# The lock-in of major standard crops and the prospects of underutilized alternative species: A technological systems and institutional analysis

**Nadav Feuer and Yaakov Garb**

**Arava Institute for Environmental Studies**

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"Efforts so far have been directed to raise the awareness on the need to work on underutilized species and to start redressing their status of neglect. An area that has not been investigated yet is the analysis of when *a species will evolve* from its status of underuse and neglect *to become a well utilized crop.* This is a very relevant point if we want to make sure our efforts will lead ultimately to the "full promotion stage" beyond which the crop will no longer be considered underutilized." – Stefano Padulosi, Director, Neglected & Underutilized Crop Species, International Plant Genetic Resources Institute

**Abstract:**

Within the confines of the technical regime of agriculture already characterized by systems lock-in, emergent crop innovations surfacing from the pool of neglected and underutilized species face prohibitive sociotechnical resilience. Dominant crop domestication techniques have served to narrow the genetic pool and nutritional diversity while consolidating the commercial and end-user demand within a suboptimizing framework that artificially suppresses radical changes to the regime. The inquisitive frontiersmen of agricultural exploration extant in the mid 20th Century have been incrementally subverted by sociotechnical arrangement distinguished by institutional malaise, overspecialization, and a research incentive structure that discourages wide-ranging democratic participation in crop recognition and development. However, as many scholars have noted, international actors often perceive their central role as exclusionary and are reluctant to recognize the fundamental multiple informational source aspect of their agricultural endeavors. By exploiting the hybrid institutional structure underlying the conservative network for agricultural innovation through a holistic socionatural identification for neglected and underutilized crops, the misleading productivist ideal driving the technical regime can be infiltrated and undermined. In this way, sustainable development can be furthered not only directly by emergent crops for combating desertification, salinization, and chemical usage, but indirectly through a regime shift marked by a return to local and natural mechanisms and rural development. The sociology of technological evolution can help us understand both how this lock-in has come about and what potential opportunities exist for changing the dominant agricultural regime.

## 1.0 INTRODUCTION

The increasing role of organic food markets, "slow food" movements, and community-supported agriculture in the northern hemisphere has made some progress since the early 1990's toward supplanting an entrenched technical regime for agriculture. While these events have inserted small wedges in the global agricultural system, they lack the teeth to uproot the larger sociotechnical organization built around a small and overdeveloped group of major cash crops. The growing unease over the matter of food security in the world is the result of a maturing realization that the genetic base of most human caloric intake from plants is dangerously narrow. The current mainstream model of domestication, dominated by Mendelian pedigree breeding, has been maintained at the loss of horizontal, or broad, resistance to plant pests and diseases and a drastic reduction in the variety of plants eaten worldwide. The ephemeral benefits of this mode of development are not immediately apparent, which has led to a deceivingly efficient economic outlook. This economic arrangement has, over time, been maintained artificially by an institutional support network premised on overspecialization, a restricted research environment, and poor capacity for self-criticism. The growing interest in the advancement of so-called neglected and underutilized crops presents a particularly good opportunity to investigate a viable competitor to the narrow technical regime for agriculture and to uncover the avenues by which the regime might be most easily infiltrated. These crops often have the benefit of higher nutrition, good hardiness and yields, and are often unaffected by the international community of plant diseases and pests that plague major cash crops. Many are resistant to extreme environmental conditions or are suited to adverse anthropogenic conditions, such as salinization, global warming, and desertification. Concepts drawn from the study of the evolution of technical systems will be used to illuminate the systemic processes that lead to the resilience to change of dominant technical regimes on the one hand, and their interruption by new competitors on the other.

## 2.0 OPPOSING FORCES: DOMESTICATION AND INTRODUCTION

Domestication, the anthropogenic equivalent of a natural evolutionary mechanism for crop adaptation, is broadly applied to the entire continuum of crop breeding activities, from rural, usually decentralized efforts to major international research projects for developing advanced domesticates. This process of micro-evolution is aimed at reducing the wild family of a crop to a few “agro-ecotypes” that are suited to a particular ecosystem and perform better there (Robinson, 2002: 35). Although this process inherently involves reducing the genetic diversity of the plant species, the scale to which this is carried out is highly variable. Classical Mendellian pedigree breeding aims at isolating one desirable characteristic (such as disease immunity, flavor, yield, etc.) by propagating successive yields of crops with the single alpha-candidate that best typifies the desired trait. Resistance breeding, on the other hand, employs a wide selection of the cultivars for propagation that best exemplify the desired characteristic. Genetic diversity is degraded in both processes, but much less so in the case of resistance breeding. While pedigree breeding allows for much more precision in isolating the sought characteristic, it often does so at the cost of other positive traits, which, collectively, are termed *hardiness*. For example, immunity to a particular disease might be reached, but vulnerability to a specific pest might increase. Additionally, because the genetic base of the new domesticate has been reduced so drastically, an entire field of this crop would be negatively affected if a pest succeeded in one, a process known as frequency dependent selection.

According to Raoul Robinson (2002), an internationally-recognized pathologist and plant breeder, horizontal resistance has been diminishing for the whole twentieth century (86-88). The vulnerability to other pests and the monocropping paradigm induced by pedigree domestication initiates a series of adaptive measures, including protective chemicals and preemptory breeding for resistance, that do not solve the underlying problem. While incidents like the Irish Potato Famine (1840’s) and the corn rust epidemic in the United States (1970) have vividly illustrated the importance of genetic diversity and horizontal resistance, longer-term and chronic damage occurs on a regular basis. Many Cavendish banana farmers (representing 90% of the international market) today in most regions of the world report spending around 50% of their costs simply on controlling the *black sigatoka* disease (Canine, 2005). Through denial of various negative externalities in the system, however, multinational firms, research and development agencies, and state actors continue to push for pedigree domesticates and commoditization in the food sector. The countervailing force is plant introduction, which serves to diversify risk from pests, add new and interesting crops, and increase productivity.

The history of crop introduction is one that towers over the current day efforts for the promotion of neglected and underutilized crop species (NUCS). Historical successes, such as the introduction of the Andean sweet potato to isolated New Guinea, which permitted crop yields several times what was possible, have only a few contemporary equivalents (such as the introduction of the Andean potato to Europe) (Diamond, 2005: 284; Biggs and Clay, 1992). In 1938 A.J. Bruman pointed out that,

> "One need not look very far for a list of new plants in this or in any other country. The great coffee industry of Brazil and Central America, the sugarcane industry of the West Indies, the tobacco industry of Turkey and India, tea and cacao in Ceylon, rice in South America and Southern Europe, rubber in the East Indies, maize and cotton in many lands all traces their beginning to a few unostentatious plant immigrants disseminated by the busy plant hunter."

New crops in the modern context must arrive from the pool of neglected and underutilized crops. However, the openness, curiosity, and adventurousness of early 20th century plant explorers and the more flexible technological regime extant at the time did not survive after the post-World War II industrial mentality rooted itself. Over this time, the technological system experienced what one might call an erosion of its "creative diversity" on a technical, agency, and institutional level (Rammert, 2001). Although a resurgence of interest in NUCS has surfaced, particularly after the 1996 Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources, the institutional capacity for introducing these crops on an international level is very small and the political willpower and openness is relatively low.

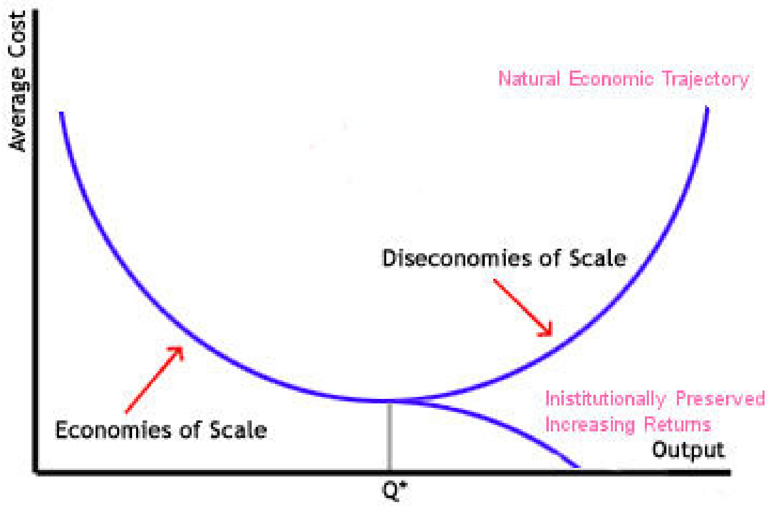
Rural populations of the world are the primary consumers and agents of preservation for NUCS. Although the international banana market may not see more than the Cavendish banana, local growers worldwide are eating hundreds of different varieties of the banana. In this context, alternative crops often provide the bulk of caloric intake worldwide. Beyond the local sector exist niches (usually embedded within various alternative food movements) that create demand for NUCS, in addition to crops, such as *Triticale,* which potentially have a broad internationally market in their future. Other NUCS are currently being used or considered for varying industrial processes or to play roles in national and international plans addressing conservation and sustainable development.

## 3.0 ENTRECHMENT OF THE AGRICULTURAL REGIME: PASSIVE AND ACTIVE BARRIERS

The capitalist momentum driving the current agricultural market operates through appropriation of natural production processes and substitution of natural products on a global scale (Goodman et al., 1994). Commercial interests and consumers see a façade of inputs and outputs that very much mimics the industrial and technological processes they are accustomed to. For the average consumer, researcher, and farmer, efficiency seems to appear when the market is aligned on fewer crops (Arthur, 1988). For example, corn of varying qualities is used for food, fodder, oil, sugary syrup, plastics, and researchers can easily prioritize resources toward corn-based agriculture and have a higher chance for receiving funding. Typical industrial research challenges also arise with annual disease and pest threats, domestication proceeding across so many levels, and market maturation fit for high-investment biotechnology. The mentality of *productivism*[1] serves to disguise the treadmill upon which the system

[1] Productivism refers to a single-minded definition of goals and assessment criteria in which greater volume and lower cost of production in the near term crowd out consideration of external costs, quality, and sustainability.

perpetuates itself. The primary divisiveness of megacrops such as corn is to crowd out the propagation of new plants through a process by which increasing returns to scale are being erroneously extended by the institutional regime past the threshold where decreasing returns genuinely set in (at point Q*, below). Individual farmers often rightly claim that consistent product in a consistent market is most important for their survival. Biggs (1992) depicts how inconsistency and unfamiliarity weighed heavily in the introduction of triticale into the Himalayas. From the perspective of sociology and technology Rammert (2001) points out that "cultural orientation, cultural practice, and institutional regimes" can support and shape technological development in difficult markets and when firms are not able to achieve sufficient certainty. The institutionally-driven agricultural system, which itself is locked-in to the dominant agricultural regime, maintains these parameters for farmers, but at the cost of true economic surpluses to be discovered in alternative crops.




An economic surplus would mean that the *real value* of the crops has increased. The supposed surplus of intended megacrops commonly disregards environmental and ecological considerations and hidden costs. These costs most clearly include the diversion of valuable international research resources just to hold ground, and the environmental impact by farmers who incrementally increase chemical usage while they wait for relief from a distant international research community (IRRI). Occasionally, a disease slips through the cracks, and causes major agricultural loss (Robinson, 1996: 34). As worldwide water budgets become more strained and salinization of land increases through irrigation and chemical applications, governments around the world are impelled to take action (Yeo, 1999). Jolliff (1996) calculates that American crop subsidies in the 17-year period leading up to 1996 were $935 billion (1995 dollars), compared to the ~$2 billion annual agricultural research budget over the same time-period.

Funding for neglected and underutilized crop species typically becomes available only once the crop is nearing its commercial stage or the critical financial needs inherent in the dominant regime have been taken care of. There is also need to overcome the expressed attitude that new crops do not have merit or farmers would already be growing them. In many cases, the institutional regime artificially discourages their use, does not encourage their use in basic ways, or carries an embedded normative rule against "small-time" crops. Myers (1999) outlines manners in which development of NUCS is indirectly discouraged: first in the ineligibility for crop insurance or loans (uncertainty is too high for many lending institutions), or the lack of standards for the crops penalizes farmers making a quality crop or does not give farmers a chance to convince buyers of the quality of their crop. However, a growing movement for sustainable development and rising levels of food and environmental awareness may be pushing development of NUCS in a positive direction. Projects can be billed as supporting conservation (Christensen, 1987; Williams and Haq, 1993) and substituting NUC cultivation in for surplus megacrops opens doors to new markets and is an efficient manner of eliminating the subsidized surplus that dominates agricultural subsidies (Jolliff, 1996).

## 4.0 THEORETICAL TOOLS FOR UNDERSTANDING LOCK-IN AND OPPORTUNITIES FOR CHANGE

According to Raoul Robinson (2002: 10-13), a lifelong observer of the global agricultural system, the technological regime of agriculture is characterized by continual reductionism that has resulted in a century-long bout of suboptimization. By this characterization, the dominant agricultural system has artificially functioned at lower systems levels in order to maintain a bulwark against potential emergents that might destabilize the system of advantages accrued by various actors within the technological regime. The broad network of embedded institutional, political, and most-often economic commitments creates the context for an "institutional entrapment," which drives the in inertia of the global agriculture regime (Berkhout, 2002). In order to maintain these commitments, certain mechanisms for instituting "lock-in" are employed at various levels by actors within the sociotechnical regime (Arthur, 1988).

Most clearly, suboptimization has been sustained through the manipulation of conventions, preservation of identity, constructed technical overlapping, artificial competition, and permanent dislearning of a holistic approach to cultivation. Conventions, after Michael Storper, make up the set of practices and expectations imposed upon the production structure (Murdoch et al., 2000). Under this approach, standards of efficiency and reliability are outlined for the production sector and often the end-user; public conventions, such as patents, are manipulated to reinforce dominance; and civic conventions, or views on what make up societal benefits, are often defined by the dominant regime for the purpose of self-aggrandizement (Murdoch et al., 2000). Identity structures, such as function, purpose, and societal importance are crystallized in a similar fashion to conventions (Sundstrom et al., 2002). The barometer by which emergents or potential emergents are gauged is a function of identification mechanisms that favor incumbent entities. David (1985) describes how "technical interrelatedness" and quasi-irreversibility are crucial mechanisms for maintaining lock-in. In the global agriculture market, this refers to the broad network of actors producing and relying on subsidiary markets for such things as byproducts, sorting equipment, processing equipment, and contracts. Quasi-irreversibility is the process describing farmers dislearning of their "trade" as a whole in favor of highly-specialized, input-based agriculture, as well as the takeover of large-scale corporations. If these systems level mechanisms do not adequately protect the lock-in, an old-fashioned sectoral system of competition exists to combat holism at the private sector level (Geels, 2004).

Ways in which lock-in are naturally overcome, however, combine with strategic mechanisms employed by proponents of holism to create pressure to resist artificial reductionism. First and foremost is the fact that nature is not a passive backdrop to the process of lock-in. Under the framework of actor-network theory (ANT), Murdoch et al. (2000) show how natural interventions, such as crop disease and weather, are examples of how nature can not be severed from the production process and continues to be an active force. Allaire and Wolf (2005) show how a natural elastic phenomenon tends to exist as a counteractive force to "infinite decomposition" of products and the industrial linear model of standardization. Successive recomposition of usable attributes, followed by standardization does lead to increased capture of consumer surplus as well as heightened end-user comprehension, but it spawns a balancing demand for more traditionally reputed and differentiated products (Allaire and Wolf, 2005; Biggs, 1990). Biggs goes on to describe how mechanisms for maintaining lock-in often only infiltrate the professional community at a superficial level, and do not operate at the behavioral, or functional level. While professionals may consider themselves to operate from a central-source model, in which innovation is made at large institutions and permeates downwards, most professionals function according to a more democratic, or multiple-source manner of information collection and integration. As a result of these natural processes at work, openings in the regime often appear without strategic intervention, as Van den Ende & Kemp (1999) relate:

> "Within a technological regime there are usually tensions in the form of product imperfections, capacity limits, and unsatisfied demands (which form focal points for research, the basis for competition and interventions from third parties)." (p. 837)

Recognizing and mapping the current and potential points of tension in the technological regime for agriculture is a crucial step in understanding where the *weaknesses in the insulation* exist.

Strategic avenues for overcoming lock-in can augment naturally-occurring tensions in the technological regime. These avenues, however, depend on the purpose outlined for the intervention: a livelihood approach aims to assist the producer's life situation while a commodity chain approach is focused on fixing weak spots in the development and commercialization of the crop (Christinck, 2004). Since the most intervention is needed at the larger global market, we will focus on strategies aimed at improving the entry of NUCS at an institutional, individual, and market level. The process of *recursive innovation*, or the co-evolution of markets and preferences with radical new technologies, attempts to serve the means/practices of other social worlds (mostly users and appliers) from the onset of development (Rammert, 2001; Geels, 2002). One avenue for recursive innovation is creative identity innovations, such as claiming to be a source of beta carotene, but also cultural or ethical innovations, such as organic labeling or audience-specific marketing. Recursive innovation very often also involves the creation of what Murdoch et al. (2000) terms "socionatural hybrids," or crops that appeal to the social needs of the end-user while appealing to a more traditional, perhaps ecologically-oriented audience. However, novelty is often contrary to the ability to commercialize a crop, because households require the time and the incentive to domesticate (in the social sense) a new product to their life. In these cases, what Allaire and Wolf (2005) coin "transfiguration of imagery" can be used to allow unfamiliar NUCS to "hitchhike" on intermediary symbols or products that have familiarity and meaning to end-users. Also drawn from the work of Allaire and Wolf (2005) is the potential for rehybridization of the institutional regime, perhaps through intentional dissemination of the conceptual evidence underlying their own multiple-source aspect of institutional behavior. However, alongside all of these mechanisms is the potential for a grassroots development of a crop through integrated niche branching (Hoogma et al., 2002). In particular, niches are often forthcoming in areas that have been denuded or destroyed by industrial agriculture (disillusioned areas) or areas still untouched by "modern" agriculture (pristine areas, especially in developing countries) (Murdoch et al., 2000).

## 5.0 FUNCTIONING OF THE CURRENT TECHNOLOGICAL REGIME

Werner Rammert (2001) separates the notion of culture as an underlying playing field of the technological regime into the following three components: (1) institutional regimes, (2) cultural orientation, and (3) patterns of practice. To this list, we add a fourth component of endogenous natural forces, which are particularly relevant in the case of agriculture. Within the global agricultural system, each of these components is marked by barriers and constraints that artificially lock-in the dominant technological regime and preclude even exploration of new crops (Arthur, 1988). The interplay of these components is often facilitated by the embedded influence of actors, who often play competing roles in enabling or retarding the development of underutilized crops. Section 6 outlines weaknesses in these barriers and points of intervention.

### 5.1 Syntactic or Institutional Contribution to Lock-in

The challenge presented to various institutions related to crop management by neglected and underutilized crops is both a struggle to overcome extant conventions and their own overly centralized outlook. The International Agriculture Research Centers (IARCs), which receive funding from a variety of public and private sources, are the primary umbrella organization preeminent in this field. Their fundamental dilemma arises in that each Center has a set of "mandate" crops on which they work, and have determined are critical for "holding ground." As disease damages rise with broader propagation, the treadmill of costs for basic research moves faster, and more resources are diverted from innovation (Bertram, 1993). The IARCs, however, are credited for the discovery of triticale, as well as a tropical wheat and pigeonpeas. After 25 years, triticale now reaches yields that compare with super-domesticated breadwheats and with higher nutritional value (Vietmeyer 1989). One of the IARCs, the International Board for Plant Genetic Resources (IBPGR) is now focused solely on collection, characterization, conservation, and new crops. Their latest victory has been the large-scale diffusion of rocket (*roquette)*, a flower used in salads in upscale European markets. Other institutions with research-minded administrators, such as USAID, the World Bank, UNICEF, and others are also involved from time to time, with funding or sometimes direct organization of projects (Biggs, 1990).

Attempts at fundamentally shaping crops and crop systems were carried more in earnest in the 1970s and 1980s. The CGIAR, or mother of the IARCs, was deeply involved in the development of the Green Revolution (GR) and dabbled in alternative Farming Systems Research during the 1970s. The GR, which commercialized a few varieties in large areas of Asia, reduced crop diversity and, in the short term, dramatically increased production. Like many events in this formative time, the GR also set precedents (if mistakenly) for research endeavors and laid down public and standards conventions that would shape future projects. Efforts to develop Farming Systems Research, which tried to find roles for NUCS in intercropping with major crops, were a counteracting force that unfortunately did not take off. Agricultural institutions also often disregard or unknowingly pass over potential breakthroughs occurring outside the centralized institutional domain (Biggs, 1990). This is why we find scientists, such as Corley (1989), complaining that, "new crops taken up by the plantation industry will have a much greater chance of success than those promoted unilaterally by scientists or aid donors." Institutions, including governments, have a history of impeding progress or proceeding far too slowly.

In the past, it may have appeared glaringly obvious to institutional promoters of NUCS that these crops could bring major benefits to agriculture, personal health, biodiversity, and so on. If the crop has benefits that are clearly backed up by statistics, reports, field tests, and personal experience, why should it fail to reach a larger audience for domestication and eventually sale? Institutions with a progressive vision find themselves fighting to retain their centralization and thereby remain unavoidably bound with the larger professional agricultural research community. Progressive organizations, such as the IBPGR, are aware that they are "on to something" and their unique role calls for less mainstream methods, but they remain bound to a sociotechnical landscape[2] (made up of their parent organizations, funders, fellow agronomists, and their own professional needs) that often suppress this behavior. The demanding institutional formula of international conferences, "cooperation" at a high academic or political level, strategy documents, and annual reports leave just enough time to compose a few detailed monographs and documents.[3] These methods are clearly the industry standard, but they only

[2] The term "sociotechnical landscape" was first employed by Geels (2002) to refer to the broad set of structural trends made up of heterogeneous factors, such as economic conditions, conflicts, political configurations, cultural normative values, and environmental problems. The "landscape" is external to the technical system at hand and makes up the context in which the system operates.

[3] A sampling of these monographs can be found under Sorenson (1996) and Padulosi and Pignone (1996)

sincerely address the scientific narrative of the crop and not many of the real social, political, and economic barriers.

Within the public sector, the motivation for exploring neglected or underutilized crops, and the corresponding capacity to carry out an effective program must be aligned for a national crop improvement program to be carried out. The web of laws, economic incentives, and research funding is only slowly able to adapt to the new crops and new methods demanded by the propagation of neglected and underutilized species. These factors are, in turn, deeply affected by the entrenched agricultural industry within the country. As an indicator of the power of the agricultural lobby, we can look at desperately arid countries, such as Jordan and Israel, which provide agriculture with more than 50% of their nations' sweet water at a deep subsidy.

The advantages and limitations of different institutional environments is described in **Appendix I,** which describes the success rates and development style of various institutional frameworks.

## 5.2 Pragmatic or Practical Contribution to Lock-in

Ideally, a plant with significant agricultural potential would move from acknowledgment of its good qualities to exploitation for the social good very quickly. Williams and Haq (2002) describe how "successful action mostly resulted from identifying a specific and important single end-use, assembling a substantial germplasm[4] collection followed by selection, breeding and multilocational trials and commercialization. This was the case for *Triticale, Amaranthus,* buckwheat and sesame." By this recipe, the process sounds fairly straightforward, and it is implied that a linear, perhaps centralized model of crop innovation is suitable and effective. This recipe, however, does not address how to skirt or conform to conventional reliability standards, secure fair public advantages, or break through interrelated technical dependencies.

The market for new crops lacks what is often referred to as a *sectoral system* to complement the scientific institutional community and comprehensively navigate through conventions and the overall sociotechnical system. A sectoral system is a group of firms or organizations that simultaneously encourages cooperation and engenders a healthy environment of competition (Geels, 2004). The firms making up this system, ideally, would be characterized by a degree of "interpenetration," or overlap in their overall purpose and perhaps a few specific practices, but would also maintain their identity as discrete units in the technological system (Geels, 2004). An example of such a system is that for the lesser-known safflower cooking oil, in which a series of major companies and farmer associations, making up a group called Montola Growers, research and market their own variety of safflower oil while at the same time creating awareness about safflower oil in general.[5] Through this sectoral system, safflower growers are able to improve upon both the production side and end user acceptance of their product. The sectoral system's embeddedness at various levels of production, processing, and promotion gives it the capacity to abide by established conventions or the clout to change them. Interpenetration allows actors within the sectoral system to make rational decisions about changing the technical guidelines under which they operate instead of erecting barriers.

A *sectoral system* for NUCS is not absent because of inadequate financial incentive, willingness, or lack of potential participants, but rather because of poor recognition of partners. Potential sectoral participants operate in a fairly isolated manner or marginalize and underappreciate potential members of the sectoral system (Hall et al., 2003). As a result, each actor lacks proper resources and has gaps in the proper disciplines necessary for research, propagation, and commercialization. If recognized as legitimate, research already carried out by

[4] Germplasm is the total genetic variability available to a population of organisms. In agriculture, it is usually represented by the amount of diverse seeds, cuttings, or laboratory genetic material available for breeding.
[5] This can most aptly been seen by viewing Montola's website: <http://www.montola.com/why_oil.html>.

"practitioners" (farmers, universities, small-scale breeders, seed companies, etc.), could be included more readily in the international effort for plant innovation.

The largest diversity of actors and the largest potential for sectoral cooperation is to be found within this subgroup of practitioners. Although no statistics exist to explain the contribution of each in the propagation of NUCS, a few general points can be made. Firstly, that subsistence and small-scale farmers have and continue to carry out the bulk of the discovery, initial selection, and subsequent landracing of many NUCS (Biggs and Clay, 1982). By marginalizing this role, the international community for NUCS propagation fails to benefit properly from a *service that is already being provided*.

The most basic practitioners, the rural farmers and gardeners living in every corner of the world, have catalogued and put to use most of the plants they find around them. Their experimental method is generally defined as *endogenous,* involving purposeful selection of superior crops combined with natural selection in a limited geographical area (Biggs and Clay, 1982). Jared Diamond (2005) describes the basic process by which rural farmers in New Guinea may have conducted this process on an informal level:

> "[New Guineans] are constantly picking up local plants, asking local people about the plants' uses, and selecting some of the plants to bring back with them and try growing at home. In that way, someone 1,200 years ago would have noticed the casuarina seedlings growing beside a stream, brought them home as yet another plant to try out, noticed the beneficial effects in a garden—and then some other people would have observed those garden casuarinas and tried the seedlings for themselves." (p. 285)

In the next level, this group of practitioners includes research-minded farmers, and farmers living in areas of high climatic stress and inconsistency (which spurs natural selection) (Biggs, 1990). They also include many farmers who have been given or have bought seed from an institutional or governmental body instead of cultivating local plants. This collective group of farmers plays a major role in contributing to the research of public institutions and government, as well as taking on responsibilities not within the capacity of institutions. As the size of the farming enterprise increases, the more likely the farmer or owner will switch from a landracing mentality to a domestication mentality, in which performance of a particular crop becomes important enough to devote significant resources to it. However, at the largest scale, the industrial farm, NUCS are unlikely to be grown due to the heavy embeddedness and dependence upon the megacrop technological regime.

The mass introduction of international domesticates often threatens rare crop species, as well as disrupting indigenous patterns of living. High-yielding international varieties are pushed on local farmers with very good intentions, but often fail to perform well due to lack of proper resources (such as irrigation, fertilizers, chemicals) and knowledge, or simply due to differences in the agro-ecosystem. The quasi-irreversibility of dislearning indigenous agricultural techniques and losing germplasm in favor of international varieties diminishes rural capacity for democratic participation in the development of new species (Berkhout, 2002).

### 5.3 Cultural Orientation and Semantic Contribution to Lock-in

Within the global agricultural system, parallel cultural forces ignore non-consumerist social worlds as legitimate demand and operate under the assumption that marginal differentiation of production for existing crops is the long-term solution for maintaining consumer demand. Traditional social worlds are usually end-users such as grocery stores, which demand attributes like appearance, consistency, and flavor, or industrial end-users, who desire consistency, extractability, and quality of extracted material. If the intended audience for the crop, however, is a rural subsistence population and the goal is development, the financial incentives are usually low and clarity of the demand is poor. This situation might require hardy, multi-purpose plants with cottage industry capability rather than a simple adaptation of a current megacrop (Evenson, 1974; Farmer, 1979, both in Biggs, 1990).

The guiding principle of *infinite decomposition*, which implies the production of more end-user goods from the same original crops, creates a barrier against new crops. This differentiated occurs along lines of agronomic inputs, retail consumers perspective of end-user wants, and service needs (Allaire and Wolf, 2004). As the number of crops being employed on a large-scale worldwide is decreased by domestication, the number of products made from the narrowing species base must increase correspondingly. New crops with very useful qualities often find their characteristics unneeded in the modern market, which has found a way to manufacture a substitute from an existing crop. The matter of "creating new markets" for these crops would otherwise be simple to overcome if the "material nature of society" extended to agrofood. People happily expect new candy bars, but are they as accepting and encouraged to purchase a "new" banana? Traditional marketing, which is expensive, can smooth over transitions like this, but, given the poor sectoral capacity and resources available for new crops, this does not seem particularly feasible.

### 5.4 Natural Forces and the Endogenous Contribution to Lock-in

Despite technological improvements aimed at overcoming natural forces, nature cannot be severed from the agricultural system and it continues to play a key role (Murdoch et al., 2000). By this, we are not referring to traditional inputs from nature, such as radiation, natural soil nutrients, rain, and so forth, but to nature's set of reactions and defense mechanisms. Nature is now more of a nuisance within the framework of modern agriculture. It is associated, for example, with rain that does not come or comes too strong (drought, flooding, global warming), lowering yields (salinization), high chemical costs (pests and diseases), and consumer scare (mad-cow disease, genetic engineering).

The human response to these nuisances flows in two directions: (1) finding substitutes that are drought tolerant, pest-resistant, halophytic, and unaffected by consumer scare, or (2) "fixing" existing plants based as each problem arises. The barrier against alternative crops arises when disproportionate resources are allocated to fixing existing plants and social disorder rather than seeking a substitute. Enormous resources worldwide are spent fighting plant diseases with chemicals and fighting consumer rejection of GE crops with anti-labeling legislation and ad campaigns instead of researching substitutes. The drain of resources away from new crop innovation and the cementation of stop-gap or technical solutions directly discourages the market for NUCS.

## 6.0 POINTS OF INTERVENTION IN THE TECHNICAL REGIME OF AGRICULTURE

The entrenched agricultural regime supported on all levels by restrictive conventions, identity preservation, resistant technical arrangements, and decades of quasi-irreversible changes to the sociotechnical landscape nevertheless contains many avenues for intervention on the behalf of neglected and underutilized species. The development of an ecological convention under the context of growing movements for sustainable development and mounting environmental complications has created the opportunity for the insertion of NUCS as socionatural hybrids. This encompasses a series of intervention methods, including transfiguration of imagery, innovation of a recursive manner, hybridizing of institutions, integrated niche branching, and simply allowing nature to create points of intervention.

### 6.1 The Endogeneity of Nature – Letting Natural Forces Do the Work

The sociotechnical landscape can be softened for NUCS by activities external to the crop development, which collectively broaden the size of the support network. Changes in demand preferences, legislation, and awareness resulting from the eruption of infectious disease, such as mad-cow (BSE), foot-and-mouth disease, and the avian flu are compared to consumer resistance to GE crops (which are, almost by rule, only megacrops) (Freidberg, 2004). In these cases, end-users become acutely aware of the vulnerabilities of and weaknesses in the global agricultural system. The resulting actions invariably hurt the system or directly help alternative systems. In the case of GE foods, and, in fact, concerning the risks associated with the industrialization of agriculture, upper-scale cuisine demands, the growing organic and health food markets, and growing awareness of food nutrition all assist in the reshaping of the sociotechnical landscape to look more favorably upon NUCS (Allaire and Wolf, 2004). These niches, which will be discussed below, are building off of momentum already created by nature in the form of environmental and health problems.

The dramatic cases of infectious disease and technology scare (GE crops) are, however, sitting upon a foundation of much longer-term and more recognized environmental problems in modern agriculture. Soil salinization, pests and diseases, and inclement weather threaten the industry in much deeper ways than food scares. Not coincidentally, there exist NUCS that both live and thrive under these conditions or actively reverse them (Choukr-Allah, 1997). There are viable xerophytic (heat-tolerant) and halophytic (salt-tolerant) species, as well as hydro-efficient plants (good water equations), and comprehensive disease and pest resistance. These species, and their simple efficiency, must simply be prioritized over technological solutions, advancement of chemical protection mechanisms, plant biotechnology, and evasive advertising. A reinventing of the wheel to technologically parallel nature's advancements can be argued on a environmental and technological level.

### 6.2 Transfiguration of Imagery – Hitchhiking NUCS on Recognized Symbols

The factor most neatly aligning neglected or underutilized crops within the extant technological regime is the quasi-symbiotic, or in some cases parasitic, relationship NUCS may share with incumbents in the dominant agricultural regime. In the case where the NUCS do not create any new demand for themselves, they can be seen as parasitic, or as piggybacking on existing products or processes and "stealing" demand away from these products. According to Allaire and Wolf (2004), this is a backdoor mechanism of identity network expansion via intermediary symbols that already have end-user meaning. This is the case of safflower oil, which has increased markedly in popularity in large part due to the emergence of corn-safflower cooking oil mixes.

The primary result of this parasitic effect is to enhance or enlarge the diversity of products in a given market (vegetable oils, for instance), spur a measure of competition, and raise consumer awareness about the qualities of each product. An increasing number of species and varieties over time will make the entrance of additional new varieties more accepted by consumers and more routine by the industry. As alternative crops join, the global agricultural system necessarily expands the agricultural regime, and, in doing so, sets the stage for a shift toward agriculture focused on sustainable development.

Jacobssen (2004) description of the niche for wind and solar energy development in Germany has many similarities with the overall concept of new crop development. Primarily, this is because wind and solar energy, like NUCS, are "nested" within other regimes (the energy regime, in the case of renewables), and whose rise represents a regime expansion rather than a shift in the German context (Van den Ende & Kemp, 1999). The expanding role of wind and solar as a subset of energy production is similar to how we envision the evolution of new crops as subsidiaries to the major megacrops.

In the beginning, the overall trajectory of the agricultural regime need not be reoriented, because expansion more appropriately calls for a process of *creeping infiltration* by substitutes (Berkhout, 2002). This is why hybrid cars have appeared and not teleporters, and why, in all likelihood, crops resembling dominant crops, or at least being marketed in relation to dominant crop markets, will be the driving force behind the initial expansion. The emergence of English names for exotic crops, such as "custard apple," or marketing slogans, like "it goes in your salad" are indicative of this process taking root. Since the product is new to the consumer, appealing to something familiar, such as blemish-free produce or as an alternative ingredient in well-known recipes, can help push it off the shelves (Allaire and Wolf, 2004). However, NUCS must also be flexible enough to exploit episodic trends in end-user needs, such as diets, alternative oil (ethanol) demands, and health research. In many cases, such transfigurations of established agricultural imagery are part of a holistic innovative process and are embedded in the proponents' strategy for propagation.

### 6.3 Recursive Innovation – Aligning Crops to Diverse Social Worlds

Propagating and commercializing a crop should involve a wider view, namely that the entrance of new crops into the functional world involves a type of "domestication" for end users, involving at least symbolic approval (emotional acceptance), practical work (integration), and cognitive work (or learning) (Lie & Sorenson, 1996). User preferences and markets must usually "co-evolve" with radically new technologies, which can be carried out by recursive innovation, or considering a wide range of the consumer audience from the onset of strategizing (Geels, 2002; Rammert, 2001). We learn that success is not as simple as spurring adoption; one must integrate new technologies in routines, which can involve heavy lag time in learning, adjustments, and consumer "domestication" (Lie and Sorenson, 1996). This is often complicated by the fact that most NUCS are not single-use products and must be integrated system-wide to see their true profitability; they often share food and medicinal value, as well as present opportunities to use processing byproducts (Williams and Haq, 2002).

The clearest avenues for "insertion," however, correspond to unfulfilled industrial and consumer need created by production gaps in the current technological regime. Williams and Haq (2002) describe a few of these emergent "interests" in their seminal article, *Global Research on Underutilized Crops*:

- [Industry] For use as raw materials in certain industrial processes (fibers, oils, resins, rubber, film coatings, etc.)
- [Livestock] For use as fodder
- [Government] For countries attending to diversify agricultural production, especially to supply demand for luxury crops.

Neglected and underutilized species can also fill gaps in the needs of the international political community. With the dispersion of environmental regulations and awareness, as well as global environmental action plans, like *Agenda 21*, NUCS have become increasingly supported under the aegis of species conservation and cultural heritage preservation, or simply to develop an alternative agricultural reality that stems or slows deforestation and contributes to sustainable development. In general, the diversity and breadth of potential uses of NUCS is such that their promotion and development can be integrated into many current interests and markets.

Perhaps the most successful example of product insertion is genetically engineered crops, which have risen to prominence due to creative matchmaking with extant industrial needs and cultural identity structures. The goal of marketing within traditional crops is to aim for identity preservation (IP), or the differentiating of agricultural products for different markets in order to capture more of the consumer surplus (Sundstrom et al., 2002; Bender, 2003; Desquilbet and Bullock, 2003). This concept, however, is being used in reverse (i.e., *identity convergence*) by proponents of GE crops, and can also be used as an infiltration mechanism for NUCS.

Defying the normal commodity-based trading system, which thrives on "new" products, GE crops often strive to be seen as "substantially equivalent," often in the face of protest from environmentalists. There are a few reasons for this, some of which shed light on the emerging strategy for NUCS. First, there is efficiency in simply adding GE crops to established systems of processing and distribution; second, the fears in the agricultural biotechnology sector about consumer rejection are diffused by induced homogenization; and third, farmers can secure government subsidies if the crops are seen as "equivalent" to ones that already receive subsidies (Directorate-General, 2001). In essence, promoters of genetically engineered crops capitalize on the markets for food that is traditionally eaten, while simultaneously attracting customers with the "modern" lure (Biggs, 1990). Developers of NUCS would be wise to capitalize on the first and third aspects of IP, which have already been developed and proven by the biotech sector.

Developers of NUCS should also more heavily consider the prospect of aiming for a secondary use (usually animal feed, or industrial processes) as an entrance to the market. Unbeknownst to many European citizens, large quantities of GE animal feed are being used in the EU, despite the consumer rejection. Another lesson drawn from the biotech sector is their smart "technology-packages," or "synergies," which use existing channels of distribution, or multiple product lines to attract convenience buyers. Promoters of NUCS should focus on finding relatedness to mainstream crops (in transportation, packaging, industrial use, etc.) in addition to the traditional set of desirable plant characteristics (disease resistance, drought and cold resistance, earliness of maturity, palatability, and high yield) (Bruman, 1938; Plucknett et al., 1983). The typical Round-Up Ready soybeans have been successful at all levels of market penetration due in large part to this factor.

### 6.4 Integrated Niche Branching

NUCS that lack a clear "backdoor" entry or are not presented with a "window of opportunity" (defined by tensions in the sociotechnical landscape, such as internal technical problems, or changing consumer demands) may require a niche in order to be properly "incubated." As Geels (2002) astutely points out, these niches are not simply "out there"; they must often be artificially created. In this respect, a range of niche varieties exist for an up-and-coming crop. Elaine Solowey, author and NUCS specialist in Southern Israel, describes the stepwise preservation and niche creation system as one that progresses from wild niches (conducive agroclimates) to deeper levels of human technological complexity (specific inputs) and anthropogenic usefulness (Solowey, 2006: 24). However, niches can also be created by tensions in the sociotechnical landscape that incite human actors to take up a particular cause.

In the realm of neglected and underutilized crops, small farmers, even subsistence farmers are very likely candidates for niches, either for field testing or research, if the program is properly conceived and executed (Biggs, 1992). Along the course of the development from wild niches to more advanced human niches, the possibility and likelihood for niche branching and therefore accelerated development increases (Hoogma et al., 2002). Concurrent education and marketing campaigns can help move this process along faster as well (Solowey, *in Interview*).

Countervailing forces responding to the industrial objective of infinite decomposition also serve to create natural niches. Conceptually, these niches follow a trend towards small-scale and traditional, as well as towards closer "systems of regard", or closer communication between producer and consumer that increases awareness, quality of produce, and reduces costs.

Alternative food networks, such as organic and "slow" food, as well as community service agriculture (CSAs) are clear examples of these niches at work (Sage, 2001). Technology-specific coalitions (the buds of a *sectoral system*), such as organic food organizations or consumer groups, form to advocate and influence institutions, thereby softening the sociotechnical landscape enough for government legislation to change or be better enforced, research and development budgets to rise, and, on the functional side, awareness to increase so that "green demand" becomes a significant market force.

### 6.5 Hybridizing Institutions – Engendering Professional Support for New Crops

Many scientists describe themselves as working under a central source (or top-down) model of agricultural innovation, but the actual behavior of the researchers, institutions, extension services is more akin to a multiple source model, in which diverse actors from all levels of the professional spectrum contribute to innovations (Biggs, 1990). The political, economic, agroclimatic, and institutional contexts revolving around the "center," which created the conditions for a given innovation, often receive little of the credit for it. There is a need to openly recognize that the agricultural regime derives its inputs from local, national, and international sources, and the conscious exploitation of these collective resources is necessary to bring about the greatest diffusion of innovation and highest social good. In other words, institutions must be hybridized so that knowledge creation and diffusion rest upon a combination of private, public, and collective exchanges that allow legitimacy for alternative systems to emerge (Allaire and Wolf, 2005).

What is seen by major institutional actors as productive research (innovation) as opposed to maintenance research (which complements past advances) will have to align itself to the needs of the larger community, which, by nature, are closer to the needs of practitioners and end users. The by-product of expanding the consulted research community to a larger professional audience is a natural system of checks-and-balances, in which dominant interests do not maintain themselves without proving their worth. There is evidence that this hybridization is occurring very rapidly. Plans drafted by the Steering Committee Meeting for the Global Forum on Agricultural Research (GFAR) for 2006 include many concepts outlined here. These include researching under both a livelihood and commodity chain approach (rural welfare and rural supply chains), differentiation to niches (high-value markets), recursive innovation (aiming at diets, health, nutrition), recognition of need to self-hybridize institutions (acknowledging poor institutional knowledge and local learning potential), and aiming for sustainable development (shift away from idolatry of cash crops).

Public institutions, which represent the largest capacity for research in the world, are particularly suited to hybridization because of their commitment to national interests and looser funding, professional, and oversight environments. As a crop filiere[6] continues growing towards a critical mass, the development of the crop will at some point reach a juncture, where certain national or international laws, or regional customs, will come to bear or be created. At the very least, facilitating the passing of legislative and regulative hurdles is an important role played by the public sector. The ideal context for the promotion of NUCS, however, is the development of a comprehensive system leading from overarching policy, as well as legal, and economic incentives to training, testing, and distribution via extension services (Biggs and Clay, 1982). This concept of a national system of innovation framework in the agricultural research sector is gaining ground (Hall et al., 2003). In 1982, an All-India Coordinated Research Project on Under-Utilized and Under-Exploited Plants mapped out the specifics of "what" and "how" in a

[6] A filiere, of French origin, is a word often used in network analysis to describe the link existing between stakeholders of an innovation from the beginning of its development through to marketing and diffusion.

public setting. The system erected carry out the project was lacking in a few areas, but its general motivations are useful to study. As stated, the project

> *"[…] was initiated to include research on selected food crops (winged bean, rice bean, amaranth, buckwheat, chenopods), fodder plants (woody species), energy plants (sugarcane, bamboo, sweet potato), hydrocarbon and industrial plants (guayule, jojoba, and others), oil yielding plants, and some drug producing plants. All these were prioritized according to economic importance. In parallel, priorities were established for plants for extreme environmental and emergency situations in desert, arid, saline, and flooded area."*

Generally, they followed a priority framework later developed by Williams & Haq (1993), which aimed using NUCS to accomplish the following:

- supplying deficit products (e.g. oils)
- satisfying particular int'l trade requirements
- new crops to new products that have market potential
- old crops for new purposes or local use
- addressing stressed ecosystems (e.g. improving soil quality)

All agricultural institutions, whether public or private, are deeply influenced by the dominant professional research framework. Advancement of NUCS requires shaking the stability of the existing system on a cognitive, normative, and regulative level (Geels, 2004). On a cognitive level, one of the primary difficulties in promoting NUCS is aligning the professional and institutional framework to fit the goals of new crop propagation. Agricultural engineers and reigning institutions (USDA, FAO, CGIAR, etc.) are characterized heavily by strict adherence to the technological trajectory wrapped around megacrops. Also pervasive is the dominant knowledge base, which includes engineering practices, corporate governance structures, and manufacturing processes (Geels, 2002). Strict curriculum in university agriculture departments, for instance, is a barrier to the initial development of a NUC. This field's newness can also be used to its advantage—for instance, in the development of a new discipline that could develop and move along NUC development on an academic level. We might call it *botanometrics*.

## 7.0 CONCLUSIONS

Neglected and underutilized crop species represent an unprecedented opportunity to challenge the dominant agricultural regime in a more comprehensive manner than accomplished by organic and other alternative food movements. These species have the potential to undermine the narrow basis of domestication that has allowed the consolidation of crop species through the infiltrative capacity of plant introduction. Scientists and technical system theorists within agriculture and outside have demonstrated the potential weaknesses in the dominant technological regime for agriculture and highlighted avenues of intervention and insertion. In the near future, NUCS will always be secondary markets vis-à-vis the megacrops in the global landscape, but their share of the market could increase markedly. We have reviewed the role of the actors making up the network of support for neglected and underutilized crop and have exposed the dynamics underlying their institutional regimes in order to allow further actor-network mapping and enable critique and strategic assessment of intervention. Alternative food movements have, since the early 1990's, shown how feasible various styles of intervention can be and have laid the groundwork for a holistic shift in the regime toward genetic diversity, decentralized and democratic participation in research, and focus on sustainable development.

Williams & Haq (1993) criticized heavily the lack of mobilization among the institutional community for developing a comprehensive database. As it stands currently, many institutions hold databases of various quality and varying levels of compatibility. Finding the necessary information at a worldwide level is not only difficult, it is, in itself, a separate research project. A database would have had the benefits of linking public and private sector research (and likely the developing and developed worlds), highlighting the needs of developing countries, and helping develop more effective prioritization. Governments often provide low funding, counter-funding (as in the case of agricultural subsidies for major crops), or adopt restrictive legislation. Williams and Haq (2002) show that only a handful of developing countries have a national plan of any merit, and only networks consolidated under the FAO, ICUC, SPC, and AVRDC, have any substantial influence. In many least developed countries (LDCs), it is also not uncommon to see constraints set on private R&D (Pray and Echeverria, 1991), and a system of patenting that discourages development.

With the advance of desertification, global warming, and water scarcity, the role of xerophytic underutilized crops, or those with heat/drought tolerance, will only become greater. Traditionally, the usefulness of these crops has been underappreciated due to the dominance of Northern Hemisphere crops in the international market, and the desert, the traditional home of xerophytes, has been altered by modern agriculture and irrigation to grow these types of crops. However, the desert is a fragile ecosystem, and the initial deceptively good yields that tempted farmers everywhere from the Fertile Crescent to the American Southwest are already experiencing the inevitable degradation from salinization, waterlogging, and mineral build-up. The high evaporation rates of the desert combined with the irrigation of unnaturally large tracts of land in the world have been the major cause for water scarcity and unsustainable aquifer plundering. The time for xerophytic crops to emerge and begin replacing water-heavy has never been so critical—and this process will occur under the same parameters as other neglected and underutilized species.

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## APPENDIX I – INSTITUTIONAL PATHWAYS

**Table 1. Pathways of Entrance to Larger Markets or Research Communities**

| Type of Pathway | Advantages | Limitations |
|---|---|---|
| Local entrepreneurs | Quickest avenue to propagation<br>Adapted to local conditions already<br>Efficiency of private enterprise | Financial resources<br>Expansion possibility hemmed<br>Continue to serve limited population or niche |
| Independent researchers | Deep understanding of local knowledge<br>Genetic resources and institutions at disposal<br>Breeding intentionally for regional or international commercialization | Funding access and cycles inappropriate for comprehensive domestication<br>Marketing capacity is limited<br>Incumbent on investors to carry out physical propagation |
| International organizations | | |
| Seed bank or gene bank | Guaranteed preservation of genetic material<br>Catalogued data for international use*<br>Available for other pathways simultaneously | "Seed Museum" effect<br>Dwindling resources for research/breeding<br>Narrow range of available support actions<br>Losing funding internationally<br>Focused primarily on major crop species |
| Development organization | Vast resources and guaranteed funding sources<br>Embedded in the institutional framework<br>Media capacity<br>Influence on int'l and national agricultural and political agenda | Bureaucratic hurdles<br>Mandated for agricultural endeavors apart from NUS<br>Lack of in-house marketing |
| Educational institution | Financial resources are accessible<br>Academic credibility<br>In-house propagation<br>Student energy | Primarily receiving support for research purposes<br>Bound by departmental and institutional bureaucracy |

* Assuming sufficient resources and database capacity for adequate cataloguing and accessibility to international entities