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Climate-ready Crops and Bio-capitalism: Towards a New Food Regime?

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Abstract. The relationship between climate change (CC) and the potential for transition to a new food regime can be analyzed through the development of Climate Ready crops, which aim to provide a solution to the problems facing food production in the future. Using a bio-capitalist approach, this analysis focuses on the ways in which corporate actors and others map out and frame the challenges posed by CC in technoscientific and biophysical terms and potentially impact agri-food systems. Thus, the debates surrounding the future of food production and the challenges of CC, for this article, are analysed through the lens of bio-capitalism and the concept of food regimes to assess the limitations and potential consequences of biotechnological adaptation strategies for agricultural sustainability. This approach views biotechnology as one of the productive forces of capitalism, which attempts to produce surplus value from living systems in ways that ensure the continued accumulation of wealth through not only commodity forms but also their legal appropriation and control through Intellectual Property Rights (IPRs), mostly through the reproductive control of plants and animals used in agricultural production. The practical limitations of this adaptation strategy are explored from a bio-capitalist perspective to analyse how technoscientific interventions in the context of CC are organizing local and global forms of social and biological exclusion and inclusion, and how these exclusions challenge the global food economy. The difficulties and unevenness presented by global climate change reinforce the idea that new regimes of food production, which aim to work within the complexity and resilience of specific ecosystems, are needed. This stands in opposition to the current productivist paradigm. This article considers how global climate change exposes the weakness of biotechnological solutions, which in turn are creating the conditions for the emergence of a neo-productivist regime.

Introduction: Climate Change and Food Bio-capitalism

The challenges posed by climate change (CC) and the need to double food production by 2050 (FAO, 2008) have given new impetus to the agricultural biotechnology sector. Biotech research has benefited from massive public/private R&D in-

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vestments, creating new market opportunities for industry for research into crop adaptation to environmental stress. Several biotech corporations are isolating and patenting 'climate ready' (CR) genes hoping to engineer high-yielding crop varieties tolerant to abiotic factors – such as drought, salt, temperature extremes, high UV light – and capable of using nitrogen more efficiently. However, by defining climate-related environmental stress narrowly along technoscientific possibilities and the isolation of biological traits, biotechnology research into CC fails to radically alter our reliance upon the conventional agri-food paradigm. Furthermore, CR crops create false expectations about increasing crop yields and how best to deal with CC, foreclosing research on local varieties and local knowledge systems and practices that address variable climactic conditions. CR crops represent a higher order of genetic complexity and ecological risk than first-generation GM crops; early field trial reports indicate that poor crop survival and productivity may severely restrict their use (Margulis, 2009). Beyond the technical realities of this approach, it is clear that CR crops represent an attempt to construct a new narrative around our ability to cope with the potentially devastating consequences of climate change in the context of an industrially driven food production system.

Food Regimes and Climate Change

Climate change expresses a new phase in agricultural development, as it marks the possible transition to a neo-productivist food regime. The concept of food regimes approaches the global production and consumption of food from a political economy perspective, enabling the emergence of the relational aspects of capitalist structures and actors which shape agricultural forces of production and consumption across space and time and define key historical moments (McMichael, 2009). The concept has evolved and given rise to a more complex understanding of global food production and consumption patterns. Periods of transition from one regime of capitalist accumulation to another have been characterized and discussed elsewhere but they can be summarized as: the extensive food regime (pre-1914), the intensive food regime (1947–1970) and the third food regime (1980–present) also known as the corporate environmental food regime (Friedmann, 2005). Within the third food regime, Burch and Lawrence (2009) describe the financialized food regime where global finance firms and instruments increasingly occupy new sectors of the agri-food system (including hedge funds, private equity firms, sovereign wealth funds, etc.) and agri-food companies operate more like financial institutions. According to these authors, the process of financialization signals a fundamental change to 'stakeholder capitalism' where financial institutions determine the course of agricultural production (either towards food or fuel for instance) and further entrench inequalities between North and South. Pechlaner and Otero (2008) describe characteristics of the third food regime as 'neo-liberal' because of the global restructuring of agriculture along the lines of trade liberalization, regulatory and intellectual property rights (IPR).

The scientific and biophysical limitations embodied in the search for 'climate tolerant' food crops enable us to think of other ways to frame the ecological crisis within a new crisis of capitalism, which could mark the transition to a new food regime. The neo-liberal restructuring of local and global agri-food networks has created zones of social and biological exclusion and inclusion, including growing inequalities within the food system between North and South (see Pechlaner and Otero, 2008) which give rise to recurring food crises. The food crisis consists of the ongoing historical layering of a series of embedded relations, seen through what Harvey (2005) would call historical–geographical materialist transformations, which McMichael summarizes as: '[r]ising costs, related to peak oil and fuel crop substitutes, combine[d] with monopoly pricing by agribusiness to inflate food prices, globally transmitted under liberalized terms of finance, trade and food security arrangements associated with neoliberal policies' (McMichael, 2009, p. 282). Climate change adds a new layer to this historical process by defining the ways in which ecological relations become embedded in market logic, thus further concealing 'the relations and processes underlying the corporate appropriation of agriculture' (McMichael, 2009). The question of access to Southern biodiversity stocks or the rural South has been a major factor in shaping global environmental agreements such as the Convention of Biological Diversity as well as neo-liberal trade negotiations within the World Trade Organization (WTO). The search for patentable genetic materials by agri-food corporations (including the biotech industry) has taken place in the same geographical spaces where food insecurity and food crises have been devastating. Ecological degradation deepens these tensions, creating the conditions for new models of food production to emerge, referred to as neo-productivist because they interrupt the flows of the hegemonic global agro-food system but yet aim to work within a capitalist framework. Climate change creates an opportunity to invest in new adaptation strategies for food production via the technical possibilities of adding bio-value to crops which do not threaten the global economy. It should be mentioned here that this author does not start from the premise that there is one food economy but rather that what we call the global economy is made up of multitudes of diverse food systems that exist on different scales. Clearly, the dominant food regime interacts with these various food systems in different ways but always with the intent to control them and assimilate them into the industrial paradigm.

The technologization of nature is not the most salient feature of the current food regime but rather signals the advent of a new technological accumulation regime that controls and drives scientific innovation for the purposes of enabling market penetration into all individual and collective aspects of life (Uzunidis, 2003). In this context, the pace of technoscientific innovation is determined by profitability rather than the ability to solve real problems. This technological accumulation regime provides the means through which the properties of living systems become appropriated via titles, patents, governance and other quasi-legal instruments within a neo-liberal trade regime that ensures the generation of capital. This means that the agricultural production process is not just constrained by technological progress but by state supported corporate control over scientific research, the development of 'value added' technologies (biotechnologies, nanotechnologies, etc.) and the expansion of new markets for the products of 'innovation' even before these become fully operational (Uzunidis, 2003). The centralization of capital by large agri-food and pharmaceutical complexes means that, under this technological accumulation regime, surplus capital is channeled mostly through the global financial system and the creation of bio-value. The production of bio-value entails investments in scientific research whose purpose is the biotechnical/informational reformulation and control of living processes in order to generate commercial returns (Waldby, 2002). As such, the perspective of a new technological accumulation regime transcends normative debates between what Friedmann calls the 'corporate environmental food regime' (Friedmann, 2005) and both the 'financialized food regime' (Burch and Lawrence, 2007) and the 'neo-liberal food regime' (Pechlaner and Otero, 2008). Rather it locates changes in the food system within the restructuring of the so-called 'knowledge economy' giving rise to the bio-economy as a major factor of capitalist accumulation. Not only does the appropriation of biological processes (organisms, DNA, etc.) via the restructuring of scientific research towards the development of technological applications create bio-value and reinforce financial and informational control over the planet's resources, it also establishes itself as one of the most important capital accumulation strategies because it establishes the international legal and economic rules and institutions that guarantee its realization.

The social and philosophical transformations that bio-value imply that concepts such as biological life, crops and food are interpreted from a bio-economy perspective. This entails the reorganization of boundaries between science and agriculture as well as a new understanding of the status of food crops and agricultural practice. It also raises questions about the kinds of food economies that can be reconciled with the ever-expanding capital value of 'salt tolerant' or 'drought tolerant' crops, including the ability of the biotechnology industry as a whole to make food crops ever more productive (Waldby, 2002). A corollary question concerns the effects that CR crops might have on existing food and agricultural systems in light of the technical possibilities these varieties represent. The reformulation of living processes at the molecular level generates capital value via technical innovation regimes that legitimize the deployment of bio-commodities that engender the need for increased bio-value. For this reason, promoters of CR crops must demonstrate that the bio-valuable product benefits the environment and not just the biotechnology industry. This is why CR crops embody not just potential profits but also the promise of biotechnology as a social project.

The Political Economy of Science and Technology and the Bio-capitalist Approach

Capital accumulates by producing its own distinctive historical geography (Harvey, 2005). What this means in practical terms is that it does not follow a territorial or state-centered logic but functions by instituting patterns of wealth accumulation by simultaneously organizing dispossession. This is what Harvey calls 'accumulation by dispossession'. The mechanisms that enact this process, which are structured around the dialectic between Northern 'over-consumption' and Southern 'under-consumption' of agricultural goods and along embedded historically contingent colonial relations, include the provision of Intellectual Property Rights (IPRs) through TRIPs Agreements on genetic materials, seed plasma and other biological materials as a way of further subordinating nature to market relations. Under these conditions, *nature* is reduced to the *environment*, and so becomes intellectual capital. As a result, the global food system is transformed without effective regulation, social planning or systematic legitimation and the role of experts becomes to improve the performative capacity of the planet's diverse environments (Luke, 2005).

Bio-capitalism, according to Rajan, is a concept derived from political economy which explores the different ways in which 'life' gets (re)defined through the contradictory processes of commodification, thus providing a window into how the life sciences and the bio-economy articulate new forms of capitalism. In particular, debates about corporate ownership of living systems often mask 'the capitalist dynamics… that present themselves as somehow altruistic or external to the market'

(2003, p. 91) and that create the possibility of articulating different forms of meaning and value – as in corporate pronouncements around food security, climate change, energy security, etc. The articulation of new market logics via the commodification of 'life' entails the establishment and enacting of novel legal and economic structures, which not only transform the way knowledge is produced and money is made but also include strategies for delimiting what is public and what is proprietary. The relationship between bio-value and bio-capitalism can be summarized in the following manner: bio-value refers to the technological reformulation of life in order to commodify it, while bio-capitalism provides the material and social conditions for the creation and expansion of commodification through the technical possibilities of bio-value. Clearly, these two processes are mutually constitutive.

Bio-capitalism also expresses the ways that Capital reacts to the various forms of resistance to the commodification of life. Anti-capitalist struggles such as food sovereignty movements push capital to find new accumulation strategies and new territories to exploit. This is true of regulations concerning labeling of GM food in the EU most notably. Rajan talks about the speed bumps that slow down bio-capitalism but which also help it adapt to changing political conditions (Rajan, 2003). The barriers to accumulation condition the speed at which capital is renewed and the ways in which biotechnology is integrated in the production and development of productive forces (Uzunidis, 2003). The point about anti-capitalist struggles is that they also articulate a bio-political dimension, which organizes and de-organizes how and where capital accumulates.

In the case of food and agriculture, patents on seed and germplasm have had profound and devastating impacts on people's ability to survive by limiting access to what were once 'free' and commonly held goods. These simultaneous social and biological inclusionary/exclusionary processes aim to overcome ecological and economic limits by operating under a kind of 'capitalist delirium' (Cooper, 2008), which is concerned mainly with 'the limits of life on earth and the regeneration of living futures' by turning crisis moments into value as a way of creating surplus. Nevertheless, this process rests on the premise that globalization is made up of spaces where economic integration occurs formally and others where it occurs informally: 'between places that appear to be playing by international rules and those that cannot' (Battacharyya, 2005, p.26). Bio-capitalism is built on differential patterns of inclusion and exclusion. For instance, the sourcing of genetic materials or plant varieties might be illegal in some places but remain beyond state control in others. Similarly, the testing of new genetic crops might be tightly regulated in some places while allowed in others. This is indicative of the kinds of risk-taking activities some regions must engage in because they are unable to compete with mainstream industry and trade (Battacharyya, 2005).

Climate change represents one of those crisis moments (delirium) whereby new forms of capitalist accumulation are 'transforming biological production into a means for creating surplus value' and through the use of patents, on climate-ready genes for instance, have enabled agribusiness to own the organism's generative potential without having to own the actual organism. The internal consolidation of agribusiness, including strategic alliances between pharmaceutical, chemical and biotechnology companies, coupled with recent speculative bubbles around food and agriculture, are also indicative of this restructuring of capitalist relations. The process of creating bio-economic value where none existed before (Cooper, 2008), through the creation of new commodity forms that redefine 'life' (Rajan, 2003), is

contributing to the realignment of capitalist forces along geo-political interpretations of the environmental crisis. The production of bio-value is central to the development of bio-economies because it focuses political and institutional mechanisms and resources on the modalities of turning living processes into economically viable products while seemingly responding to the ecological crisis. This is where a critical science studies approach can shed light on the accrued 'scientization' of agricultural processes. Science plays a controversial role in environmental decision-making and yet it is politically and socially central. However, scientific uncertainty and the lack of coherence among competing scientific paradigms (agroecology vs. molecular genetics for instance) is also indicative of competing political, cultural and institutional value systems that determine the choice of environmental problems that become 'scientized' (Sarewitz, 2004), hence funded and promoted as part of a broader economic agenda that largely benefits the developers of new technologies.

Climate change creates new economic impetus for developed countries plagued by food surpluses, stagnant agricultural economies and a high degree of dependence on fossil fuel. It represents a key moment of capitalized bio-production whereby plants (via the suppression of their reproductive capacity via hybridity or engineered sterility) are 'improved' to overcome the impacts of a fluctuating environment in ways that prevent their free reproduction and 'depotentialize the future possibilities of life, even while it puts them to work' (Cooper, 2008). The upshot of this process is a fundamental shift in patterns of food production and consumption whereby new competitive processes played out in the countryside between food, energy and the environment (Harvey and Pilgrim, 2011) determine the control and structure of the agri-food system.

Technoscientific progress, including the creation and conditions for control of bio-value, provides the impetus for restructuring capital relations within the food system. Through innovation, state and private actors play a key role in the restructuring and development of scientific applications for the agricultural production process. As such, the rapid pace of instrumentalization of science and technology towards the commodification and appropriation of public and individual goods rests upon what Uzunidis calls a new 'technological accumulation regime', which generates capital not only via the creation of products and their applications but through the modalities of their implementation and control via, among other things, property rights and titles (Uzunidis, 2003). Hence, the technoscientific production process generates excess capital, which is redirected through the global financial system, and private banking and investment institutions in line with the characteristics of the financialized food regime discussed by Burch and Lawrence (2009). Agricultural biotechnology plays a key role in this process because, as Pechlaner and Otero (2008) have argued, it establishes a framework for neo-liberal regulatory reorganization (including IPR) which creates the conditions for technological expansion through innovation and greater capital accumulation within the global food system.

Agriculture, Energy and Climate Change: The Triple Threat

The relationship between agriculture and climate change has been the subject of much policy discussion around ways to either adapt crops or devise ways to mitigate the challenges temperature increases will pose for food production. From an agribusiness perspective, the risks that climate poses for food production in light of the FAO's projections that food production will need to be doubled by the year 2050 can be best met by increasing crop yields. Indeed, under this Malthusian scenario, the FAO projects that the world population will increase by 50% by 2050 to 9 billion, meaning that 50–100% more food will need to be produced (FAO, 2008). The general consensus is that the demand for food will increase, although estimates of actual needs may vary (Royal Society, 2009). In light of climate change and population growth in relation to current agricultural production, the consensus seems to be that agriculture has to intensify and focus its efforts on increasing yields as well as reducing pre- and post-harvest losses in order to meet critical needs, shifts in food consumption patterns and, more generally, increasing demand (van Beek et al., 2010). However, the issue of yield increase is complicated by several factors: soil degradation, which causes the loss of arable land, the competition between land for feed or land for food (it is estimated that 75% of the world's arable land is used for feed crops); an increasing demand for intensive chemical pest management and fertilizers; and the rise in energy costs including increases in irrigation costs due to water scarcity. This means that in order to maintain current crop yields, energy expenditures must keep increasing (Pfeiffer, 2003). In other words, the efficiency and productivity of Green Revolution crops are leveling off, and although marginal lands can be reclaimed for agriculture, their contribution will not ease energy needs linked to industrial food production. Moreover, most of the arable land available on our planet is already in use and is rapidly declining due to urbanization, erosion and salinization (EPSO, 2005).

Agriculture is also a major producer of greenhouse gas (GHG) emissions, as it is highly dependent on fossil fuels, and contributes up to 32% of direct and indirect emissions if all aspects of the food system are calculated (Greenpeace International, 2009; McIntyre et al., 2009). Recent studies show that agriculture is the most important contributor to human-induced climate change; carbon-footprint analysis shows that the whole chain from food production to consumption makes up to 20% of global GHG emissions (Herwitch and Peters, 2009). This has driven the development of the agri-fuels industry to lessen agriculture's dependence on 'big oil'. The alignment of food as energy source further illustrates the subordination of food and agriculture to market relations; the rise of this 'food–fuel complex' illustrates the ways climate change is used to justify capital consolidations along bio-capitalist lines. Policy support for bio-fuels worldwide has greatly increased based on the assumption that bio-fuels would not increase the concentration of greenhouse gases (Ponti and Gutierrez, 2009), leading to speculations that the global expansion of bio-fuels will in the long run affect both global food supply and agriculture production. Plans for a 'bio-pact' between the EU and Africa, which would see developing countries growing food crops to meet the energy needs of the North, could exacerbate the food–fuel competition, forcing countries to choose between farming for food or energy, severely threatening food security and leading to serious ethical trade-offs for farmers (Ponti and Gutierrez, 2009).

The framing of climate change and agriculture articulated by the triple threat of population growth, changing food consumption habits and demand for renewable fuels from crops, suggests that the intensification of food production might be the only answer. The problem becomes: how to devise ways to stabilize or improve yields in a fluctuating agricultural environment? In agronomic terms, this means that the locus of action is via improvements to plants, their generative capacities and changes to their architecture in order to cope with climate change and its impacts on agriculture. Technological advances and investments in plant sciences and biotechnology form the cornerstone of this approach, which aims to make plants more 'efficient' under agronomic practices that decrease the use of inputs such as water, fertilizer and pesticides. A combination of plant breeding, plant genomics and molecular biology, relying on an open access to genetic diversity and faster breeding techniques, will contribute to the creation of new crops with high agricultural value and with increased environmental benefits (EPSO, 2005). Thus, pressures to improve yields will lead to increased investments in agricultural biotechnology where the locus of action will be transferred from the field (irrigation, application of inputs) to the plant's genome, via the molecular transformation of crops that can produce higher yield and contain a broader spectrum of genetic traits allowing higher resistance to abiotic (environmental: temperature, moisture, UV light, etc.) as well as biotic (disease or pests) stresses.

Climate change will also have major impacts on food security, being another argument to promote intensification. Some regions of the world will be affected differentially from climate change. It is estimated, however, that two-thirds of the world's agricultural regions will feel the direct impacts of a temperature increase of 2ºC. Higher latitudes will possibly make some gains in terms of productivity (allowing for longer growing cycles) but these will be offset by yield declines in developing countries. Irrigated crops will experience large declines in many parts of the global South as rainfall patterns and water availability become affected. Climate induced crop losses have been estimated to reach as much as 50% in sub-Saharan Africa in the next 10 years (ETC Group, 2009). According to FAO, a global temperature increase of 2–4ºC over pre-industrial levels could reduce crops yields 15–35% in Africa and Asia and 25–35% across the Middle East (Smith, 2010). An increase in CO_2 and temperatures will lead to stress-related crop losses directly impacting agricultural productivity. According to Monsanto, the world's largest agri-biotech company, the only way to address such challenges sustainably is through what they call the new agriculture technology, which includes a combination of modern crop breeding techniques with biotechnology, which will lead to 'more production on less land, and collectively reduce the amount of resources needed per unit of production' (Monsanto, 2010). Specifically, Monsanto's 'produce more conserve more' initiative focuses on yield using: 'several climate-related stress tolerant traits, such as drought tolerance, [are] now in development, which further help protect and advance yield gains… Nitrogen use efficiency is also a key trait that has the potential to significantly reduce the GHG-emissions and other undesirable environmental effects of fertilizer use' (Monsanto, 2010). Can biotechnology meet the productivity gains needed to respond to the challenge of climate change (in particular for developing countries) and population growth on agriculture? Research into climate-ready (CR) crops is trying to address this issue. The status of CR crops in development as well as their potential remains uncertain despite the massive investments made by corporate actors.

Obviously, the impacts of climate change on biodiversity in the developing and developed world will be profound; however, current studies and monitoring systems make it difficult to assert the consequences of changes in climate on the key elements of agriculture and food production. Unfortunately, full inventories of biodiversity stocks and the impacts of temperature changes on these are unavailable. However, as plant and animal diversity become eroded and diminished due to human action, agribusiness companies are poised to identify, characterize and isolate the genetic materials they perceive as important to crop and animal survival under conditions of climate change. The search for climate-ready genes has been the focus of corporate research strategies for companies like Monsanto and BASF in a bid to capture not only the global market for seed by patenting the seed and genes from plants capable of surviving extreme environmental stress, but also to capitalize on fears surrounding climate change by promoting proprietary biotechnological solutions for food and energy production (ETC Group, 2010). It is indicative of how scientific information and ecological inventories can serve to create what was referred earlier as surplus value, including bio-value. This enterprise relies on the continued access to the planet's biodiversity facilitated by global governance structures that contain legal provisions for the acquisition and sourcing of bio-resources.

The Need for Abiotic and Biotic Stress-tolerant Plants

The scientific and technological complexity of climate change and the call for 'adaptation' strategies using molecular techniques that go beyond the current one gene–one trait interaction (such as herbicide or insect tolerant crops) raises many techno-scientific, economic, social, political, ethical and ecological questions, not adequately addressed with first-generation transgenic crops. Since the performance of crops under stress depends largely on their capacity to adapt to whole agro-ecosystems through evolutionary adaptation, the compounding effects of engineering multi-gene–multitrait organisms – including their interactions in the environment – may lead to unpredictable ecological and health consequences.

Abiotic stress refers to non-living factors (weather, soil conditions, etc.) which can impact living organisms negatively. In the context of climate change, the type of plant that would survive extreme temperature and related environmental stresses include: plants that are adapted to greater extremes of weather (cold or heat), drought tolerant plants (wheat or corn), salt tolerant plants for saline land due to flooding or irrigation or for salt-water farming. Plants that require less chemical fertilizers would also be beneficial because they are less energy intensive and reduce dependence on fossil fuels. Finally, plants that fix their own nitrogen or take up nitrogen more efficiently would also be considered valuable since they also require less fertilizer. Research and development is underway to produce such plants in the hopes of commercially releasing plants that would resist climate change by identifying climate-ready genes that could be genetically engineered into the world's most important agricultural varieties to produce a new generation of bioengineered crops.

In 2008, the Action Group on Erosion, Technology and Concentration (ETC) reported that the largest of these companies, including BASF, Bayer, DuPont, Monsanto and Syngenta, had already filed 532 patent documents on so-called 'climate ready' genes at patent offices around the world predominantly in the patent offices of major food producing countries – including Argentina, Brazil, China, Mexico and South Africa. Since 2008, 65 more patent documents related to the ability of plants to tolerate environmental stresses have been filed. By 2010, over 1663 patent documents (part of 262 patent families that include related patent applications) had been published worldwide making claims about abiotic stress tolerance in plants. Six corporations (Monsanto, DuPont, BASF, Syngenta, Bayer and Dow) control over 77% of the patent families (ETC Group, 2010). Monsanto, the world's largest seed company, and BASF, the world's largest chemical firm, have forged a US$ 1.5 billion partnership to develop such crops (Smith, 2010), raising questions about the potential for these corporations to provide sustainable and viable solutions.

However, the ETC Group argues that 'patented techno-fix seeds will not provide the adaptation strategies that small farmers need to cope with climate change', and that the so-called 'gene giants' are trying to monopolize on climate change. Farmer-led strategies for adapting to climate change – such as efforts to diversify crops and bring them to the market-place continue to be weakened and eroded, and governments fail to protect and fund local breeding strategies and conservation initiatives (Cotter and Tirado, 2008; ETC Group, 2008; Greenpeace International, 2009).

So-called climate-ready genes are different from the biological stress genes currently used in most GMOs designed to make plants resist pests and herbicides. They are complex and involve multiple genes with different functions rather than the single gene constructs of current GM varieties. The genetic construction of plants / crops that can tolerate salt, heat, flood and drought and that can grow in degraded soils via the appropriation of genetic traits is thought to represent yet another attempt by the biotechnology industry to control the global food supply, but also the 'yet to be commodified' biomass market (ETC Group, 2010). An article in *Businessweek* provides a snapshot of the commercial potential for drought-resistant corn in the US: 'After battling for a decade to corner the $11 billion market for insect-resistant and herbicide-tolerant technologies, the world's biggest seed companies are vying to develop crops that can survive drought. At stake is a new global market that may top $2.7 billion for the corn version alone' (Kaskey and Ligi, 2010). Currently, approximately 50 varieties of drought tolerant maize (mostly obtained through a combination of traditional breeding and molecular biology technique) are being grown on about one million hectares (CGIAR, 2009).

The Ecological and Bio-political Limits of this Approach

Beyond the scientific and technical limitations of the approach taken by agribusiness to respond to the challenges of climate change, the issues of bio-piracy and biodiversity must be considered. As agri-biotech firms try to find ways to adapt crops to temperature changes, the patented genes they are presently securing and the engineering of plants with these environmental stress genes precludes the search for local adaptation and mitigation efforts. Moreover, the extensive use of these organisms will kill off diversity, which is most crucial in highly variable environments and under human-induced climate change. The more diverse species or varieties present in an ecosystem, the greater the probability that at least some of them can cope with changing conditions.

As of today, very little funding is dedicated to research on local varieties and rich local knowledge systems and practices to address variable climatic situations; instead, investments in research and development continue to be spent on GM crops. The consensus seems to be that patented gene technologies will not help small farmers survive climate change, but instead will continue to concentrate corporate power, drive up costs, inhibit public sector research and further undermine the rights of farmers to save and exchange seeds. A recent report published by the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) suggests that the future of agricultural technology lies in a rich and complex appreciation for how ecosystems function. This kind of approach entails a modest use of inputs with the goal of substantially reducing the carbon footprint of agriculture yet providing higher yields in the context of a more sustainable future; thus contributing less to climate change shocks, and being more resilient to certain kinds of crop failure. In this scenario, IAASTD experts discounted the use of GM crops as the most viable solution. In a parallel vein, scientists have confirmed that no increase in crop yields are observed after more than 15 years of GE crops production in the US (Gurian-Sherman, 2009). The IAASTD report concludes that long-term data on environmental implications of GM crop production are at best deductive or simply missing and speculative (McIntyre et al., 2009). It seems that large knowledge gaps exist in terms of regional long-term environmental and health monitoring programmes in the countries with the most concentrated GM crop production; it is impossible to establish safety base-lines for assessing second-generation climate-ready crops raising fears about their safety. Clearly, market efficiency rather than the complexity of ecosystems drives the search for bio-value.

Herbicide tolerance was one of the first genetic modifications to add bio-value to food crops, signaling the success of the biotech industry and a new era of food production. These crops, produced to lessen farmers' dependence of chemicals and improve health and the environment, represent an interesting example of how bio-capitalism and bio-value work in practice and about the bio-political frameworks used to manage the bio-economy. The development of herbicide tolerant crops led to the creation regulatory principles strengthened by an IPR regime that would enable their environmental release and successful commercialization worldwide. Today genetic contamination of non-GM weedy species by transgenes from GM crops is a major ecological problem. The rapid and uncontrolled escalation of herbicide resistance since the 1980s and since the introduction of the first transgenic crops means that at present, resistant biotypes exist for herbicides with 16 different modes of action. Every continent now has herbicide resistant weeds (Heap, 2010). Faced with a potential ecological disaster, the agri-biotech industry responded by producing GM varieties tolerant to more than one herbicide so herbicides can be rotated to avoid the development of resistance; by using soil acting residual herbicides to kill off the seedlings of resistant biotypes. In both approaches bio-value is added in order to deal with the problems of chemical dependency and an increased toxic burden on the environment. Climate ready plants far from eliminating the need for chemical herbicides and pesticides will incorporate herbicide tolerance and continue to accelerate the process of multiple resistances in crops via transgenic contamination, thus legitimizing the search for more efficient bio-commodities. Genetic contamination, once thought to the Achilles' heel of the biotechnology industry, seen through a bio-capitalist lens, provides the impetus to invest in scientific strategies that alter the reproductive capacity of plants as a strategy to manage transgene escapes while, at the same time, preventing the economic losses due to Intellectual Property Rights infringement. The production of GM plants that cannot germinate after one season via suicide seeds (so-called terminator technologies) (Abergel, 2008) create the incentive for increased corporate control over seed production. Moreover, terminator technologies embody bio-politics through genetic modification. The biotechnology industry enforces and secures intellectual property rights whilst eliminating potential transgene escapes; at the same time, it is disciplining and controlling the use of bio-commodities only for those willing and able to pay for it. It is likely that CR crops will reinforce this pattern.

Still, it seems that generating maximal surplus value is not the only strategy used to legitimize the use of biotechnology in farming but that 'other forms of symbolic capital' are created in order to perpetuate bio-capitalist market logic (Rajan, 2003). Bio-capitalism encroaches on previously uncharted territories using strategies that

extend beyond market logic, which employ a discursive politic centered around the rhetorical value of biotechnology in terms of the food crisis, climate change, etc. By criminalizing local practices such as seed exchanges, bio-capitalism draws the line between the devaluation of public and free goods and the creation of bio-value around private and commoditized goods. Hegemonic contestation around food issues is thereby constrained around the contradictory purpose of resistance to and support for global market access and various models of agricultural production. In terms of traditional food systems, bio-value is produced when the 'vitality' of living systems is technically diverted and reorganized (Waldby, 2002), which signals the de-embedding of farming from its social and ecological contexts. Bio-capitalist agricultural production threatens fundamental subsistence reproduction; it directly interferes with the reproduction of life and the vital working capacity of communities. The shift away from social reproduction towards capital accumulation raises questions about the long-term sustainability of community-based and traditional food systems.

Conclusion

Bio-capitalism has targeted biodiversity via the technological possibilities offered by agricultural biotechnology as a key area in which to articulate our relationship with nature. More than simply the molecular tools to identify, isolate, re-arrange and construct genetic information about nature and living organisms, biotechnology as a social and political project encodes bio-capitalism via patent rights through the 'opportunities' afforded by climate change, which make it a major force of capital accumulation in the food economy. In the field of agriculture in particular, genetically altered plant and animal varieties threaten to displace long-established domesticated and wild species as well as alternative forms of agriculture such as organic or traditional farming.

Bio-capitalism's incursion into what was once public but has now be recast as private via intellectual property rights (IPRs) threatens to appropriate biological information. In addition, as the search for CR genes typifies, innovation rarely comes from the private sector; private research is not only enabled by the sourcing and appropriation of 'public' raw materials from the South but also massive inputs of public funds and the development of public institutions in the North. As a result, the commodity form resulting from this process threatens to supplant the very sources of genetic diversity which ensure the creation of bio-value. In addition, the originally sourced material acquires a decommoditized status that Rajan calls a 'mechanism of rhetorical abdication' that confers the commodity a kind of natural status while giving the decommoditized form symbolic capital, that of a 'gift' (Rajan, 2003, p. 110).

The ecological issues arising from agricultural development in general, and from genetic modification in particular, might be local in nuance, but they are very clearly global in extent. It is therefore important to contextualize the real possibilities of staging more complex ecological disasters via the synergistic effects of irreversible contamination events within an already compromised environment and relate them to the politics of GM food and corporate monopolies, especially in vulnerable economies or economies that export their 'nature' (Escobar, 1999): which would include the food sovereignty movements that are at the cross-roads of the food and ecological crises (McMichael, 2009) and which politicize and resist the neo-liberal food trade regime.

No new regulatory regime has been designed to deal with second generation GE crops such as climate-ready crops; they are not substantially equivalent or familiar to previous GE crops. They represent a higher order of genetic and biological complexity, representing new and unpredictable risks, which requires different assessment procedures and a precautionary regulatory approach. As mentioned, the current regulatory frameworks in place to deal with the safety of first generation GE inadequately protect non-GM farmers from biotech crops, and have resulted in global and irreversible contamination events of crops such as canola, rice, corn and soybeans, including the emergence of so-called 'superweeds' needing persistent applications of chemical herbicides or pesticides as crop 'management tools'. Given that 'genetic engineering's limitations and our limited knowledge about plants' regulated response to environmental stress, unregulated single-trait GE crops are a threat to food security in a changing climate. The prospect of large monocultures of GE plants failing completely under unforeseen weather events is a recipe for disaster' (Cotter and Tirado, 2008, p. 6). All of this means that the agribusiness biotech complex will continue to search for new ways to dominate and exert power in the food system, regardless the existence of other potentially better strategies for adaptation locally via breeding and deep ecological understanding of biodiversity and local ecosystems.

In light of the above conclusions, it is clear that the difficulties and unpredictability that climate change presents for food production reinforce the need for new regimes of food production articulated around knowledge about the complexity and resilience of local ecosystems. The bio-capitalist approach has provided a framework for understanding how a transition to a new food regime might be accomplished. The multiple logics of capitalism enable this system to absorb the contradictions that both threaten and ensure its existence. In practice, this means that the 'neoliberal globalist regime' formulated by Pechlaner and Otero (2008) around agricultural biotechnology might include potential variations within it that allow local food policies with features of the 'food sovereignty' approach. While ecological and biological limits form the basis for new forms of bio-capitalist exploitation to emerge, the flaws inherent within the technoscientific paradigm, which seem incompatible with the types of strategies needed for agriculture to cope with the effects of climate change, could signal the shift to a new food regime as discussed by McMichael. At the very least, it could mean that we are entering a transition period towards a neo-productivist regime that places greater value on locally adapted sustainable food production methods. I have suggested in this article that an understanding of the empirical, technoscientific and epistemological limits of the approach exemplified by climate-ready crops, using a science studies and food regime analysis, enables critical reflection about adaptation strategies regarding food production practices and climate change. It also contributes to the debate surrounding the possible emergence of spaces for neo-productivism within a productivist agri-food system, to the extent that these can coexist (Potter and Tilzey, 2005).

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