WALTER P. FALCON*

Globalizing Germ Plasm: Barriers, Benefits and Boundaries

INTRODUCTION

Globalization and liberalization were rallying cries of the 1990s and, as a consequence, the world economic system at the turn of the 21st century is much more open than it was only a decade ago. Yet world agriculture, in many ways, has been a rather stubborn holdout. One particular subsector of agriculture – plant germ plasm – provides a particularly arresting counter-example to globalization. Herdt (1999) has described the consequences of privatization and nationalization of plant genetic materials as the closing of another 'commons', comparable in importance to the closing of the land commons in England between the 15th and 19th centuries.

In this paper, I seek to shed light on the causes and potential consequences of restricted germ plasm flows among nations. My objective is to provide a synthesis of existing literature and an account of several events in which I took part, with a focus on food security in poor countries. My discomforting conclusions are that the mechanisms restricting flows are complicated, the data on the size and direction of flows meagre, the outcomes uncertain and the policy mechanisms for alleviating the problems largely untested. Yet, if the recent institutional innovations highlighted in the final section of this paper can be replicated on a sizeable scale, cautious optimism still seems warranted about the future spread of improved germ plasm.

Following a short historical introduction, I identify four separate forces that are now interacting in ways which should worry everyone concerned with the transfer of technology, particularly improved crop varieties, to scores of the world's poorest nations. These elements are new provisions on intellectual property, especially patenting in the United States; an increased concentration of new enabling technologies into a few large multinational companies; heightened anxieties over transgenic foods, especially in Europe; and new problems arising from old ambiguities in the Convention on Biodiversity. Individually, these components are reasonably well described in the literature. Collectively, however, they are poorly understood and their combined impacts on the poorer countries of the world are very troublesome.

*Stanford University, Stanford, California, USA and International Wheat and Maize Improvement Centre (CIMMYT), Mexico Federal District, Mexico. I am grateful for the helpful comments of Rosamond Naylor, John Barton, Cary Fowler, Timothy Josling, Donald Kennedy, Michael Morris, Anne Peck, Timothy Reeves, Daniel Rochberg and Nikolas Wada.

HISTORICAL CONTEXT

Need for domestic agricultural development

This paper takes as given the projected food security problems of about 70 of the world's poorest countries, many of which are in sub-Saharan Africa (USDA, 1997).[1] These projections also suggest that world cereal demand will rise by about 40 per cent over the next 20 years. Providing enough grain to meet this target will be no simple feat, since this increase will need to be accomplished with less irrigation water and perhaps with less arable land as well (Smil, 2000; Pinstrup-Andersen *et al.*, 1999). Increasing yields by 2 per cent annually is not unprecedented, but it will certainly stretch the human, financial and natural resources of the world, especially if the environment is not to be destroyed in the process.

Increasing 'the global pile of grain' is a daunting necessary condition. But it is by no means sufficient to assure food security among the poor. If developing countries with a large percentage of undernourished people are to solve employment, income and food access problems, most of the increased agricultural output must be grown within the borders of these nations. The first Green Revolution was initially most successful at improving yields in irrigated areas and in regions of favourable rainfall. Some technology remains to be transferred to these areas, but the more serious problems are in regions still subject to drought and flooding, and in countries with little physical and human capital, inadequate policies and a high percentage of the workforce in rural areas. For this set of nations, access to improved germ plasm is one vital component for a successful attack on poverty and hunger.

There are some who argue that increased yields are unimportant for such countries, since the *world* already has 'enough' grain. This argument misses the key linkages at the regional and household levels among increases in food production, growth in per capita incomes and increases in food consumption. Both external technology for and internal knowledge about these agricultural systems will surely be needed. Increasing productivity *and* alleviating poverty are both crucial and very much related. To frame either of the foregoing propositions as 'or' rather than as 'and' questions does not usefully serve those developing countries plagued by serious food security problems.[2]

Changed institutional circumstances

Men and women have been improving plant genetic materials for 10 000 years (Smith, 1998). Both the origins of various crops and appropriate methods for their improvement continue to be sources of controversy. The central issue for this discussion, however, is whether recent developments represent only minor variations in plant improvement processes or rather a fundamental watershed in the scope and methods of plant breeding, especially as they affect poor countries of the world.

Prior to the Second World War, much of the basic and applied seed technology for agriculture, especially for cereals, originated as public goods from the nonproprietary sector. In the USA, for example, land grant universities played key roles in developing germ plasm and then in ensuring that the resulting genetic materials flowed with few restrictions across state and national boundaries.

Hybrid maize was a partial exception to this pattern of public provision of germ plasm: companies typically drew on basic research from the public sector when developing hybrid maize, but they then privatized inbred lines, mostly through the use of trade-secret mechanisms. In 1970, more formal protection was given to the private sector in the USA via the Plant Variety Protection Act. This legislation gave developers of 'distinct, uniform and stable' seeds patent-like protection for 17 years, including the right to set conditions on the sale and resale of seed.[3]

Two mutually reinforcing events occurred during the last quarter of the 20th century that greatly altered the norms of germ plasm development. The first event – really a process – was the development of modern biotechnology, including computational and other laboratory methods for discovering, cloning and transferring separate genes. When these specific methods were combined with the second component – a series of new legal rulings on patenting – the plant genetic environment was radically transformed. In addition, the new biology gave entrepreneurs the scientific methods, such as plant fingerprinting, to detect and enforce patent infringements. New interactions among law, biology and information technology were thus the primary forces that brought about a new institutional setting for germ plasm development and transfer.

PRINCIPAL ELEMENTS OF CHANGE

Moves towards protection and patenting

The protection of intellectual property is long-standing and such protection embraces much more than just patenting. Yet it is patenting (rather than trade secrets, trademarks, plant variety protection or copyrights) in the USA that has caused the most confusion in the plant genetics world during the past two decades. Other countries obviously also have patent offices; however, the scale of the biotechnology industry in the USA, coupled with the large US share of internationally traded agricultural goods, has made the USA the forerunner on intellectual property issues.

The US Patent and Trademark Office (USPTO) works on the principle of 'prior knowledge' in determining whether or not a discovery is 'novel' and 'non-obvious'. When scientific history is long and discoveries are gradual, USPTO is generally regarded as being competent and consistent, although the Office is sometimes accused of having a bias towards new patent applicants (Barton, 2000). When there is a sharp break with past scientific methods, however, USPTO has little prior knowledge on which to build, and questionable decisions occur. Such was the situation following *Diamond* v. *Chakrabarty* (1980), when, on appeal, the US Supreme Court ruled in a five to four vote that a live micro-organism, constructed by gene-transfer technology, was patentable.[4]

Great uncertainties arose with *Chakrabarty* and later decisions as to what was patentable and also how broad or narrow the patent coverage could be. Given this uncertainty, there were understandable pressures for firms to maximize the number of biotechnology patents, and to do so as rapidly as possible – reminding one of speculative land grabs in an earlier era. Initially, the bar on gene claims was perceived to be low, and the number of patent applications exploded during the 1990s (Enserink, 2000).[5] With little prior history, USPTO had great difficulties in implementing the 'utility' aspect of applications; that is, in determining whether or not a new proposal had merit. Although there was widespread scientific agreement that short sections of DNA – sometimes called Expressed Sequence Tags – were too narrow as a basis for patenting, more than a million such claims were filed with USPTO (ibid.).[6] There were equal concerns that patent claims might be unreasonably broad. In a case especially notorious and worrisome to developing nations, the USPTO issued broad protective rights in the USA for a type of yellow bean (*Phaseolus vulgaris*) grown commonly throughout Mexico (Friedland, 2000). The yellow-bean patent also raised the ugly spectre of bio-piracy and the misappropriation of the research products of others.

The USPTO is apparently now in the process of raising the claims bar with respect to 'utility' (Enserink, 2000). Nevertheless, two lasting problems arise from the new patent processes as they affect poor countries. First, thousands of relevant patents have already been issued that affect the 'creation' of modern agricultural germ plasm appropriate for developing countries. Intellectual property coverage includes genes, traits, molecular constructs and transformation procedures – so-called 'enabling technologies'. For important genetic modifications like the new vitamin A-enhanced rice, dozens of patents can be involved in a single transformation (Guerinot, 2000). As discussed below, the multiple-patent problem already affects the industrial structure in the private sector. Multiple patents also effectively force the public sector to use alternative research methods if crucial patents are unavailable for use on products important for poor countries. Second, the fear that 'outsiders' will patent existing products, such as yellow beans, has left national agricultural research systems and the international agricultural research centres in a quandary as to whether or not to employ patenting as a defensive strategy against bio-piracy.

Privatization of research and industrial concentration in the seed industry

The patenting of genes and traits has had a profound effect on both the structure of germ plasm science and on industrial concentration in the seed industry. Leaders of several large firms such as Monsanto and Novartis arguably saw agricultural biotechnology as a mechanism for generating dominant commercial strategies for their companies. Although consumer and stockholder reactions eventually interceded to limit the strategies and to decrease genetically modified organism (GMO) budgets within these companies, there were two early waves of investment activity that reshaped the plant genetics industry.

The first of these waves featured the acquisition of smaller biotech start-ups by large multinational firms that were predominantly focused on agricultural chemicals (Brennan *et al.*, 1999; RAFI, 1998). These mergers and acquisitions were driven primarily by 'freedom to operate' considerations. Companies and many public agencies simply found themselves unable to cope with the economies of scale inherent in certain types of molecular-based research and with their inability to acquire both the expertise and patents needed for cutting-edge research (Brennan *et al.*, 1999).

The second wave involved the acquisition of seed companies, also by the large chemical and pharmaceutical firms. When the latter realized that revenue generation would be difficult if based strictly on technology licences to seed companies, they began acquiring seed firms at a pace so rapid that the name, number and scope of the resulting conglomerates changed almost on a monthly basis. It sometimes appeared as if virtually all firms were simultaneously trying to buy, sell and sue one another! Many of the mergers seemed complete by 1999, only to be followed by another round of reorganization. Under shareholder pressures, several of the mega-firms began to spin off or combine their genetic material and seed units.

Much more could be written about the personalities and purposes behind the various mergers and realignments, and about the several public relations disasters that befell them. However, five important implications derive from the new industrial structure summarized in Table 1. First and foremost, the plant genetics industry is now heavily concentrated in a half-dozen major firms, which also hold substantial numbers of key patents on germ plasm and related enabling technologies such as gene guns (physical devices for injecting DNA through cell walls) and agro-bacterium (*Bacillus thuringiensis* or *Bt*) transformation systems. Second, any research institution, public or private, wishing to use either the seeds or the enabling technology must, as a practical matter, have commercial relationships or alliances with these firms. Third, the control of patents and seed distribution exercised by these companies has substantially increased the barriers to entry for new firms in the field of germ plasm development. The scale of these operations is now enormous: for example, Dupont paid $9.4 billion for just one company, Pioneer, to underpin its seed operation. Fourth, given the profitability needs of these companies, much of their research has been aimed at innovations that can generate linked sales of seeds and chemicals. It was no accident, for example, that two of Monsanto's early seed products, Roundup Ready™ corn and soybeans, were linked to the company's major herbicide. Lastly, the need for private profitability has created many 'orphan' crops and countries; that is, commodities and nations that are simply unprofitable for the private sector to pursue.[7]

Together, these circumstances pose serious difficulties for the poorest countries of the world. Most of these nations have small gross domestic products (GDPs) and rely importantly on non-hybrid or tropical food crops not of principal concern to major plant biotechnology companies. Furthermore, they typically lack the trained scientists needed to gain access to or develop the new technology.

As a consequence, international agencies supplying research products that are public goods face the deepest kinds of questions. What kinds of alliances should the not-for-profit-sector form with the private sector to move key aspects

TABLE 1 *Changing structure of the 'plant genetics' industry (circa June 2000)*

	Purchases		
Company	Agricultural Chemicals	Biotech	Seeds
Monsanto (merged in April 2000 with Pharmacia & Upjohn to create Pharmacia Corp.)		Agracetus Calgene Ecogen (13%) Millennium Pharmaceutical (joint venture for crops genes)	DeKalb Asgrow (corn and soybeans) Holden's Foundation Seeds Delta and Pine Land (deal cancelled by Monsanto) Cargill Int'l Seeds Plant Breeding Int'l
AgrEvo (merged in December 1999 with Rhône-Poulenc to form Aventis)	Hoechst & Schering	Plant Genetic Systems PlantTec	Nunherns Vanderhave Plant Genetic Systems Pioneer Vegetable Genetics Sunseeds Cargill U.S. Seeds
Rhône-Poulenc (merged in December 1999 with AgrEvo to form Aventis)			Alliance with Limagrain which owns Nickersons, Vilmorin, Ferry Morse and others
Novartis (announced in December 1999 plans to spin off Novartis	Ciba-Geigy and Sandoz, merger Merck bought pesticide business		Merger brought together Northrup-King, S&G Seeds, Hilleshog, Ciba Seeds, Rogers Seeds Co.

Crop Protection and Seeds to merge with Zeneca Agrochemicals, forming Syngenta)			
AstraZeneca (announced in December 1999 plans to spin off Zeneca Agrochemicals to merge with Novartis Crop Protection and Seeds, forming Syngenta)		Mogen International N.V. Alliance with Japan Tobacco on rice	Advanta (merger of Zeneca seed and Vanderhave)
Dow Chemicals	Dow purchased Eli Lilly's 40% share of Dow Elanco	Mycogen Ribozyme Pharmaceuticals, Inc.	Mycogen bought Agrinetics United AgriSeeds became part of Mycogen
DuPont		Alliances with Human Genome Sciences Curagen	Pioneer Hybrinova
Seminis/Empresas La Moderna		DNA plant technology	Asgrow (sold corn and soybeans to Monsanto) Petoseed Royal Sluis Seminis

Source: Modified from RAFI (1998), Brennan *et al.* (1999) and supplemented by numerous stories from the *Wall Street Journal*.

of the technology into crops and countries that otherwise would be left behind? How much financial and human capital should be spent on 'inventing around' patents not easily obtained under favourable licensing terms from the private sector? And should CG centres and other similar agencies simply disregard the ownership of intellectual property if the products or processes are not patented or registered in a particular country?[8]

Transgenic (GMO) controversies

Industrial structure and patents present a formidable set of technology access problems for poor countries. In a less direct, but no less important manner, these nations have been partial victims of transgenic organism battles. Volumes have been written about the controversy surrounding GMOs as they affect Europe and the USA.[9] However, few analyses have been made of the effects of this debate on poor countries.[10]

Most observers recognize that the use of transgenics carries both costs and benefits. There are potential problems, for example, with respect to allergens and also potential negative effects on ecosystems and the goods and services they provide to humans. There are potential benefits as well, such as increased plant resistance to biotic and abiotic stresses (Nelson *et al.*, 1999). Honourable men and women can assess risk–return profiles quite differently across nations and economic classes and, not surprisingly, there have been vigorous debates on the nature of those profiles.

The GMO debate has also featured several other themes. For example, consumer confidence in regulatory agencies appears to be substantially lower in Europe than in the USA, in part because of the European experience with mad cow disease. European consumers seem also to have a keener interest in labelling and in consumers' rights to know than do their US counterparts (Gaskell *et al.*, 1999). Opinions have differed on the regulation process, specifically as to whether it is the research process (for example, transgenic versus classical breeding) or the final agricultural product that should be regulated.[11] More strident parts of the debate have entailed charges and counter-charges over whether GMOs have been used as an excuse to advance protectionism (Nelson *et al.*, 1999).

This paper does not assess the merits of various positions in the GMO debate; rather it emphasizes the effects of that debate on developing country interests. Developing countries are concerned that their interests are being neither sought nor heard in many of the arguments over transgenics.[12] In discussions at CIMMYT, numerous leaders from developing countries have said that they resent having either Americans or Europeans speak for them in arguments over the risk–benefit ratios of transgenics. They also express concern that key research initiatives with biotechnology will not be pursued because of what they perceive to be the private sector's focus on the wrong products, for the wrong reasons, at the wrong time.

Representatives from developing countries have instead pointed out that the development of apomixis – a reproductive trait that would permit the seed of a hybrid plant to be replanted and to retain characteristics identical to those of the mother plant – would be invaluable to them for regions not well served by the commercial seed industry. They also argue that the potential for nutritional enhancements, such as vitamin A, could have enormous benefits for poor consumers. Similarly, they assert that drought and pest resistance or striga control for maize in Africa might be the difference between life and death for millions of people on that continent, yet might only add to maize surpluses in the USA.[13] In short, most groups in most developing nations believe that each nation should make its own decision on transgenics. They fear particularly that the transgenic products first introduced by the private sector have needlessly fuelled the GMO debate (Conway, 1999). If that debate, in turn, kills some or all of the incentives for firms to develop the new technology, policy makers from developing countries fear that the technology's potential will not be mobilized for food security improvements – over which there otherwise would be little controversy. They also fear that any involvement on their part with GMOs may jeopardize aid funds from a number of donors.

Ironically, some of these same spokespersons feel that, even if biotechnology does go forward, it will not be accessible or usable by them. As one example, poor countries feel very much caught up in a trade war not of their own making. They are concerned that regulations developed under the biosafety convention using 'precautionary principles' will cause GMOs to be barred from entry into Europe and perhaps elsewhere. They worry that these rules could then preclude developing nations from the possibility of using transgenic technologies to expand their agricultural trade.

Convention on Biological Diversity and other international initiatives

Private sector issues have featured prominently in the foregoing discussions of patenting, industrial concentration and GMOs. Unresolved issues from the Convention on Biological Diversity also threaten to impede germ plasm flows from public and non-profit agencies.[14]

The current flow of germ plasm is impressively large. Indeed, the potential slowdown of this flow is the major concern of this paper. For the most part, these flows originate from 1320 ex situ genebanks (FAO, 1998). These banks contain a total of over 6 million accessions (varieties or landraces) for all crops and an estimated 95 per cent of all landraces for the cereals (Smale, 1996). Among these banks and accessions, none are more important for developing countries than those maintained by the 16 Centres of the Consultative Group for International Agricultural Research (CGIAR). Collectively, the centres' genebanks hold about 600 000 accessions. This sum is only 10 per cent of the total in all genebanks, but there are many duplicate samples throughout the world. Fowler (2000) estimates that the CG collections, which also contain a much higher percentage of the associated landraces than do typical national collections, contain almost half of the genetic diversity for the foodcrops.

A breeder seeking a particular variety or a specific trait would therefore most likely be in touch with the specific CG Centre focused on that commodity. Centres hold virtually all of these genetic materials in trust for the world and they make available research quantities of seeds to all legitimate breeders regardless of nationality or affiliation. Moreover, under a supplemental FAO (Food and Agriculture Organization) agreement, none of the varieties in trust can be patented by either the public or private sector, a proviso 'enforced' by the material transfer agreements under which the seeds change hands.

At a superficial level, there appear to be few problems with public germ plasm flows to and from poor countries. Unfortunately, deeper analysis reveals two quite troublesome issues, both of which revolve around definitions within the context of international treaties. New accessions to the genebanks constitute one of the hurdles. The 1992 Convention on Biological Diversity (CBD) reaffirmed state sovereignty over genetic resources and provided them with authority to control access. The devil of that provision is in its details. Article 2 of the CBD states that the country of origin of genetic resources means 'the country which possesses those genetic resources in *in-situ* conditions ... surroundings in which they have developed their distinctive properties'. Even the genebanks with the best historical data on accessions are able only to pinpoint the country from which the variety was *collected.* No genebank can identify the 'origin' of a variety, much less of individual alleles, in part because a workable definition of 'distinctive properties' is lacking. Most of a variety's 'old' properties were defined in Neolithic times, or even before. New properties have evolved or co-evolved through mutation or crosses, either intended or accidental, but often the country of origin even of the 'new' properties would not be known with certainty. Moreover, if a 'distinctive property' were discovered and its origin confirmed, how would compensation be determined? For example, one of the most popular wheat varieties in the world, the VEERY line, is the product of 3170 crosses involving 51 parents from 26 countries! It thus seems quite clear that the CBD approach to access and benefit sharing is unworkable in both scientific and practical terms.[15] However, if most of the varieties and traits of economic or ecological interest for a species have already been collected, the direct consequences of the CBD may be minor.

Unfortunately, an indirect consequence of the CBD debate is more serious. Decision makers in numerous agricultural ministries have now started to believe that they are sitting on genetic fortunes and that they must therefore restrict the movement of germ plasm from their countries to capitalize on these 'goldmines'. These restrictions can take the form of rejecting requests by prospecting missions for new varieties or landraces and, more importantly, of being unwilling to exchange plant genetic materials for research and field trials with neighbouring countries and research groups. Such an approach is shortsighted, because the basic financial assumption on which it is based is wrong. Smaller, poorer countries are those most likely to gain from cooperative breeding efforts and the exchange of plant materials. Preliminary evidence from 1992, for example, indicates that developing countries received approximately 100 times more seed samples than they sent (Fowler and Smale, 2000). Although it is often said that developing countries are 'gene rich', while the developed countries are 'gene poor', this statement masks the reality that many of the poorest countries, for example the Sahelian countries and many island states, have relatively few genes to trade or sell. A restricted access regime would thus be particularly harmful to them.

A second definitional problem also plagues the international flow of germ plasm and particularly the CG Centres. As noted previously, most accessions in the Centres' genebanks are held in trust, and cannot themselves be patented. But at what point does an accession cease to be an accession and become a product or derivative that *could* be protected? Does a new research product exist after one cross of two accessions? After ten crosses? At what point do derivatives become patentable? And, if they are patentable, are countries of origin (defined how?) entitled to compensation for the patent and, if so, on what basis is compensation to be made? These are more than rhetorical questions, for they go to the heart of the way in which the public and not-for-profit sectors organize themselves in the new world of biotechnology and intellectual property.

The problem, in fact, is even more complicated than the one suggested above. A breeder working on wheat, for example, in a particular country would likely contact CIMMYT, the relevant CG Centre, but not to ask for an *accession*. He or she would be much more likely to request particular lines that CIMMYT breeders had already refined with respect to certain traits or characteristics. In breeding for disease resistance, for example, CIMMYT may have found a gene or set of genes that it uses in crosses for elite (advanced) breeding lines. On the other hand, CIMMYT, a not-for-profit institution committed to helping resource-poor farmers, is unlikely to have sequenced or cloned that gene, which are steps now deemed necessary prior to securing a patent.

But what if a private firm, public agency or individual were to request seed samples, do the sequencing and cloning, and then obtain the patent? In order to continue using the gene, the Centre, and indirectly the poor countries as well, might need to obtain a licence from the patent holder. Under certain plausible circumstances, the Centre might even be excluded altogether from using what was essentially its own research. Under these circumstances, should not the Centre producing these public goods protect, through patenting, its ability to deliver these goods to the poor?

A final issue hinges on the use of intellectual property for research versus commercial purposes. There is still a widespread tradition in both the public and private sectors to trade research material and genetic constructs *for research purposes*. But problems arise when Centres or national systems develop varieties for release to farmers based on techniques or constructs that were made available on a research-only basis. Holders of the original intellectual property are then in powerful bargaining positions to extract rents from those who have used the property – innocently or otherwise – in the development of the new variety.

In summary, the flow of germ plasm for agriculture has changed from a relatively open system of public sector development of germ plasm to a much more confidential, rights-oriented system of seed development and diffusion. Obviously, the new system has produced significant new products that have benefited numerous companies and many farmers. However, issues of patenting, industrial concentration, transgenics and international initiatives are now interacting in ways that are limiting germ plasm flows to poorer countries. Without wise decisions at this time, there is every reason to believe that these constraints will become more binding in the future. Two relevant questions thus remain. Are these constraints important, or are they merely interesting? And, if important, what kinds of institutional innovations are now required to reverse these trends before they further impede the attainment of food security in poor nations?

THE GREEN REVOLUTION REVISITED

Running history backwards is always a delicate analytical procedure, yet it is sometimes revealing. In the paragraphs that follow, I address the important question of whether the initial Green Revolution would have been possible if the current 'rules' on germ plasm had been in force from 1950 to 2000. I believe that the answer is 'no'.

A key feature of the Green Revolution was the strategic use of dwarfing genes in rice and wheat plants to prevent lodging under the growth made possible by high-fertilizer regimes. As Evans (1998, p.137) states, 'The greatest impact on world food production as the population grew towards 4 billion came from the deployment of dwarfing genes in wheat and rice in the 1960s.' The wheat story is particularly interesting. Ironically, the wheat dwarf gene. Norin 10, probably came from Korea via Japan (Evans, 1998). It was brought to the USA in the late 1940s, manipulated by several breeders, and sent in a series of crosses to Norman Borlaug in Mexico in 1954. This dwarfing trait, when combined by Borlaug with other desirable genetic and agronomic characteristics, launched the Green Revolution, and there ensued four decades of extraordinary growth in wheat yields. Some 40 years later, slightly more than 80 per cent of all of the wheat grown in developing countries is planted to semi-dwarf varieties (Pingali, 1999) (see Table 2). A phenomenal 75 per cent of the semi-dwarf area in wheat is planted to CIMMYT lines (or lines with CIMMYT ancestors), virtually all of which include the Norin 10 gene.

Could a comparable sequence of events have taken place under current institutional circumstances? In my view, the probability is low. The key assumption in this thought experiment is whether or not the dwarfing gene would be patented or kept in the public domain. If patented, how hard would the patent holder have worked to promote this characteristic in a crop that is self-pollinated, not easily subject to hybridization and, therefore, not a great generator of seed sales? Perhaps an entire new line of hybrid wheat would have been developed, but would it have reached 80 per cent of the areas of less developed countries? Unlikely. Would CIMMYT or some other agency have been in a position to send out seed samples, which in 1994 alone totalled 1.2 million packets, three-quarters to developing countries and almost all carrying the dwarfing gene (Fowler and Smale, 2000)? Probably not. Would global yields of wheat have been lower, more mountain and forest land lost to crop production, and more people left food-insecure? Probably so. Protection of the dwarfing gene would almost surely have been successful in OECD countries and from a private profitability perspective. However, the social costs in terms of benefits forgone – at least on the basis of this retrospective analysis – would have been extremely high.

TABLE 2 *Area (million hectares) grown to different wheat types in 1997, classified by the origin of the germ plasm*

		Spring bread wheat	Spring durum wheat	Winter/facultative bread wheat	Winter/facultative durum wheat	All wheat types
	CIMMYT cross	17.8	3.4	0.6	0	**21.8**
National Research System Cross	CIMMYT parent	22.4	1.2	1.9	0	**25.5**
National Research System Cross	CIMMYT ancestor	12.6	0.02	4.2	0	**16.8**
National Research System Cross	Other semi-dwarf	7.7	0.11	11.6	0.1	**19.5**
National Research System Cross	Tall	5.2	0.3	2.2	1.0	**8.7**
	Landraces	1.4	1.5	4.1	0.1	**7.0**
	Unknown cultivars	1.0	0.1	2.6	0	**3.8**
	All	**68.1**	**6.7**	**27.2**	**1.2**	**103.2**

Source: Pingali (1999).

Other scenarios could be written about the dwarfing gene; however, the analysis just presented seems sufficiently plausible to persuade one that the issues of germ plasm flow are important as well as interesting. The dwarfing example also suggests some of the future institutional modifications that should be made in the interests of global food security.

MOVING FORWARD

Changed attitudes

A great many agriculturists wish that the rulings that permit the patenting of living organisms had never been made. Nevertheless, many of them will also concede the benefits of patent protection to the pharmaceutical industry, because of that industry's long lead times with product development and the high cost of human trials. They understand further that many of the key decisions affecting agriculture, in fact, have their origins in the life sciences.[16] While they typically see no similarly compelling logic with respect to agricultural products, they also see no way of turning back the clock. Providing germ plasm to poor countries thus requires altered attitudes, procedures and institutions.

Changes in biology, information technology and law now dictate altered procedures for both the private and the public sectors. There has been a role reversal, and now the proprietary sector rather than the public sector is the dominant force in germ plasm development. Inevitably, the public sector will become less open as circumstances dictate the development of intellectual property, or at least the use of such property controlled by others. Confidentiality agreements have (or will) become the norm for not-for-profit institutions, rather than the exception. The private sector, in turn, will need to become more sensitive to consumer desires and to the problems of orphan countries and crops.[17] Much of the solution will be in the form of new public–private partnerships more in the private tradition, and part will be in altered strategies that keep substantial portions of the new science as public goods.

Continued use of the public domain

One obvious way to assist poor countries is via disclosure processes that preclude patenting by others. Such processes keep germ plasm and genetic technologies in the public domain, thereby providing the freedom to operate for agencies producing public goods. This approach has long been a hallmark of the public sector; interestingly, it is also becoming a feature of some firms within the private sector,[18] Monsanto's recent willingness to share genomic information on rice is one important example (Gillis, 2000). There has been much speculation about this decision, but it has set an important precedent for the private sector. Similarly, the announced intention to publish (disclose) electronically the full genome for *Arabidopsis thaliana*, a member of the mustard family, is another important example (Somerville and Somerville, 1999). A comparison of these two genomes will be especially revealing, because there is strong homology suspected between the genomes of rice, *Arabidopsis*, and 250 000 other plant species. But there is also a potential downside to disclosure. Protection is afforded only to that which has been disclosed, and not to the 'surrounding' data or constructs. Moreover, partial disclosure may give others clues that result in their patenting the rest of the genetic mechanism in question, an action that the initial disclosure was specifically trying to prevent. Therefore, in spite of the widespread progress with genomics, the specific technologies that govern function, use and manipulation of these recorded genes, or sets of genes, are increasingly likely to be held under some form of intellectual property protection. Such protection provides, in turn, both the opportunity and the forcing mechanism for new partnerships and alliances within and between the public and private sectors.

Limited use of defensive patenting by the public sector

Most public sector agencies are not well set up to deal with the protection of intellectual property. The culture and mission of these agencies, the outlook of their staffs, their historic openness with scientific findings and their general lack of legal talent all militate against the use of protective devices. If these agencies wish to remain at the forefront of future agricultural research, many of them will find it essential to use patents or other forms of protection. Revenue generation may be one motive, especially given the global decline in support for agricultural research. Much more important than revenues, however, will be the need for first-class research organizations to maintain operating freedom. Alliances with private sector firms may require that the public sector hold patents for bargaining purposes. At a minimum, the capacity to use protected methods and materials from the private sector will require having confidentiality agreements in place, even if patenting is not pursued directly by the public agency. Tapping the private sector's capacity and experience in scaling up from the test tube through product distribution is also likely to be invaluable. Finally, bio-piracy of public sector findings will likely become more commonplace unless the intellectual property dimensions of those findings are considered on a systematic basis.

Clearly, not all research findings need to be protected; indeed, as a practical matter, very few of them do. There are also a variety of methods, including outsourcing, which can be effective in managing intellectual property at reasonable cost. However, for public and non-profit agencies to disregard recent trends in the protection of intellectual property is to put both them and the countries they serve in jeopardy. Unfortunately, a great many of these agencies are seemingly still at the denial stage on this issue.

Renewed efforts at capacity building in poor countries

If poor countries are to reap the benefits of 21st-century research, they will need help. Part of this assistance can come from intermediary agencies who can help transform, adapt and develop new forms of technology for orphan crops and lagging regions. But there are severe limits to what outsiders can do, just as there are severe limits to what technology alone can do to solve problems of food security. Inadequate investments in human resources within these countries is a major part of the problem, and recent educational and R&D investments are not sums that should make either developed or developing countries very proud. While it is true that the number of trained personnel in sub-Saharan Africa was greater in 1991 than in 1961, as Pardey *et al.* (1997) show in their important study, it is also true that sub-Saharan numbers are still pitifully small. The total number of agricultural research workers in 21 countries of sub-Saharan Africa in 1991 was less than 7000, and total expenditures in 1991 (in 1985 dollars) for agricultural research were less than $700 million.[19] In a global review of agricultural research systems, Traxler and Pingali (1999) have classified some 40 national research systems with respect to their ability to provide significant amounts of parent materials for their crossing programmes (so-called Stage 3 capacity), their ability to undertake crossing programmes and to produce the occasional variety (Stage 2 capacity), and all others (Stage 1 capacity). They concluded that only seven national research systems for wheat and 13 for rice belonged in either Stage 2 or Stage 3. Since the poorest countries are precisely the places which private sector firms are least likely to serve, a rapid upgrading of national research capabilities is vital for *all* forms of technology development and transfer. Unfortunately, this sobering conclusion far overshadows this paper's more specialized discussion of improving germ plasm flows.

Expanded use of market sharing and licensing agreements

More than anything else, the successful transfer of plant genetic materials to poorest countries during the next 25 years will require new types of partnerships, alliances and market sharing (Serageldin, 2000). Neither the public nor the private sector institutions will be completely comfortable with these arrangements, but the limited experience to date suggests that several forms are indeed workable. Wright (2000) has developed a useful taxonomy of formal and informal arrangements that could be used to bring biotechnology to the poor. These mechanisms include licensing under varying cost and technology-sharing arrangements, market segmentation, technology grants, joint ventures, alliances and various kinds of direct research support. There is a high probability that almost any of these forms of cooperation can be made to work, provided that the partners know specifically what they wish to achieve, each party has something to offer others in the partnership, and everyone is willing to spend sufficient time to understand each other's positions and to build trust.[20]

Institutional arrangements designed to use biotechnology specifically in support of poor countries are in their infancy, but progress is being made. For example, Novartis presented the International Rice Research Institute (IRRI) with the *Bt* gene construct for rice as a gift in 1993. CIMMYT began a strategic alliance in 1998 with Institut de Recherche pour le Développement (IRD) and three private companies (Novartis, Limagrain and Pioneer) for the development of apomixis in maize. CIMMYT has also begun a very specific collaborative arrangement with Monsanto on the development of hybrid wheat, and the International Livestock Research Institute (ILRI) has joined with The Institute for Genomic Research (TIGR) on sequencing research related to the parasite *Theileria parva* that causes East Coast Fever in cattle. These are only examples, but they are important examples because they demonstrate the diversity of arrangements now being undertaken.

Five preliminary but important conclusions can be drawn from the early experience of the CGIAR Centres. First, it *is* possible to negotiate effective public–private arrangements, even those involving several private companies in non-exclusive relationships; however, the negotiations tend to be neither quick nor easy. (Negotiating time appears to go up by the square of the number of parties involved!) Second, it has also proved feasible to provide preferential access to research findings for particular national agricultural programmes. Mexico, in the case of CIMMYT's apomixis project, is an especially noteworthy case, in that this nation is a centre of origin for maize.

Third, market sharing has been a key element in most of the early agreements. The private partner typically retains the rights to distribute, sell or license products in the developed countries, whereas the public agency retains rights for the developing world. Many countries fall neatly into one category or another: however, countries such as China and India are typically a source of contention among public and private parties concerning whose rules should prevail in the market-segmentation agreements. Although relatively poor in per capita income terms, both countries are large in terms of aggregate GDPs, and both also have strong agricultural research systems. But the problems regarding how the market is to be segmented, how poor regions within richer countries are to be dealt with, how the trade flows of products are to be regulated between the two sets of countries and how the technology differential is to be implemented (gifts, licensing at zero cost and so on) help explain why negotiations between the public and private sectors are rarely easy or short. Indeed, principles of market segmentation and the development of prototype agreements appear to be important areas for further research.

Fourth, public sector negotiations with the private sector have been complicated substantially by the changing structure of the biotechnology industry. The many changes within and among various mega-firms have been disruptive in the formation of partnerships to serve poor countries. Perhaps the seed and biotechnology industries have now reached quasi-stability and, if so, negotiations may be much easier in the years ahead.

Finally, there is the generosity factor. Much has been written about the short-run profit imperative for private firms, a point that at one level is obviously correct. However, the early negotiating experience of the CGIAR Centres indicates, on balance, that companies in the private sector have a gratifying concern with poverty issues and have been remarkably generous with respect to legitimate use of their technologies in support of poor countries. It has indeed been possible, if not easy, to find 'win–win' solutions that embrace both the public and the private sectors. These new kinds of partnerships represent the greatest hope for improving germ plasm flows into poor countries during the 21st century.

NOTES

[1]The number 70 is clearly arbitrary. The USDA analysis (1997) uses a series of food gap, income growth and income inequality variables to identify 66 countries with moderate or severe food security problems. However, the two largest developing countries, China and India, have very strong national agricultural research systems. Correlations between per capita GDP and 'agricultural research vulnerability' are thus far from perfect – a point of some importance for the final section of the paper.

[2]Lipton (1999) provides a useful statement on various positions on these topics. Various viewpoints are also highlighted in a series of articles under the heading, 'Can Biotechnology End Hunger?' in the Summer 2000 issue of *Foreign Policy*.

[3]Plants that reproduce asexually had long been covered in the United States by the 1930 Plant Patent Act; however, that act excluded bacteria from protection. See also note 4.

[4]In a series of lower-court decisions, cells, organelles, genes, molecular constructs and lines were also held to be patentable.

[5]Many of these fragments were of interest because of potential human health products rather than for their importance to agricultural crops.

[6]A few of the early applications received patents; however, ESTs were given new, more stringent guidelines for patenting in March 2000.

[7]Sachs (2000) has written perceptively about technologically excluded countries in the process of development.

[8]Ingo Potrykus, the chief architect of vitamin A-enhanced rice is quoted as saying, 'So many fields of research are blocked by corporate patents. I had to ignore them or I couldn't move at all' (*www.gene.ch/infor4action/2000/Mar/mag00002.html*).

[9]The terms 'transgenic' and 'GMO' are used interchangeably in this paper to refer to an organism that has had a gene or genes from another species inserted into it. These concepts differ from genomics, which is the study of structure and function of very large numbers of genes within an organism.

[10]Gaskell *et al.* (1999) provides a useful summary of European versus US attitudes. One of the most complete discussions of biotechnology in developing countries is that of Persley and Lantin (2000).

[11]In April 2000, a committee of the US National Academy of Sciences concluded that regulation of 'genetically modified pest protected plants' should be product- rather than technique-based (National Research Council, 2000). Although most US scientific opinion has supported this position, it has fared less well politically.

[12]Persley and Lantin (2000) as well as Gisselquist and Srivastava (1997) provide case studies on biotechnology in developing countries.

[13]The 'Insect Resistant Maize for Africa Project' provides a very illuminating example from Kenya of African attitudes and approaches (KARI, 1999; Mgendi, 1999).

[14]Much of this section draws on conversations with, and research by, Fowler (2000).

[15]When the Convention on Biological Diversity was adopted, it was recognized that certain issues, including the status of genebank collections assembled prior to the coming into force of the Convention, were still unresolved. Since 1994, FAO has been hosting formal, intergovernmental negotiations on the status of plant genetic resources for food and agriculture, with the aim of bringing an earlier agreement, the 'International Undertaking', into harmony with the Convention. If successful, the outcome would produce a multilateral system for access and benefit sharing of genetic resources at least for the 25–35 crops most important to world food security. It is likely, however, that minor crops, including many of importance to subsistence farmers and poor in developing countries, would be 'orphaned' by this approach.

[16]Barton (1997) has written more generally about some of the fundamental differences between the agricultural and pharmaceutical sectors.

[17]That some firms in the private sector needed reminders about consumer interests is ironic and speaks volumes about the public relations débâcle that surrounded terminator technology and several other GMO initiatives. Good science was simply not enough (Conway, 1999).

[18]It may well be that publishing the human genome will also help to establish procedures and precedents for a more open system for plant agriculture.

[19]By way of ludicrous comparison, Stanford University alone had a consolidated budget of $875 million in 1991, also measured in 1985 dollars.

[20]Leisinger (2000) offers insights on the practical and tactical aspects of building partnerships and alliances. A very useful statement of principles on public sector–private sector alliances for assisting poor countries can be found in the Tlaxcala Statement (CIMMYT, 2000).

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