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Review

Agroecology: A Global Paradigm to Challenge Mainstream Industrial Agriculture

Hector Valenzuela

Department of Plant and Environmental Protection Sciences, University of Hawaii at Manoa, 3190 Maile Way No. 307, Honolulu, HI 96822, USA; hector@hawaii.edu; Tel.: +1-808-956-7903

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Abstract: Considerable controversy continues to exist in scientific and policy circles about how to tackle issues of global hunger, malnutrition, and rural economic decline, as well as environmental issues, such as biodiversity loss and climate change adaptation. On the one hand, powerful vested interests, with close ties to government, media, and academic institutions, propose high-input technology-based solutions, speculative and neoliberal "market-based" solutions, and export-oriented agricultural models. On the other hand, an international scientific and grassroots Food Movement has emerged, calling for a redesign of the Global Food System in support of small-scale agroecological farming systems. A call to re-evaluate our current Food Systems was made in 2008 by the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). Here, using the IAASTD study as a backdrop, we review the recent literature to outline key contentious points in the controversy between the need for high-input and "techno-based" *versus* agroecological farming models. A critical assessment is made of proposed strategies to protect soil resources, improve nutrient and energy cycles, protect agrobiodiversity, and promote social well-being in rural communities. With an increase in the number of affluent consumers (*i.e.*, the middle class) in the developing world, and with the continued problem of extreme and chronic poverty with other larger sectors of society, Organic Farming and Agroecology models are put forward as a sound social, scientific, and rural development strategy.

Keywords: agroecology; agrobiodiversity; biodiversity; farming systems; organic farming; ecological farming; soil management

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1. Introduction

Considerable controversy continues to exist about how to tackle issues of global hunger, malnutrition, and rural economic decline, as well as on strategies to address environmental decline and climate change adaptation. Because global agricultural activities are strong determinants of human well-being and environmental quality, the judicious design and management of agricultural systems are central to discussions about food security and climate change, and about the conservation of natural resources such as land, water, energy, and biodiversity. A call for a re-evaluation of our current Food Systems was made in 2008 by the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) [1]. Here, we review the recent literature to outline key contentious points in the controversy between the merits of "techno-based" industrial methods of farming *versus* alternative agroecological farming models.

2. Reviews about the Future of Agriculture

A review of agricultural systems in the early 1990s queried "Is the environmental price of America's unprecedented agricultural productivity too high?" and warned that "farms have become more specialized and more dependent on off-farm inputs" [2]. National scientific panel reports from the 1980s determined that in the USA alternative farming practices were practical, as productive, often more profitable, and that their adoption "would result in even greater benefits to farmers and environmental gains for the nation" [2]. Today, international agricultural development experts agree that current agricultural systems "must be transformed" [3,4]. An agricultural transformation is required for health and environmental reasons because "today's farming systems undermine the well-being of communities in many ways", including the destruction of "huge regions of natural habitat" and "an untold loss of ecosystem services" [3]. Similarly, it is recognized that agricultural systems need to shift towards alternative methods of farming that move away from "today's brand of resource-intensive, environmentally destructive agriculture" and that conventional methods of farming represent "a poor option" [5]. Along the same lines, a recent international panel report called for "the fundamental transformation of agriculture" following a dual approach that "drastically reduces the environmental impact of conventional agriculture" and that opens the door for "agro-ecological production methods" [6].

Despite the call for alternative methods of production over the years, the paradigm of industrial or conventional agriculture still dominates and permeates most mainstream academic and policy discussions about the future of agriculture [4]. An evaluation of agricultural systems from 1991 to 2003 determined that the conventional systems of industrial agriculture continued to predominate [7]. According to the authors, "the paradigm of industrial agriculture (High External Input Agriculture) has been simply amplified, by doing more of the same, with only minor adjustments in special countries. For those looking for a major transition toward a different pattern of production more focused on rural development, ecological compatibility and quality food, this is a reason for concern" [7]. Furthermore government policy and subsidies [2,8] and even the University Research and Extension system have helped to validate, strengthen and to perpetuate the expansion of current models of industrial agriculture [2,9].

Nevertheless, considerable field research has demonstrated the potential benefit to rural communities and to the agricultural sector of adopting alternative production systems [2,10]. For instance, a recent global analysis determined that organic systems are more profitable than conventional systems, even when external costs of production are not counted. While organic systems had an overall 10%–15% greater labor demand, this was considered to be less of a constraint in regions where labor is cheaper or where there is a surplus of labor [11]. As about 80% of global food demands are met by small-scale farms, agricultural development programs need to re-focus their programmatic activities to improve the productivity of small farms in the tropics [12,13]. However, for development and research programs to be meaningful, it is critical that socioeconomic conditions be considered by following participatory approaches [14]. Specific guidelines and steps required to "democratize" and establish participatory research and to promote food sovereignty for small farms in West Africa were outlined by Pimbert *et al.* [14].

3. Challenges for the Future of Agriculture

The paradigm and future prospect of modern industrialized agricultural systems is being challenged on several fronts because of its dependence on capital, external energy and agrochemical inputs, and for its adverse impact on biodiversity and on human health [2,15–20]. According to the American Medical Association, in reference to industrial agriculture, "these methods have contributed to the development of antibiotic resistance; air and water pollution; contamination of food and water with animal waste, pesticides, hormones, and other toxins; increased dependence on nonrenewable fossil fuels (including fertilizers); and a food system that is increasingly vulnerable to accidental or intentional contamination" [4,21]. Warnings have thus been raised and documented about the adverse health and environmental impacts from the intensification of both crop and livestock production systems [4,22–28].

Concerns have also been raised about the increased homogeneity of the food supply at a regional and global scale, resulting in a general decline in global food security with 85% of countries showing marginal or low food self-sufficiency indices [29–31]. Calls have also been made to revisit issues of agricultural sustainability concerning the impending environmental impacts of climate change and its effect on agriculture [3,32–34]. With potential global crop yield losses of over 50%, calls have thus been made to develop more "resilient" production systems to better withstand the impending impacts of climate change [16,35–39].

Concerns have also been raised that industrial agricultural practices are exacerbating the anthropogenic causes of climate change by contributing about 25% of global greenhouse gas emissions, about 60% of nitrous oxide emissions from the use of synthetic chemical nitrogen fertilizers and pesticides, and from its adverse impact on biodiversity [4]. Furthermore, new data indicate that previous estimates of nitrous oxide emissions from industrial agricultural systems may have been grossly underestimated, and that when "riverine" watershed emissions are considered, the levels of nitrous oxide emissions from areas such as the MidWestern USA may be up to 40% greater than earlier estimated [40]. The overall global environmental impact of these increased emissions on climate change could be significant as other similar regions of the world where intensive industrial farming practices are followed represent, globally, an area of over 230 million ha.

4. Industry and Industry-Funded Academics Support Techno-Based Solutions

Despite the many calls for a transformation of the food and conventional agricultural system, both the agrochemical industry and industry-funded scientists continue to espouse the value of industrial and "techno-based" solutions [5,33,41]. A paper authored 25 years ago by scientists from the agrochemical industry made a call for "patriotic" Sustainable Agriculture through a reliance on agrochemicals and on genetically modified organisms, emphasizing that "Sustainable agriculture is possible only with biotechnology and imaginative chemistry" [42]. A more recent article on Nature Magazine reiterated this earlier line of thought, indicating that "Feeding the world is going to require the scientific and financial muscle of agricultural biotechnology companies" [5,43]. Thus, according to this report, the world is placing its hopes about meeting future food global demands on the agrochemical industry, despite the fact that "the majority of companies' R&D spending and effort still goes towards blockbuster crops with traits, such as pest control, that benefit agribusiness, leaving neglected many crops that are important in the developing world" and despite the fact that the lack of progress to achieve these goals to date "is in large part a consequence of the hold that the private sector has on intellectual property rights to crucial technology, such as genetic markers, and the sequences of key genes and 'promoters' that drive gene expression" [43].

Thus, the mainstream thought in high level industry, media, the academic community, and many policy circles continues to espouse the idea that high capital and high-input dependent agricultural systems are the key to feed the world [4,33,36,41]. A recent United Nations Conference on Trade and Development (UNCTAD) panel report confirms that globally today the "priority remains heavily focused on increasing industrial agricultural production" [6]. For instance, according to a prime minister from Uganda attending a Global Food Summit "modern agriculture requires capital and technology", and as such the need for "both local and foreign investors" [44]. It is well-recognized that the agrochemical industry in general promotes "the benefits of chemical crop protection and biotechnology products, their importance to sustainable agriculture and food production" [16,33,41]. Thus, a central feature of agricultural assistance programs in Africa organized by the World Food Program, with support from the Bill and Melinda Gates Foundation, was to provide financial assistance to small farmers through the introduction of a regional speculative market for grains, to allow them to "acquire better seeds, fertilizers, and pesticides, more advanced irrigation systems". The access to cash, as explained by Bill Gates, would thus "impel small farmers to purchase more loans, more pesticides, more seeds" [44]. However, when implemented, the strategy to assist small farmers went belly-up, as the speculative markets led to a 13% increase in the price of millet in local markets and to a 7% price increase at a national level, a program which "would eventually send more people into poverty and starvation. The monetary gift triggered all manner of unforeseen consequences" [44].

Models of agricultural "intensification" based on a continued reliance on external inputs, chemicals and proprietary seed have been espoused for Africa by several academic and policy groups such as the Montpellier Panel [38] and by the Africa Progress Panel [45]. Similar calls for agricultural "intensification" have been made for Asia and other regions by leading academics, based on the use of "genetically modified organisms and transgenic animals" and on "high-yield plant varieties, irrigation, adding fertilizer and pest control measures" [46,47]. In echoes of the Green Revolution of the 1970s, many of these industrial agriculture models have been sponsored and implemented through subsidized agricultural programs and through neoliberal "public-private" partnerships [5,13].

5. Does Conventional Agriculture Meet Basic Sustainability Criteria?

Several studies have challenged the claims of sustainability made by proponents of modern industrial or conventional agriculture farming systems. A life-cycle analysis of conventional agriculture found that central features of the model failed to meet key sustainability criteria, including its dependency on high fossil-fuels inputs, a trend towards food industry consolidation, adverse human health impacts, a loss of agrobiodiversity, and soil degradation, among others [48]. The unsustainability of current conventional production practices was also outlined more recently by an international panel of 63 scientists [6] and as described from a pest management perspective by Ramon Seidler [49] a former Senior Scientist at the USA Environmental Protection Agency.

The overarching trend over the past twenty years for the "single tactic" pest management approach used on most of the major grain crops grown globally, and predominantly in the USA, was also deemed to be unsustainable by a team of weed scientists [4,50]. According to this review, the adoption of single-tactic approaches in conventional agriculture, such as herbicide resistant traits, has "potential negative consequences for environmental quality" plus "the short-term fix provided by the new traits will encourage continued neglect of public research and extension in integrated weed management [50]. Such a general structural decline over the past 15 years in the physical infrastructure and human capital required to establish and support Integrated Pest Management Programs has already been documented in expansive agricultural areas such as Texas [51]. An analytical comparison of mainstream agronomic systems in the USA that are based on the "single tactic" pest management approach, as compared to the more diversified systems in Europe, found a generally lower sustainability in the USA systems [39]. The lower sustainability of the USA *vs.* European cropping systems was observed in the form of relatively lower yields, increased pesticide use, increased consolidation of the supply industry, and a general narrowing of the germplasm diversity in the Midwestern USA, as compared to the European cropping systems [39].

6. Calls for an Agroecological Approach

Over 35 years ago, the International Commission on International Development, and later others, called for a shift towards alternative agroecological models of agriculture that were cognizant of local socioeconomic conditions and that protected ecological balance [16,52,53]. A similar call for the adoption of agroecology in Asia was made at a Conference organized by the Asian Productivity Organization [54]. Referring to some of the "green revolution" technologies that prompted the call for these alternative models of agriculture, such as the "ill-advised application of agricultural chemicals", Ekstrom and Ekbom [16] indicated that these concerns 30 years later "are as much a reality today as then".

Table 1. Some strategies for the establishment and implementation of agroecological farming systems.

Follow a Participatory Approach, Based on Indigenous or Local Knowledge
● Reliance on Indigenous knowledge to maintain agrobiodiversity such as for the preservation and use of herbs and medicinal plants [55].
● Use of experiential knowledge in the preparation of research and outreach programs [56].
● Bottom-up approaches for the design of research and outreach programs [13,54].
● Follow a Farming Systems Research/Extension and Development approach [57,58].
Regeneration and Maintenance of Soil Quality
● A healthy soil is needed to strengthen system resiliency [59].
● The value of cover crops and organic matter to soil quality [60].
● The value of soil quality to manage pests on the farm [61].
Resource Conservation and Establishment of Eco-Efficient and Integrated Systems
● Conservation of basic farm natural resources [60].
● Improved nutrient use efficiency and integration of farm activities [62,63].
● Integrated crop-livestock systems [17,62].
● Improved nutrient cycles [31,63].
● Improved ecosystem services [64].
● Management of physical and biological resources to manage pests on the farm [61].
Agrobiodiversity
● Germplasm conservation by local communities [65].
● Value of organic farms to support biodiversity [17].
● Promoting vegetational diversity to improve below-ground biodiversity [20].
● The importance of small farms to maintain biodiversity [66].
● The importance of public seed sources to maintain agrobiodiversity [39,67].
● The importance of biodiversity and habitat management for pest control [61].
Landscape-Wide Management Programs
● Value of landscape approach to maintain biodiversity [17].
● Landscape approach to maintain environmental "stability" [68].
● Landscape approach to facilitate community management of natural resources [13].
Socio-Economics or Social Considerations
● Need to consider socio-economical conditions [34,69].
● Value of promoting multifunctional agriculture [1,70].
● Need to include ethical considerations [69].
● Need to promote and maintain socially equitable systems [62].
● Need to incorporate gender considerations [13,71].
Research Considerations
● Need to create new research protocols, to study agroecosystems from a holistic and landscape perspective [72].
● Bioindicators need to be implemented for assessment of soil and environmental quality [73].
● Need to elucidate the ecosystem services provided by soil biota to restore ecological balance on the farm [74].

More recent calls have been made towards a wider adoption of agroecology, as outlined in Table 1, given the many documented benefits such as improved resource utilization, reduced externality costs, and less adverse impacts on the environment or human health [1,4,6,17,37,62]. Among the benefits reported from the adoption of agroecological practices include increased profitability [11,75]; comparable yields and pest controls [76–79]; improved water use efficiency in horticultural crops [80], as well as crop performance during drought years [78]; improved soil quality and organic matter content [77,78]; improved and more uniform Nitrogen mineralization, increased organic matter content and soil microbial activity in rotations with tomato [81]; improved biodiversity, ecosystem services, and resilience at both the farm and landscape levels [20,36,75,82,83] and as observed in Kiwi fruit orchards [84]; an improved sustainability index as observed with cacao in Mexico [39,85]; improved nutritional profiles, as observed on long-term trials with tomato [75,86,87]; as well as a reduction of pesticide residues in the body [75,86,88,89], including in children [90]. In turn, the greater ecological balance obtained in agroecological systems through crop diversification and increased soil health often results in a greater activity of above- and below-ground beneficial organisms, resulting in enhanced internal biocontrol mechanisms on the farm [76,79]. Another concern of the industrial agriculture model is a narrowing of the germplasm base, and a decline in agrobiodiversity within the farm and at a national level, as observed in the USA over the past 35 years [39,91]. Crop diversification and a wide germplasm base are considered integral to establish and maintain sustainable and resilient agricultural systems, because "In a future of climate change, public breeding and *in situ* conservation are likely to be fundamental to the survival of billions of people" [29,35,39].

The most prominent recommendation in support of agroecology was made by the international IAASTD assessment, which consisted of a panel of over 400 scientists from over 60 countries, as part of a multi-year global-scale study sponsored by the United Nations and the World Bank [1,4,16,70]. It is recognized that alternative production systems are available to maintain productivity and protect valuable natural resources, but that for their wider implementation, "it might be required of our society that it changes some of its paradigms and 'values' in order to preserve our support system, the soil and its health, for the future generations" [36].

Thus "the conclusion that emerges is that a radical rethink is needed in the orientation of agriculture" and that "The solutions will not be narrow sectoral or technical innovations but nested sets of innovations at the scale of the plant, the agronomic system, the landscape, and the institutional environment" [72]. This paradigm shift, according to an international panel of scientists, would consist of a "significant shift from conventional, monoculture-based and high external-input dependent industrial production towards mosaics of sustainable, regenerative production systems that also considerably improve the productivity of small-scale farmers", as well as a "shift from a linear to a holistic approach in agricultural management" [6].

7. Conclusions

Because of increased global population pressures, of the impending impacts of climate change on food production, and of the increased trend toward the market price volatility of the major global staple crops, there have been increased calls for a transformation of modern agricultural systems. The debate and the narrative about the future of agriculture is permeated by the narrative of powerful vested interests with close ties to government and academic institutions that make a call for a continuation of capital and input-intensive technological based solutions for agriculture. However, scientific surveys and reviews have documented a range of human health and environmental externality costs from industrial or conventional production systems, and these surveys have questioned the sustainability of such systems because of their potential adverse impacts on the long-term quality of the soil, natural resources, and on future generations.

As a result of the concerns about the lack of sustainability and lack of resiliency observed in modern industrial agricultural production practices, calls have been made for a paradigm shift in the design of agricultural systems. Agroecological approaches have been put forward as viable solutions to increase agricultural productivity, to increase economic well-being as well as the social and gender equity in rural communities, and to increase agricultural productivity while minimizing reliance on external proprietary technology, capital and synthetic chemical inputs. Key features of an agroecological approach include the decentralization of the production and marketing process, the need to follow a holistic and integrated participatory approach, an emphasis on minimizing erosion and enhancing soil quality, the conservation of natural resources, the promotion of agrobiodiversity and of ecosystem services both at the farm and landscape or watershed level, and the need to fully integrate socioeconomic, social and gender equity considerations in all phases of the agricultural research, extension, and developmental process.

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