages of population and income. Although they did not steer the nation straight east on a course of unchanging water withdrawal as crop production nearly doubled, C and the two Ts did counter P and A to decrease water withdrawal at the greater longitudes of crop production. Technology steered national journeys rather well on the sustainability planes, with longitude measured in crop production and latitude in both lands cropped and water withdrawn.

5.3. Biotechnology

Prime Minister Tony Blair confirmed the implications of biotechnology and GMOs:

> There is much misunderstanding about the risks and benefits of genetic modification of plants. We need the right regulatory framework to protect human health and the environment. But if we can put in place these proper safeguards, there is the potential for improving the productivity and quality of crops available to farmers and consumers throughout the world. [23].

I will write of risks first and then benefits.

On World Consumer Rights Day in March 2003, protesters against GM food recited perceived risks [24]. Fears encompassed mislabeling or not labeling, and included the spread of pollen to injure butterflies or even patents that might control the crops on which modified pollen fell. The recital of such fears extends even further to a scenario where modified crops take over natural crops. One opponent of modified crops said, "This is about controlling the food chain from the seed to production and even distribution. And its promoters are trying to gain economic and political control to influence governments."

The Director General of Consumers International said, "There is little evidence so far of damage to health caused by GM foods. But that may not by itself be reason to feel reassured." When three international companies agreed to freely share their technology with African scientists in order to increase food on that hungry continent, they were greeted with, "Consumers International is skeptical about the motives behind this move given the immense public distrust of GM technology and

its perceived benefits" [25]. Seizing arguments and specters from environment and health to politics and ideology depreciates valid concerns. Although the needs of the hungry are remembered and research can patiently remove fears [26,27], the social implication of apprehension nevertheless persists.

In order for benefits to counter apprehensions, one must look to the consequences of genetic modification already in hand and to pest control, the impetus for present practical modifications. Gianessi et al. examined eight combinations of crops and pest control already adopted and planted in 2001 [28]. The pests included viruses, insects, and weeds. Crops ranged from a few thousand hectares of papaya and squash and one-third of a million hectares of canola up to many million hectares of cotton, corn, and soybeans. The authors reviewed publications, interviewed researchers, and analyzed the impacts on costs, pesticide use, and yield. They subjected their analyses to review and incorporated suggestions.

To farmers, saving $1.5 billion while growing the eight combinations of crops and pests is the preeminent estimated benefit. To an apprehensive society, however, saving 21,000 metric tons of actual pesticide ingredients looms larger. Herbicide-resistant soybeans brought about two-thirds of the pesticide reduction. Farmers rapidly adopted glyphosate-tolerant soybeans (glyphosate is sold commercially as the product *Round Up*), which saved money and pesticide compared to weed control with tillage and alternative herbicides. Although alternative herbicide programs have been developed, switching from modified soybeans and substituting alternative herbicides will be costly to farmers. The switch would also require a partial kilogram of more active herbicide per hectare, which would add up to 13,000 tons more pesticide over 20 million hectares. To approach the environmental impact more directly, Nelson and Bullock [29] weighted the alternative herbicides by toxicity and found that a switch would substantially increase the toxic doses applied over 1400 Midwest farms.

Increased yields from the disease and insect resistance of four of the analyzed combinations qualify them as landesque technology. The preeminent increase was 1.6 thousand tons more corn from the insect resistance of six million hectares of modified corn.

6. The future

The recent course of the index of labor input in US agriculture foreshadows no large laboresque implication. After declining 4% per year from 1940 to 1980, changes in labor input slowed in the 1980s and slowed even more during the 1990s. Mechanical innovations will inevitably improve, such as when farmers refine planting and fertilizing through the use of global positioning and then market their products electronically. As long as the cost of removing Florida oranges from the trees looms as large as all the costs of growing them, opportunities for laboresque innovation will remain open [30]. And as in the past, mechanical innovation will enlarge the scale of farms. But the spotlight will remain on landesque technology.

After reading about the landesque accomplishments that have saved millions of hectares during the existence of *Technology in Society,* the reader might ask: "What more can be asked of technology in agriculture?" I would respond: much.

Landesque technology must be maintained lest yields return to previous levels when water was toted in jugs cooled by a burlap wrapper.

> For certainly progress in civilization has not only meant increase in the scope and intricacy of problems to be dealt with, but it entails instability. For in multiplying wants, instruments and possibilities, [progress] increases the variety of forces which enter into relations with one another and which have to be intelligently directed .... The victory of a final stability can be secured only by renunciation of desire. Since every satisfaction of desire increases force, and this in turn creates new desires, withdrawal into an inner passionless state, indifference to action and attainment, is the sole road to possession of the eternal, stable and final reality [31].

To prevent the world from withdrawing to the yields of yester-year and either enduring hunger and starvation or expanding croplands at the expense of nature, yields must be maintained. And maintaining yields requires confronting the constant evolution of pests, the depletion of soil, the ravages of salinity brought by irrigation, and the frequent changes of climates.

Water for irrigation remains preeminent among the environmental challenges to continuing present yields. The deficit between the withdrawal of water and its continuing supply, which is made up by pumping deep aquifers, has been estimated at 160 cubic km, less than the 500 cubic km of the Mississippi annually flowing by Vicksburg but more than the 90 cubic km of the Nile at Aswan Dam [32,33]. Technology continues to be crucial for enabling nations to navigate sustainability planes like those in Fig. 2 with longitude of food production and latitude of irrigation water.

Beyond maintenance, still higher yields are possible. The physiology of plants holds no limits over yields. In France in 2001, wheat yielded about twice that in the Ukraine and potatoes four-fold [4]. Compared to the winner in a maize contest in 2001, the average yield in Africa was only 6% and in the world only 17%. The US average was only about one-third of the winning yield, leaving ample headroom under the botanical limit [34].

Nevertheless, one fears that rigidities will slow yield increases. Environmental, social, and psychological constraints may slow agricultural advancement just as much as less discovery in laboratories and plots. For example, "It is possible that the higher standards being developed for transgenic plants will, in the future, be applied in some fashion to other agricultural technologies and practices" [35].

And a trade war looms: "Coming amid continued bitterness over the Iraq war, a biotech suit against the EU threatens to strengthen anti-US sentiment in many parts of Europe. EU officials warn that European consumers would respond with a boycott of US food products—a threat many US food exporters take seriously" [36]. Although money for research may seem trivial compared to such warring

forces, the funding crunch is ominous at international agricultural research centers that keep the Green Revolution going.

The rewards for higher yields are too great, however, to tolerate slower improvements in landesque technology as nations navigate the sustainability plane. The first reward is feeding humanity along one dimension; the second is a Great Reversal in the other dimension, sparing nature by feeding humanity better while using less cropland [37,38].

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