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Assessing The Human Genome Project: Effects On World Agriculture

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ABSTRACT The Human Genome Project is the attempt to sequence the complement of human DNA. Its ultimate purpose is to understand and control human genetics. The social and ethical concerns raised by this attempt have been much debated, especially fears concerning human genetic engineering and eugenics. An almost completely neglected aspect of the genome project's potential effects is its impact on world agriculture. The Human Genome Project will provide source information to transform commercially and therapeutically valuable segments of the human genetic code into agricultural products using the newly extant technologies of gene farming. This application of developing genomic technologies has at least two foreseeable effects: 1) Transforming global agricultural markets and ecologies, raising possibilities of novel forms of neocolonialism and the further destruction of genetic diversity; and 2) transforming world health and society through new modes of pharmaceutical production and the unregulated expansion of medical access to novel and traditional therapeutics.

Introduction

The Human Genome Project (HGP) is the scientific effort to read the book of humanity as encoded in its genes (National Research Council, 1988). It seeks the complete nucleotide sequence of DNA that provides for a reductionist description of what it is to be a human being. The ethical ramifications of the Human Genome Project are not surprising. Fears are raised of neo-Nazi eugenics programs or the use of gene-fingerprinting as a tool for Big Brother governments. Many feel that the new genetics is intrinsically dangerous or unethical for a wide variety of reasons, not all religious (Weatherall and Shelley, 1988; US Congress, 1992).

Such scenarios are much debated. But in the history of major innovations in science or technology, expected ramifications are never the whole story. Even comparatively mundane and philosophically unstimulating technological advances such as the spread of the "Green Revolution" lead to profound and unexpected changes (Kloppenburg, 1988; Hynes, 1989).

Mapping the human genome provides understanding of human gene structure and ultimately the mode of gene action. Genes or clusters of genes can be cloned and expressed in selected organisms for manufacture of their active products (Singer and Berg, 1991). Such successes in the Human Genome Project will immensely promote the enterprise described by Phelps (1989) as "turning genes into drugs." In the scramble to take corporate financial advantage of the HGP, there are, "more traditional biotechnology companies, like those of Gilber and Fox, which will develop therapeutics from genome research" (Anderson, 1993). Concrete successes from earlier genetic engineering research already exist: human genes including insulin, human growth hormone, and tumor necrosis factor have been cloned and sequenced for specific therapeutic ends.

As pointed out by Busch *et al.* (1991), from the

beginning, human health care, not agriculture, has been the focus of most interest in biotechnology. For this reason, most discussion of the effects of genetic engineering is currently focused on human gene therapy: the molecular insertion of functional genes into victims of genetic disease (Weatherall and Shelley, 1988; Hogdson, 1990; Lesney, 1992). A comparatively unexamined facet of this technology that the Human Genome Project will enhance is the melding of medicine and agriculture. It involves the use of genetically engineered animals and plants to produce industrial scale levels of human proteins, hormones, and gene products through gene farming.

In fact, in its links to other kingdoms, calling it solely the "Human" Genome Project, is somewhat misleading. NIH operates the Genome Initiative Advisory committee, which cooperates with NSF and USDA, both of which have expressed their desire to play "at least a modest role in the Genome Project. Their common theme... botany. Plants." (Davis, 1990) NIH is helping to fund *Arabidopsis* mapping and lately France has joined the international human genome effort, including wheat as a model organism. The annual Genome Sequencing Conferences (primarily for the human genome) also include plants as model organisms. So directly as an outgrowth of the "human" project, plant genome work is already under way and will provide greater opportunities for efficient gene farming.[1]

Gene farming is simply the commercial practice of using traditional farming techniques to produce engineered genetic products in crops or farm animals (Van Brunt, 1988; Pursel *et al.*, 1992; Lesney, 1993). Such techniques, made possible by the new information, provide the possibility of transforming agriculture in the developed, but perhaps most especially the developing world. Not only "just" the source of food and fiber, the new farms may become the cheapest, and perhaps only source for the great masses of humanity, of medicines based on the molecular products of human genes. Change will inevitably arise from this developing field of modern bio-pharmaceuticals. At the very least such a scenario poses new possibilities for cash cropping and neocolonial agriculture. At most it may change the pattern of world health care and quality of life in unpredictable ways.

The technology behind this potential transformation has only recently become apparent. While informational gaps exist, developments are rapidly filling them in. Laboratory, greenhouse, and pilot farm projects are already in place for the first (and easiest) of the human gene products such as antibodies and hemoglobins. Purification technologies are being perfected, and some of the more critical problems of selective drug targeting are being addressed. Much of this technology has historical precedent. Before recombinant human insulin from a microbe came purified pig insulin from the slaughterhouse. Horse estrogens have been purified for treatment of human females. From aspirin to quinine, up to very recently the majority of drugs have been obtained from plants. In much of the world the herbal practices remain (Akerele *et al.*, 1988). The idea of gene-farming for medical purposes is thus a strangely symmetrical enterprise, translating the newest laboratory technology into some of the oldest on the farm .

The impact of general biotechnology on agriculture has been extensively reviewed (Souza Silva, 1988; Busch *et al.*, 1991), and even the ethics of using the new technology in agriculture has been examined (Burkhardt, 1988). But little or no comment has been made on the linkage between agriculture and medicine, especially not concerning the specific potential impacts of the new genomic research. Most discussions of gene-farming in the trade (Van Blunt, 1988) and scientific literature focus on commercializing aspects, or on research barriers. The USDA yearbook of agriculture recognized gene-farming technology for human bio-pharmaceuticals as another example of "New Crops, New Uses, and New Markets," but addressed none of the broader social implications beyond the speculated dollar values of a few gene products, nor was a connection made to the Human Genome Project (Pursel *et al.*, 1992).

This article examines those broader possibilities inherent in the transformations in agriculture as the result of the Human Genome Project. Potential societal impact will be briefly examined in the light of these new technologies. This paper makes no pretense at complete analysis, nor to Delphic foreseeing. It seeks merely to raise possibilities that might have a major effect in an area not conventionally linked to discussions of the Human Genome Project.

Effects Of The HGP On World Agriculture: Gene-Farming

The Human Genome Project will increasingly map, clone, and sequence specific genes for known products important in human health and metabolism. How products of the HGP can be utilized in agriculture is already demonstrated by pilot gene-farming projects. These efforts are based upon the culminated understanding of the "easy" gene products of the past and the *ad hoc*, grass roots HGP (primarily concerned with isolating and gene-sequencing known human products) that has been underway since the advent of the new technologies.

Human proteins were first genetically engineered into mice in 1988. Lactating mice produced human t-PA, a protein currently in use as an anti-clotting drug for heart attack patients, in their milk (Gordon *et al.*, 1987). Other gene products followed using more traditional farm animals. Transmutant sheep produced human alpha-1-antitrypsin protein (AAT) in milk. Cows

were developed to produce human lactoferrin, a milk protein, and in cattle human beta-interferon (an antiviral, anticancer compound) was introduced. Pigs have been engineered to produce human hemoglobin, the oxygen-carrying protein in blood (Swanson *et al.*, 1992) and goats a more abundant yield of t-PA. Rabbits have been transformed to produce protein factor 7 and human erythropoietin. Mice have been engineered to produce human growth hormone in their milk, prelude to the eventual production in sheep, goats, or cows (Van Brunt, 1988).

Human genes have also been fused to plant chromosomes to yield large quantities of experimental human bio-pharmaceuticals. Tobacco and potatoes have been produced that yield human serum albumin, another blood protein. Oilseed rape and Arabidopsis have been developed that produce the human neurotransmitter Leu enkephalin as a storage protein in seeds (Vandekerckhove *et al.*, 1989). In 1991, researchers in North Carolina harvested a partial acre of tobacco that had been genetically engineered to produce Compound Q, currently used to treat AIDS patients. Although not a human protein, this system demonstrates the validity and usefulness of the technology at field production levels (Moffat, 1991).

Also under development are what is called "plantibodies." These are human antibodies produced in plant tissues. It has been demonstrated that agricultural plants are an ideal potential for production of specific vaccine antibodies from human sources. Up to 1% of the transformed plants' proteins have been the transgenic antibodies (Moffat, 1991). Genetic modifications to improve purification technology using extra cellular targeting mechanisms are envisioned, making even relatively primitive lab setups potentially successful to isolate such compounds. Using plants has several practical benefits including lower maintenance costs and lack of transmissible parasites. Thus, transgenic crop plants may be more acceptable, especially under less controlled conditions, than livestock herds.

Possibilities exist for using the appropriate purified antibodies obtained from transformed agricultural crops as an injected antiserum to attack disease organisms in people and animals infected but not already immune. This is especially important for diseases where fatality rates are high. Some labs believe an HIV virus-specific antiserum may be able to attack AIDS in already infected patients and have had preliminary success (Sterling, 1992). The potential effect of such technology for some portions of the developing world where AIDS cases have reached epidemic proportions (*US News and World Report*, 1992) is profound.

Antisera are also some of the most important diagnostic tools available. The vast quantities of "plantibodies" (literally tons) that may one day be produced through these methods may decrease costs and increase availability of these compounds to larger segments of the world population.

There is obvious medical and economic potential in new bacterial antibiotics, cancer-curing plant compounds from the rainforests and neurotoxins from sea invertebrates, and even the disease-fighting "plantibodies". Less obvious is the utility of producing proteins in plants and animals that most humans make in sufficient abundance to maintain health.

However, many humans do not produce "normal" amounts of typical human proteins, accounting for various abnormalities and genetic diseases including dwarfism, diabetes, and cystic fibrosis (Fox and Brunt, 1990). In other cases, the "normal" amount is not sufficient. In various cancers, coronary heart disease, and many infectious diseases, the body fails to adequately resist attack. The ability to provide therapeutic increase of these natural disease and stress fighting proteins is envisioned as a powerful medical tool (Phelps, 1989; Rosenberg *et al.*, 1990).

Until the use of transgenic technology it has been impossible to test many of these human compounds for their health and metabolic effects. They are produced in too low an amount in the average human and purification from blood, urine, or from cadavers for routine use has proved difficult.

Transgenic plants and animals offer several benefits that traditional fermentation techniques using bacteria do not. Eukaryotes are capable of enzymatic processing of gene products in ways that more primitive microbes cannot. Engineering complex gene systems into a higher organism is more practicable than into the smaller genome of a microbe (Cartwright, 1987).

Again, conceptually these are not new ideas. Production of these proteins with known pharmaceutical uses for treatment and diagnostics through gene-farming has obvious ramifications. These are simply extensions of current medical practice. Agricultural species have often been used as a source of medicinals. Biopharmaceuticals have traditionally been isolated from plants and herbal medicines are still in daily use. They are of such increasing interest that USDA has voiced concerns about herbal drugs and self-treatment, especially in their belief that efficacy must be more studied by traditional Western medicine (Duke and McChesney, 1992). Chinese medicine has been historically dependent on the herbal tradition and the production and preparation of such herbal products is an important industry (Akerele, 1988).

But in science, it is often the serendipitous and the not-so-obvious use and development of technology that proves most influential. The products of the Human Genome Project, multiplied by biological fermentation or gene farming will provide resources never before available. At the very least, biotechnological mass production of these hitherto rare (or even for-

merly unknown) proteins will allow for hitherto impossible forms of medical experimentation. For example human growth hormone (HGH), mentioned above, has recently been touted not only as a remediation for dwarfism in man, but for its potential effects as an anti-aging compound. In addition, HGH has shown promise in clinical studies as an anti-wasting treatment. This might lead to long term potentials to help prevent muscular atrophy in cancer and AIDS patients (Christensen, 1991). HGH has been produced successfully in bacterial culture, so it is unlikely to be one of the gene-farmed products of the future. It can, however, be examined as a model of the effects to come. Without the mass production of this human product, such experiments would have been impossible.

Another example of a potentially uniquely useful human gene product, one thought to be responsible for preventing heart attacks and cardiovascular disease, has recently been isolated. It shows promise as an anti-clotting agent that might help reverse arteriosclerosis in some cases (Ryan, 1993). Whether such glowing scenarios prove viable or not, only the genetically engineered, massive increase in availability of human produced "drugs" has made possible such studies.

It is obvious then, that one of the most important consequences of the Human Genome Project will be the development of more powerful and precise genetic drugs. More human proteins will be identified and gene mapped at escalating rates. Extensive effects can be expected (both beneficial and destructive) on world health and society as the result of these new genetic drugs and their distribution potential through gene farming.

Government health agencies and others are also considering the specific enhancement of crop plant species for human health as a component of a regular diet. The goal is to increase naturally occurring antioxidant compounds and vitamins in plants. The term "nutraceuticals" has been coined and the National Cancer Institute is considering programs to genetically engineer foods for increased dosages of those compounds currently indicated to have anticancer properties (DeFelice, 1992). Although the genes used will likely be traditional plant genes linked to promoters that will cause super-production of the desired chemicals, other sources of the proteins including animal and microbial are also options.

It is only one further step to include the use of plants engineered with human anticancer compounds, none of which as yet provides the "magic bullet" but are useful among a battery of treatments for specific diseases (perhaps a mutated and eventually "safe" tumor necrosis factor (Rosenberg, 1990) or an effective interleukin-2 in gut/blood barrier transmissible, or easily purifiable forms for the new gene farming).

As knowledge of the human genome and human metabolism increases to localize and characterize the sequence of receptor proteins, there will inevitably come an increased ability to discover more powerful and precise plant drugs. Molecular modeling will provide preconceptions of the potential structures of effective compounds based on knowledge of human receptors and the analogous human "drugs." This would make possible easier screening of new plant species or the creation of new varieties of herbal medicines for more traditional bio-pharmaceutical farming. This is part of the concept of "rational drug design" (Netzer, 1990). Combinations of approaches become equally possible, for example the most recent use of human interleukin-2 and antibodies to create tumor specific anticancer cells (Takahashi *et al.*, 1993). Such novel therapies using human proteins can only serve to increase the ultimate world demand for gene-farmed products.

Other gene-farming scenarios are possible. Potential use of antibody-inducing plant vaccines (as opposed to antibody producing plants mentioned above) provides an alternate technology for those diseases where immunization is an effective but costly remedy (Taylor, 1993). Ultimately, increased knowledge of receptors and transport methodologies derived from the physiological and molecular studies made possible by the human genome project, *via* direct information, technology development, or ancillary funding for plant research will inevitably speed these results.

The current technological problems cannot be minimized. These include: drug stability, purification (Cartwright, 1987), target delivery (across the stomach lining (Wallace and Lasker, 1993), the blood/brain barrier (Friden *et al.*, 1993), or to specific tissues), toxicity (often a component of targeting and stability), and dosage control. But even here, increased knowledge of the human genome will provide benefits as natural proteins and targeting sequences are analyzed and revealed. Analysis and synthesis of active sites for enzymes, or receptor sectors may provide the means for producing chimeric drugs with appropriate targeting, stability, and activity ratios. Human hemoglobin in transgenic pigs is in a relatively primitive state of such development (Swanson *et al.*, 1992).

Potential Effects Of Gene Farming On World Agriculture And Society

It is extraordinarily difficult to assess the potential impact of such technologies as described, and that point is one of the key issues hopefully raised by this paper. On the one hand, such gene farming made possible by the ultimate products of the HGP is a self-reproducing method of gene production that can provide potential for cottage industries in the most primitive environments where agriculture is practiced, if the proper varieties are engineered and distributed. "Poor countries, such as Bangladesh, do not have much scientific infrastructure, but they can grow plants."

(Charles Arntzen quoted in Taylor, 1993)

At first glance this may be seen as a potential source of empowerment, a benefit from future farming with plants and animals that may prove an unexpected social breakthrough on the line of the much touted "global village." The biological fermentors, biochemical reactors, and cell culture techniques currently in use to produce large quantities of many important pharmaceuticals are high-tech systems that are easily controlled by corporations or governments where profit motive can proprietorially restrict the free availability of medicines.

Flocks of genetically engineered sheep and fields of transformed vegetables may one day be the equivalent of pharmaceutical power to the people. One can imagine an illicit peasant farming economy based, not on cocaine, but on anticancer compounds or anti-aging drugs. Purification of the drugs would still be an issue, but often times a less complex one than production. This biological proliferation and subsequent deployment of genetically engineered medicines to the third world may be the only hope of getting this kind of benefits to the masses, as Arntzen believes (Taylor, 1993). Otherwise costs will be prohibitive. In fact, one of the rationales for using plants and animals by the companies currently doing this kind of research is cost containment and simplicity, especially for therapeutic proteins required in large quantities (Van Brunt, 1988).

This rosy scenario ignores, however, the fact that the entire concept of gene farming can be seen as one more, and perhaps the newest, step in what has been described as the continuing "industrial appropriation of rural production processes." (Goodman *et al.*, 1987) This has been claimed to be one of the deleterious results of the "Green Revolution" in developing countries. This danger seems even more likely when it is seen that much if not most of the movement in this area of gene farming has been developed under the auspices of the private, industrial sector where the profit motive is paramount.

Many of the ramifications of this appropriation process have been much discussed for more traditional methods of appropriation as well as for the more "traditional" forms of biotechnology applied to increased yield of food and fiber, or the overproduction of standard plant compounds (Kloppenburg, 1988; Hynes, 1989). One interesting legal consideration may be the fact that the novelty of the "human drug" containing plants may be more easily demonstrable than traditional agronomic changes in the genome. The manifest existence of quantities of the uniquely useful human gene in its alien host may be pointed to as an inarguably concrete advantage (backed by medical science) and an immediate difference from all other existent varieties (obvious from evolutionary barriers). This may ease the demonstration of man-made change and benefit in the patenting process (for asexually reproduced plants), which is based on the concepts of "new, useful and unobvious." It is equally valid for variety protection (for sexually reproduced plants), which requires "distinctness where one of its aggregate of characteristics displays an advantage or difference over all existing varieties." (National Association of State Universities and Land Grant Colleges, 1983) No comparative yield trials or discussions of esoteric agronomic characteristics including proof of disease or pest resistance compared to other varieties may be needed. There is literally nothing to compare to (at least until subsequent market competition attempts to produce or find "look-alike" human drugs for insertion into plant varieties for particularly profitable genes). This may allow the concept of plants as intellectual property [as detailed by Bugos and Kevles (1992), as well as Kloppenburg (1988), among others] to have significant new force.

Thus, due to these profit motives, additional impacts will almost certainly involve intellectual property wars, and perhaps developed world attempts to install ownership stability (as exists with hybrid corn) by the use of novel techniques such as suicide genes and/or specific ID markers in the engineered species. One can easily envision a new, gene-farming based form of neocolonialism. This scenario is already in evidence in the arguments over North-South genetic diversity and exploitation as raised at the Rio Summit (Shiva, 1993).

Inevitably the dangers of "cash-cropping" remain real risks for third world farmers as they ever did. First comes dependence on the new specific plant "drug varieties", followed by their potential replacement by improvement (new varieties), or cheaper sources (perhaps innovations in fermentation technology). Cash flow or ownership can change direction drastically in these cases. One need only examine the history of the vanillin industry (Bud, 1993), or cite the effects of artificial or "natural" substitutes on the world sugar market (Elkington, 1986) on the producer economies. In these cases, third world nations became dependent suppliers of specific agricultural commodities for developed world markets (a typical example of neocolonial exploitation). When the developed world created alternative sources of supply by industrial means, the local and national economies of the (former) producers were severely damaged.

But we would still argue that, perhaps, these narrow market issues are part of the myopia of the current kinds of analysis being performed on the nature and implications of gene farming's transformation of world agriculture. It is only possible, in this context to list some of the broader potential benefits and problems that might arise.

If the promise of gene-farming as made possible by the increased advances in human medicine and the Human Genome Project are even remotely fulfilled, it

is the new drug availability that may most transform world health. One probable effect is on population size. It is equally possible to imagine population explosion due to increased availability of medicines, even the most simple vaccines, [a traditionally cited cause of lowered mortality and population boom (Barney, 1982)]; or population decrease due to increased birth control and defined early abortant genetic drugs. Which scenario proves likely will depend on each society effected and the controls imposed on the infusion of the new technology.

Gene-farming will also provide the potential for new sorts of drug abuse: both on the basis of incorrect dosage and diagnosis and from new abusable substances. It is not to be ignored that one of the most valued cash crops in the developing world is coca leaves for cocaine production (with only a fraction going to legitimate medical use) (Narcotics Intelligence Consumers Committee, 1990). In fact, although not a product of the gene-farming technology, examples of the first of the biotech black market human protein abuses have arisen in the use of purified human growth hormone (HGH) by athletes and weight-trainers as an undetectable substitute for steroids, and of human erythropoietin (EPO) as a stimulus to red blood cell production to enhance aerobic performance by cyclists (Spalding, 1991).

This minor start in illicit biotech drugs demonstrates the potentials for abuse. After all, natural human opiates such as leu-enkephalin have already been produced in plants (Vandekerckhove *et al.*, 1989). The eventual black-market potential for untested or unproved anti-aging drugs or cancer cures or AIDS vaccines is fertile field for future crimes and future human misery. The previous Mexican-Laetrile connection could be considered a model (Shilts, 1988). Genetic engineering is not immune to the perils of medical charlatanism, quackery, and black market drug abuse.

Other potential misuses of the technology could (in the case of the vaccine plants) lead to tragedies of anaphylactic shock, where severe allergic reactions to engineered proteins may occur, or to widespread oral tolerance (a diminished effectiveness due to oral overexposure to an antigen) which would make the vaccine, or any like it useless (Taylor, 93). There is already a safety controversy over side-effects in India, with political overtones, concerning the trial use of specific human protein vaccines (not gene-farm produced) for birth control (Jayaraman, 1993). A significant ethical and practical misuse of the technology may also be such testing of these new products on developing world populations without their informed consent. Such fears have been raised on present day experimentation with vaccines (Shiva, 1993).

More practical risks of the new technologies are typical to all pharmaceutical production systems. Proper purification of the drugs produced in these systems is an important consideration. The possibility of contaminants from other animal and plant proteins, including potentially dangerous viruses (from animal systems) always exists (Moffat, 1991).

There are many current fears regarding the potentially inimical influence of genetically engineered species on natural evolution and/or the ecology. Traditional agricultural demand may be insufficient to overcome objections to the large scale introduction of this new technology in the field, at least for the foreseeable future. But the one area where the informed public seems most tolerant of the use of genetic engineering in all forms is that of human health. This is not in small part due to self-interest of those who are ill, or who fear they will one day become so (Weatherall and Shelley, 1988). This built-in rationale provides a powerful weapon for those who would insist on the implementation of the new technologies on a massive scale throughout the world.

In fact, with the possibility of Calgene's genetically engineered tomato being rejected in the marketplace (Gershon, 1993), and massive consumer lobbying against bovine somatotropin, the milk enhancer whose potential effects have been much discussed (Buttel, 1986; Comstock, 1988), the options for the use of genetically engineered plants and animals in agriculture becomes greatly imperiled. There is one key exception: "the use of animals to produce human therapeutics or as model systems to study human disease" (Gershon, 1993). As there is already a strong economic and political impetus for the industrialization of crops and agricultural products in both the US (USDA, 1992) and Europe [demonstrated by such conferences as the First and Second European Symposium on Industrial Crops and Products (Conference Secretariat, 1993)], the potential interest in such fusions of medicine and agriculture is obvious.

The extensive use of gene-farming has important consequences for the worldwide decrease in genetic diversity. As with the more frequently considered genetic engineering scenarios of pesticide or disease resistant transgenic crops, these new products have the potential to crowd out current genotypes, and even species, because of their designed short-term economic superiority. Ecological nightmare scenarios of escaping "weeds" or pollen allergens (Crawley, 1993) may be far less likely than the deliberate introduction of new systems of relative monoculture and reinvigorated cash-cropping regimes in developing nations. The appropriation of new environments by introduced exotic crops, crowding out natural diversity, has been (Shiva, 1993) and will probably remain a continuing problem.

Finally, there are the philosophical issues to be addressed. Many biologists may have made their peace with the universality of life, as have some Eastern religions, but the increased fluidity of the genetic

concept among the general public as "human" plants and animals are developed raises many concerns (Weatherall and Shelley, 1988). Herein we may see the basis for new intellectual and political controversies based on animal rights, fears of the "unnatural", and unpredictable religious responses.

Whether modest or extreme, such philosophical and ethical questions raised by the new technology cannot be addressed scientifically but rather by the values of society at large.

Conclusions

The possible effects of the Human Genome Project on world agriculture are profound. The promises and dangers are relatively independent of the traditional scenarios of directly applied gene therapy and genetic screening usually forecast in the coming of the HGP. They involve the massive production of human gene products through gene farming on a world scale. We believe that this emerging fusion of agriculture and medicine inspired and fueled by the HGP is critically important to consider because of its broad potential impacts (both positive and negative) on human society as a whole, not just on the currently technologically advantaged peoples of the world. Ultimately, because agriculture is the lifeblood of human society it provides the optimal method for diffusing the new genomic technologies throughout the system. And agriculture provides the maximal source of potential impacts. As described, these are not the standard ramifications of increased productivity *via* pest and pesticide resistance, or even the long ballyhooed (and considered currently unlikely) chimeras such as nitrogen fixing grains.

Simplistic economics may argue that these new agricultural practices are less likely to diffuse to developing nations simply because of the economic undesirability of exporting this technology by those who possess it. This would be a classic example of selling the milk, not the cow. In addition, there may come advances in fermentation technology and bioengineering that may indeed overcome all current obstacles to allow many or most of these products to be more commercially produced in sophisticated bacterial or plant or animal cell culture.

But it cannot be forgotten that issues of commerce alone will not drive this transformation of agriculture. As with the green revolution it is the power of sometimes apparently good intentions, not to mention perceived national interests that also fuel the research machine and may increase diffusion of these technologies in ways that would seem (at first) counterproductive to genuine commercial interests.

The very promise of the use of gene farming in agriculture as a panacea for world health problems may provide the necessary impetus. The health problems of the third world are of catastrophic magnitude, "the alleviation of which depends to a great extent on vaccines and diagnostics developed from new biotechnology." (Yuthavong, 1987) For these reasons, governments, foundations, and ideologically inspired individual scientists are as likely to create the necessary bridges for perceived philanthropic or global stability issues as for immediate economic gain.[2] As with all new technology, once developed it cannot be forever contained, not even by patent protection in the West, should the developing nations on their own choose to implement or appropriate it.

In assessing the Human Genome Project, therefore, the effects on agricultural systems must be considered some of the most potentially extreme. At issue is the very redefinition of the nature of agriculture from the production of food and fiber to something historically unprecedented — the production and distribution of human biopharmaceuticals on a massive scale. Such transformation of agriculture may, in turn, change world society *via* the profoundest impacts on human health, wealth, psychology, and fecundity.

Notes

1. This is not to imply that efforts in plant and animal genome research have not always been a component of agricultural biotechnology from the beginning. Rather, it is the pronounced increase in moneys for and emphasis on genome sequencing that is indebted (directly and indirectly) to the highly visible success, both financial and rhetorical, of the more glamorous HGP. This seems especially likely for the recent creation of specific large-scale genome "projects" by USDA.
2. This is not to ignore the fact that long term government and foundation interests can appear highly philanthropic when the true and recognized goal is indeed long term economic gain. The Marshall Plan for the rebuilding of Europe after the war is an historical example of this (Vadney, 1992) as the refinancing of the former Soviet Union is a contemporary one. The requirements of a capitalist system to maintain and enhance even potentially competing markets is much recognized (Vadney, 1992) and even the behavior of foundations has often followed a similar pattern of nationalistic or paternalistic goals (Ninkovitch, 1984). Kloppenburg and others have pointed out that, in terms of germplasm imperialism, even the apparently philanthropic establishment of the international agricultural research centers at the height of the green revolution may not have been as philanthropic as might have been portrayed (Kloppenburg, 1988; Shiva, 1993).

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