Invest. pens. crit.
Vol. 2, No. 5, septiembre-diciembre 2014.
pp. 63-79

Agroecology and a vision for sustainable agriculture in spite of global climate change

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Recibido: 18 de noviembre de 2014
Aceptado: 5 de diciembre de 2014

Abstract

Global climate change, although partially understood, is becoming more and more responsible for unpredictable weather patterns that can eventually undermine food security and quality of life for all. The consequences of this phenomenon for agriculture are relevant to a growing human population, which is becoming increasingly vulnerable and often displaced by environmental disasters ever as political leaders are still challenged to find an accord to cap CO2 emissions to remediate to the ongoing climate crisis. The purpose of our work was to review recent literature about the effects of global climate change on food production in the upper Midwest region of the US and the Panama Republic to propose an original paradigm for achieving sustainability in agriculture through agroecology. Our model is adaptable to diverse agrarian contexts. It envisions small scale farming (microagriculture), which is often practiced in urban settings, and industrial agriculture (macroagriculture), as two interlinked paradigms. Strong connections and a higher level of transparency in agriculture (at both micro and macro levels) can enhance the flow of knowledge occurring between these two models of food production. As a result, a single, unified model merges as a vehicle to educate people about food systems, in an effort to achieve sustainability in modern farming systems. Thus, an empowerment of agriculture is achieved to better cope with the necessary resiliency that farming will require to withstand the whims of climate unpredictability.

Keywords: agroecology; biomass; climate change; GMOs; macrofarming; microfarming; sustainability; Panamá; U.S. upper Midwest.

Resumen

El cambio climático global, aunque parcialmente entendido, se está convirtiendo cada vez más responsable de los patrones climáticos impredecibles que pueden llegar a socavar la seguridad alimentaria y la calidad de vida para todos. Las consecuencias de este fenómeno para la agricultura son relevantes para una población humana en crecimiento, que se está convirtiendo cada vez más vulnerable y a menudo desplazada por los desastres ambientales, mientras líderes políticos aún tienen el reto de encontrar un acuerdo para limitar las emisiones de CO2 para remediar la crisis climática en curso. El objetivo de nuestro trabajo fue revisar la literatura reciente sobre los efectos del cambio climático global en la producción de alimentos en la región superior del medio oeste de los EE.UU. y en la República de Panamá para proponer un paradigma original con fines a lograr la sostenibilidad en la agricultura a través de la agroecología. Nuestro modelo es adaptable a diversos contextos agrarios. Se prevé la agricultura a pequeña escala (microagricultura) que se practica a menudo en los entornos urbanos y la agricultura industrial (macroagricultura) como dos paradigmas interrelacionados. Conexiones fuertes y un mayor nivel de transparencia en la agricultura (tanto a nivel micro como macro) pueden mejorar el flujo de conocimientos que se producen entre estos dos modelos de producción alimentaria. El resultado es un solo modelo unificado que se funde como vehículo para educar a la gente acerca de los sistemas alimentarios, en un esfuerzo por lograr la sostenibilidad de los sistemas agrícolas modernos. De este modo, se logra una potenciación de la agricultura para hacer frente a la capacidad de recuperación necesaria que se requerirá para soportar los caprichos de la imprevisibilidad del clima.

Palabras clave: Agroecología, biomasa, cambio climático, OGM, macroagricultura, microagricultura, sostenibilidad, Panamá, medio oeste de los EEUU

Agriculture and rural living at one time were inextricably linked and the prosperity of farmers benefitted a whole landscape of healthy, agrarian communities (1). Weather patterns followed reliably the cycling of the seasons, and in accord with these, farmers were accustomed to performing routine field operations that enabled the land to be used for the successful growth of crops. Climate thus shaped the regional vocation for successfully growing certain animal and plant species, and this success led eventually to the design and management of larger farming systems, in the industrialized regions of the world.

Also, within the last one hundred years impressive technological breakthroughs in agriculture fostered agricultural policies aimed ambitiously at the limitless expansion of modern farms (2). Manpower versus land management increased exponentially to achieve maximum crop yields, as technological advances became established, mainly in the northern regions of the world. Expanding technologies did not encounter much resistance because their energy needs were at that time available and inexpensive. Consequently, the design of large-scale farming systems continued to be the “successful” model for food production in U.S. agriculture and other industrialized countries, despite its massive consumption of oil and other synthetic products such as fertilizers and pesticides, mostly oil derivatives as well

(3). Critics of the present, industrial model of agriculture have pointed out its major technical and economic limitations (2, 3, 4, 5) and paradoxes (6) in addition to the role that food production plays in causing chronic, environmental distresses and amplified carbon dioxide emissions to the atmosphere (3).

At the same time, remarkable steps have been taken to achieve more sustainable systems, to insure food security and to pursue sustainability in agriculture. However, despite the successes that already have been achieved, modern, conventional agriculture remains anchored to systems of production and management whose principles assume the transferability of its farming practices and technologies worldwide, in order to maintain high production efficiency, and affordable food prices (2). Consequently, the success of modern farming remains ephemeral as global climate change poses continuous challenges to an agricultural paradigm that continues to depend on the premise that state-of-the-art technology will resolve any emerging problem. In spite of serious warnings the present form of industrial agriculture continues to remain 'untouched' by the compelling need for conserving resources, its high carbon dioxide emissions to the atmosphere and their concomitant association with global climate change.

Another distressing feature of modern agriculture consists in its heavy reliance on fossil fuels for both production and distribution of foods, which threatens the efficiency of agriculture a step further (7, 8). In the meantime, the unpredictable fluctuations of oil prices place a heavy burden on the cost of foods, and despite the on-going efforts to research the efficacy of biomass-derived fuels (9) as an alternative to non-renewable fossil fuels, oil may soon be unable to meet the present high energy demands of agriculture on the large scale.

Global climate change challenges food production more intensively, as the unpredictability of weather patterns threatens to affect crop yields with more virulent and uncontrollable pathogens (10) and also to damage irreversibly the infrastructure of farms and their resource base. At the same time, most agriculturalists recognize the compelling mandate of increasing food yields by the middle of the 21st century, to fulfill the nutritional needs of a growing human population (11). It is likely, however, that the focus on augmenting agricultural outputs may not help farmers adapt to the unpredictable changes posed by present and future climate conditions in vast regions of the world (12, 13). Water availability, its quality and its more even distribution, in addition to energy use in agriculture, remain very important additional issues in modern food production for both industrialized and developing countries.

Finally, the knowledge of growing food is becoming alien to a majority of people, as rural communities continue to shrink while the responsibility of farming falls more and more upon the shoulders of a minuscule segment of society. In developing countries food production may still engage high segments of society yet an erosion of knowledge due to an expansion of monocultures often owned by foreign companies has been affecting the livelihood of millions of small farmers and obliterating a culture of sustainable food production. Therefore, we think compelling the need for the general public to reeducate itself about food production, its environmental costs, distribution barriers and other challenges that affect present agricultural systems.

The purpose of our work was to analyze the challenges posed by global climate change in agriculture through a review of present research with focus on the upper Midwest region of the U.S. and Panamá, while proposing a vision of sustainable food production through agroecology science and management. This effort is pursued with the aim of insuring that an oversimplification about the knowledge of agriculture is avoided, as previous, erroneous approaches have been demonstrating through a transfer of techniques and technologies across borders while assuming that these would be as effective as in the agricultural contexts where they were initially developed (5, 14, 2). For these reasons, small-scale agriculture (microagriculture) could emerge as a viable model of farming not only viable to subsistence agriculturists of tropical, rural contexts, but also in expanding urban and suburban environments worldwide, while its implementation could help to engage and empower a larger segment of human society in growing food locally, thus aiding in the effort of maintaining yields and diversifying cropping systems, in the face of more frequent and unpredictable shifts in weather patterns. Concurrently, we propose that the needed shift that could occur on the macro scale of the agricultural landscape is a form of agriculture which relies more and more on the cultivation of perennial polycultures, while lessening its dependence on oil. This is not a novel concept, however (15, 3), and it is enhanced by the need for restoring biodiversity on the land as a way to ameliorate soil, water and climatic conditions (16, 17). Both approaches can be solidly founded in agroecological theory and practices and they affect one another, as food production on a micro scale aims at legitimizing the restoration necessary at the macro scale to achieve higher levels of sustainability. At the same time, the renovated, ecological *modus operandi* of macro agriculture reverberates upon microfarming systems while engaging urban dwellers and other small producers to become more educated about food production, its challenges, opportunities and needs. Such changes and interactions would lead support to a renovated form of agriculture, aimed at maximizing sustainability and a more solid basis of modern ‘farming culture’.

Limitations of agriculture and its adaptations to global climate change

The successes of commercial, large-scale agricultural systems are based on a very linear model of production and despite the breakthroughs of the green revolution of the 1960s to present, modern agriculture has not been able to insure food for all, nor overcome the challenges that still continue to affect food production (2) and its distribution. Soil loss and degradation, water scarcity and pollution, genetic erosion (18), loss of biodiversity (16, 8) and the conspicuous need for oil remain the major barriers to sustainable food production. A majority of early 20th century agricultural scientists could not at that time have envisioned these issues as major limiting factors in maintaining production efficiency and stability. Notable studies indicated the higher productivity of diverse ecosystems such as: grassland (19) and forest (20) when compared to agricultural systems. It has been demonstrated that the simultaneous cultivation of more than one crop benefits nutrient uptake, enhances resilience against environmental stresses (4, 18) and attracts pollinators and beneficial insects (21, 22, 23). However, these study results have had little to no effect on the routine operations of a majority of agriculturists and farming experts of the industrialized world, nor legitimized the need to develop more sustainable models of food production. Present agricultural research aims at resolving food production challenges one at a time, thus remaining oblivious to the synergies and interactions that in farming systems often provide the opportunity to resolve problems more successfully by embracing a holistic approach. For example, present-day research in agriculture focuses heavily on GMO technologies that help economic crops to withstand specific pest pressures and environmental stresses (e.g., drought, soil salinization, frost), yet do nothing to benefit the long-term health and livelihood of agricultural communities.

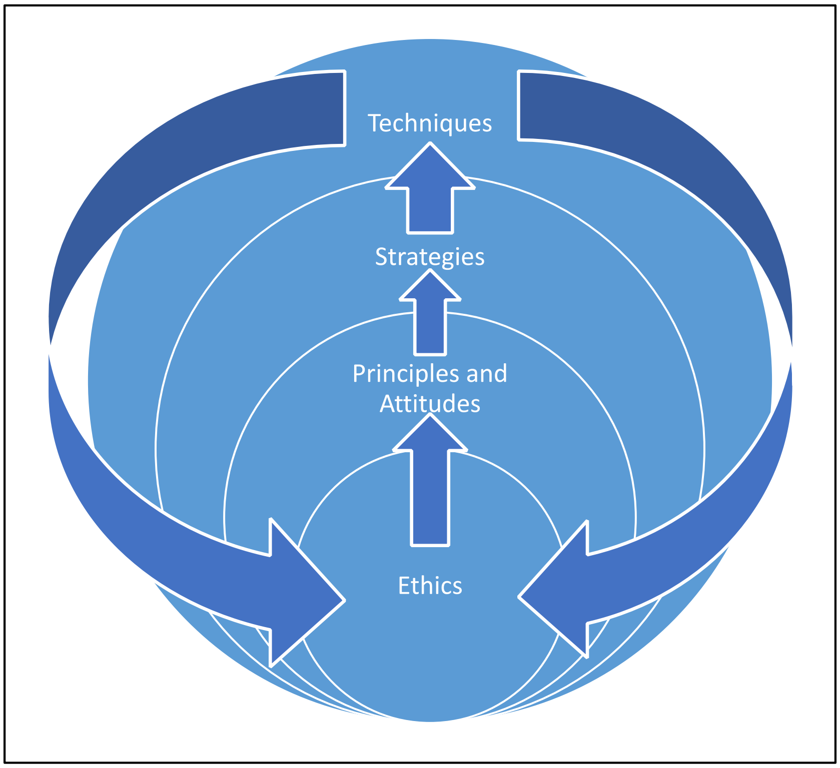
At the same time, global climate change likely will have significant impacts on agriculture in the Midwestern U.S., Panamá, and elsewhere. The Midwest U.S. region for example is endowed with some of the world's best soils and favorable climate for agriculture (24) yet, climate models for this region predict significant (>4°C) increases in average annual temperature, increased precipitation (25-30% increases in winter and spring), less predictable weather patterns, and increased frequency of extreme events such as flooding rains, late-season frosts and droughts (25, 26). Although longer growing seasons, more precipitation and increased atmospheric concentrations of CO^2 may enhance production of some crops in some locations (27, 24) the effects of climate change generally are predicted to be negative for the Midwest U.S. (28, 26). Crop production may be inhibited by 1) wetter springs that can delay planting, 2) 10-20% less rainfall during late summer and 3) hotter summers that increase heat stress and induce early maturation (26). Livestock productivity also may decline due to heat stresses, and warmer winters may enable livestock and crop pests and diseases to expand their ranges northward into this region (26). The Midwest U.S. already has experienced significant changes in climate (26). Droughts, flooding and prolonged periods of excessive heat in recent decades have caused billions of dollars in agricultural losses, and conditions are expected to worsen under current levels of releases of heat-trapping emissions into the atmosphere (27, 26). Similarly, in Panamá and other regions of Mesoamerica, a higher rate of environmental events of high intensity (i.e.: floods and soil erosion, prolonged periods of drought) could soon affect negatively the economies of these countries, compromise crop yields and jeopardize food security, despite efforts of improving the genetics of important agronomic crops, like maize (68) .

Also, it remains impossible to assess accurately the productivity of agricultural systems with the occurrence of more unpredictable weather patterns and this information void can exacerbate the effects of global climate change (29). Although industrial agriculture certainly is not immune to the damage caused by a changing climate, it remains mostly oblivious to embracing systemic change as an approach to adaptation to climate change, because policy development and enactment on this subject are often still in their infancy (30) and typically slow to be employed. For these reasons, a conservation and, or development of microagriculture, which is more common in Panamá and other central American countries, than in the Midwest of the U.S., could trigger the advocated policy and technical shifts, which are so much needed at the macro scale.

The design and functioning of micro-farming systems

Small scale farming in urban areas has been engaging city dwellers for decades, improving living conditions for many and generating vibrant local economies (31, 32, 17). Within an urban, or small farming context, permaculture can be considered the technical and philosophical tool most suitable for micro-agriculture because it includes the most holistic approach to the design and maintenance of food production systems (Figure 1). A core of moral values (care for the Earth, care for the people, more even distribution of surpluses) leads to the tenets of permaculture design (observe and interact with natural systems, practice conservation, value diversity and multifunctionality of each element, capture and store energy, respond creatively to change, integrate rather than segregate). These principles inspire the strategies (with major focus on water use, water quality and conservation) and the techniques, or methods, to fulfill the goals of the design (33).

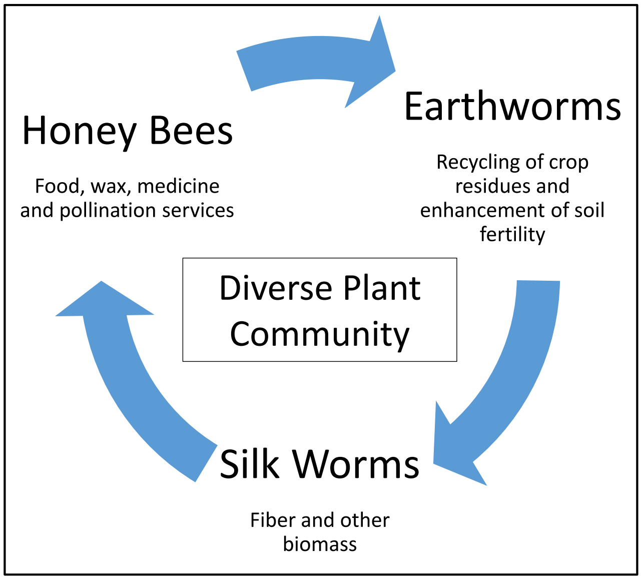
Figure 1. Values and approaches that guide the design process in permaculture



Soil quality always plays a vital role in successful establishment of crops or other plant communities (e.g.: herbs, ornamentals) (34, 35). However, the coexistence of gardens and urban farms with sidewalks, buildings and parking lots is often characterized by soil contamination and poor fertility due to loss of soil organic matter (17). Therefore, generous applications of soil amendments and compost become necessary prior to initiating any sort of cultivation of urban soils (36). Food production on a micro scale recognizes the need for enhancing soil fertility as well as adding various ecological services, which are enhanced by living soil organisms. For this reason, it proposes the use of selected invertebrate species (Figure 2).

Plant residues and other organic biomass become the low-energy input that earthworms (*Eisenia foetida*) recycle into fertile vermicompost, which amends the soil and regenerates its fertility. For example, silkworms (*Bombyx mori*) have been employed in European agriculture through centuries for the production of natural fiber (silk). Their cultivation (sericulture) has been mostly abandoned since the introduction of synthetic polymers. In different countries and cultures farmers have been consuming for millennia local available species of plants, fungi, animals (especially invertebrates), or learned how to grow them on their farms (17). Honey bees (*Apis mellifera*) are a keystone species, which demands great attention in the design and sustainable functioning of agroecosystems, large and small. Notably, these insects are famous for their ability to produce honey, wax, propolis, pollen and royal jelly, but much more important are the service they provide as a plant pollinators. Prior to its introduction to North America in the early 17th century, about 4,000 species of native pollinators (mostly insects) were servicing food production for a variety of plant species, especially vegetables and fruits. Spivak and her collaborators (21) pointed out the great magnitude of loss in food productivity should bees populations (both native and introduced) continue to decline. Regretfully, the widespread use of pesticides has weakened pollinators' ability to withstand disease. More gravely, the loss of habitat poses more challenges for the survival of bees and other pollinators. Despite the recognized needs for reconstructing refugia within farms (23) or farmscaping (22), the typical agricultural landscape remains homogeneous and often laden with toxic chemicals. Thus, the introduction of bees in micro farming systems becomes pivotal to the preservation of these species in an environment already much more biologically diverse, allowing pollinators to forage successfully and continue to efficiently provide ecological services to cultivated and uncultivated crops.

Figure 2. Selected invertebrate species for primary productions and services when employed in European micro-farming systems.



Therefore, in the proposed microfarming model, the outputs (products and services) of one species foster the thriving of others and together they amplify the beneficial effects upon the whole system.

Micro-Agriculture as a restorative ecological paradigm

Although large-scale agriculture still retains a dominant role in insuring the availability of inexpensive food, its management often affects negatively the biodiversity, soil fertility, and water quality of agroecosystems (37, 38, 39, 16, 15). On the other hand, these effects are negligible when studying small farming systems like community gardens and small family farms (35, 40, 41). Thus, the idea of micro-agriculture becomes a viable model for sustainable food production where land and open space for farming are limited.

The use of selected invertebrate species can improve food production and ecological services and also the overall quality of small-scale agroecosystems because the ecological power and resiliency of such a system are enhanced. The biocenoses established in such a context amplify the capability of micro farming systems to regenerate soil fertility and the results at this scale can be far superior to those that agronomists attempt to achieve in large cultivated fields. Earthworms (Lumbricus spp., Eisenia foetida) and other soil organisms play a vital role in this process; however, a fertile soil relies on thousands of species of invertebrates and microorganisms (42) for proper functioning and sustainability. A primary goal of micro-agriculture is facilitating soil biocenosis and to foster humification processes. Carbon fixation and its subsequent conversion into humus from biomass is achieved by a variety of soil biota, which ultimately enhances additional root growth in plants, thus preventing soil erosion and making this process absolutely vital to the sustainability of agroecosystems large and small (39, 18, 40, 4).

The specific process of humification relies on a diversity of residues within a specific biomass and in the contemporaneous presence of diverse taxa of microorganisms that operate in aerobic conditions (39, 42). It is a fact that cultivation reduces soil diversity, and excessive tillage (with concomitant oxidations and mineralizations often amplified by fertilizers applications) reduces the organic matter content of soils (43). Therefore, agriculturalists' interests should focus on achieving a nutritional balance between the crop needs and soil-climate conditions, so that the amount of carbon mineralized from crop residues comes close to the carbon derived from crops grown purposefully for biomass production. Under these circumstances, sustainability can be pursued only if this nutritional balance is achieved in the soil, and this is possible by conserving biodiversity (44, 45, 46, 16).

This process of soil rehabilitation can be pursued more rapidly and efficiently on the micro scale than in large fields, where topsoil is more easily lost to erosion brought on by frequent disturbance from heavy, mechanical implements. Therefore, maintenance of soil fertility is more easily achievable when farming is done in small plots (35). Achieving and maintaining a superior level of fertility in the soil also allows a more intensive cultivation of economic crops on limited space, with an opportunity to harvest outstanding yields (34, 33). Thus, soil fertility and a diverse plant community are key features of a sustainable agroecosystem, regardless of size.

An equally seminal feature of microagriculture is education, as a majority of people have been removed from food production for at least a generation. Although this may not be true for Panamá, also in this country large scale agriculture has deepened the knowledge gap across generations about the origin and cultivation of foods (17). Thus, developing micro farms within cities and urban municipalities becomes an effective vehicle to reconnect large segments of modern society with food production systems and approaches, nutrition and sustainability, while also developing local economies and improving health conditions for the community (47. Within the conceptual framework of microagriculture, the role played by community members becomes pivotal to its success, as this effort strives to bring together people from across the spectra of age, social status and culture. Micro-agriculture emphasizes richness of knowledge and on being technologically appropriate for the context in which it is taking place unlike agriculture on the macro scale, which is information-rich and technologically advanced. Additional attributes distinguish the two paradigms of agriculture here discussed (Table 1), yet, and despite their differences, they equally complement each other. They have potential for directing the future of agriculture toward higher levels of sustainability, if they comprehend their primary role in maintaining quality of life and if they will avoid operating in isolation.

Table 1. Selected attributes of farming, their level of availability and main characteristics at the macro and micro scale (modified after: Altieri and Rosset, 1996)

Attribute	macro-agriculture	micro-agriculture
Knowledge	Limited/Homogeneous	High/Diverse
Information	High	Limited
Technology	High	Appropriate
Energy needs	High	Very limited
Biodiversity	Very limited	Very High
In-puts of production	High and expensive	Limited and inexpensive
Growing system	Monoculture	Polyculture
Market venues	Global market	Local market
Resource needs	High	Limited
Crop yields	Maximal	Optimal
Production system	Linear	Cyclical

For several decades, reconstructed and remnant native prairies of the Midwest region in the U.S. have provided tremendous opportunities to ecologists and agronomists to learn about the complex dynamics of a biodiverse system, while attempting to transfer this knowledge to the cultivated field. For example, a study (48) on restored prairie plots demonstrated the greater efficiency and productivity of diverse fields when prairie grasses and forbs were grown in polycultures. Similarly, the remaining patches of tropical forests which are typical ecosystems of Panamá and other regions of Mesoamerica should be looked at as models for designing sustainable farms, where tree species become more often employed to provide products, services and to enhance farms agrobiodiversity (61). In contrast, monocultures of crops for alternative energy sources have often amplified the environmental degradation and an erosion of agrarian systems (15, 45). Continual soil disturbance typical of large-scale agriculture leads inevitably to erosion, salinization and loss of biodiversity and we realize that these indirect, environmental costs should be avoided at all times to insure that farming systems remain productive and resilient, especially at times of climatic adversity. Also, the risk of desertification increases proportionately on landscapes where the average temperatures are high in conjunction with water scarcity and high population pressure (49, 12). It remains unknown, however, at what level biodiversity in the agroecosystem may complement successfully the viability of sustainable farming practices. Recent studies have indicated that without maintaining an appropriate carbon balance in the soil, the productivity declines to the point that farming may come to an end (18). A shift therefore becomes necessary to design future agroecosystems that are capable of maintaining crop production while adapting to climate change. The effort of this renovated design of farming systems should consider species diversity to achieve sustainability, resilience and retention of production efficiency. Restoration ecology (15, 50) permaculture (33) and agroforestry (61) have potential for rehabilitating agroecosystems at the macro and micro scale with the ecological services they provide, while an adaptive management of these multifunctional systems (9) becomes the tool for coping most successfully with unpredictable and sudden weather changes.

Conclusion

Micro-farming systems cannot compete with conventional agriculture in terms of yields and potential of market distribution for the sale of their products and services. However, their potential for insuring a reliable supply of quality food in the urban and suburban environments is not negligible. They also are more easily adaptable to climate and environmental changes because they are more biologically diverse and reliant on local resources, knowledge and appropriate technologies (51). A patchy landscape of gardens and microfarms can become very productive, and its efficiency has been amply demonstrated by the success of urban agriculture in Cuba since the fall of the former Soviet Union and loss of support for its former food system (52, 53). Many other countries in the developing world depend on urban farming to complement food production, thus maintaining local economies and conserving valuable germplasm (54) and resources (41). These and similar systems cannot compete with the yields and profits that industrial agriculture can achieve. However, the much lower environmental impact of food production on microfarms should be appreciated and recognized (14, 55) and inspire macroagriculture to design and manage more biodiverse farms that can be more self-sustaining.

Farmers in Midwest states of the U.S. and Mesoamerican countries like Panamá may be able to reduce climate-induced economic losses by adapting their management practices to the changing environment (27, 25, 28, 56, 57, 58, 68), but adaptations involving typical crops and techniques may only be able to compensate for 50% of yield losses predicted from moderate climate warming (57, 58). Management adaptations that incorporate perennial cropping systems and agroforestry, increased diversity of crops and livestock and less reliance on annual crops such as corn and soybeans may be necessary agronomic strategies to effectively cope with a changing climate in most agricultural landscapes yet, according to this approach, achieving sustainability in agriculture is possible when farming becomes multifunctional, to enhance benefits for society in terms of production and services (9). This model aims at developing a new, agricultural bio-economy. However, to implement it thoroughly, key policies such as the farm bill in the US (3) will have to include provisions to foster the existing Research & Development infrastructure to substantiate with good science the validity of this emerging paradigm (59). Shepard and Westmoreland (60) have already described a vision for the agrarian landscape of south central Minnesota whereas Fisher and Vasseur suggest agroforestry as a tangible approach to foster sustainability in panamenian food production systems (61). Undoubtedly, a decentralization of the present food system is very much needed in U.S. agriculture, to reduce the emissions of carbon dioxide that are released into the atmosphere just to transport agricultural commodities (62) in this global, market economy. Microagriculture can demonstrate the economic benefits of a local approach to food production, as the much lower input demand for a micro-farming system (especially energy) has potential to establish a vibrant, local food system of quality, stability and regional economic prosperity, modeled after previous experiences in Iowa (7) and Pennsylvania (63).

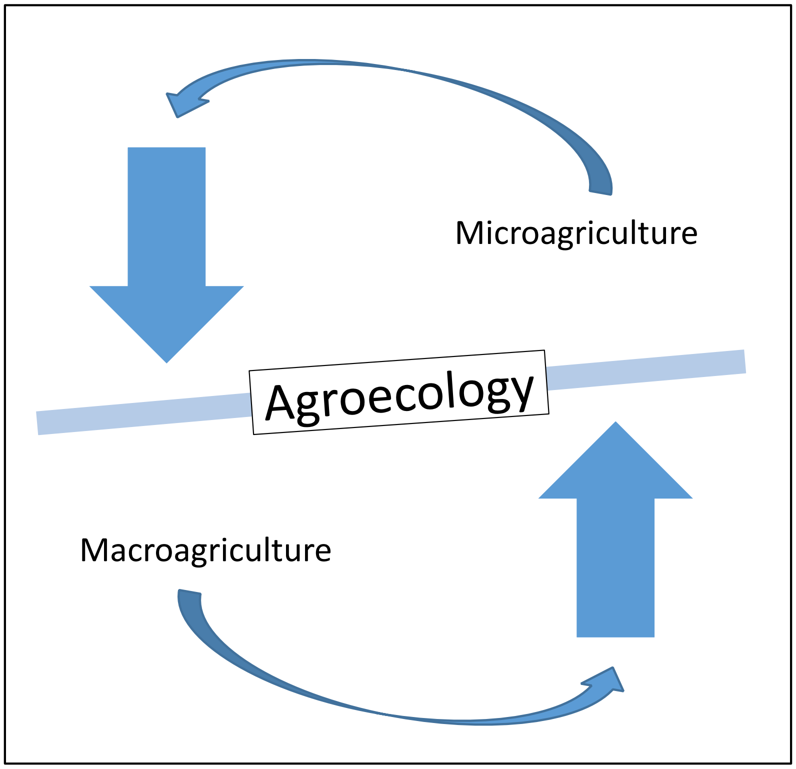
Large-scale agriculture, whether or not it is founded on the science of agroecology, causes more drastic disturbances to natural ecosystems than microagriculture. Minimizing these and similar effects becomes imperative to lessen the consequences of a changing climate upon the pests, diseases and their toll on cultivated crops (10). Also, a vision for sustainable agriculture embracing agroecology must remain committed to closing the nutrient loop of its food production cycles, while preserving cultural and environmental resources (64, 65). Microfarming systems are managed in a manner that attempts to restore and conserve ecosystem attributes and rely upon ecological services and biodiversity at a much higher level than industrial agriculture.

A form of agriculture inspired by agroecology engages farmers to diversify their operations by increasing the diversity of crops grown (37, 6); this form of agriculture can be more easily carried out at the microscale than on large agroecosystems. At the same time, microfarming acquires a true heuristic character because (if practiced in urban areas), it is visible and offers great opportunities to bring the community together, where everyone can get involved (32, 55).

In this context food production becomes valuable, educational and democratic, even when accomplished on the smallest parcel of land. These and similar demonstration, postage-stamp farming systems rely on people's knowledge more than information and technology and they can truly reflect the new, sustainable culture of doing agriculture. They are grassroots and serve the purpose of reconnecting human communities with food systems and our natural resource base. Pursuing such a diversification of the human landscape becomes pivotal in insuring food security at a time of unpredictable climatic changes. Eventually, this approach to food production becomes the vehicle to move industrial agriculture toward the much needed systemic changes that have been advocated for a long time (4, 49, 66, 3, 67) because more and more people become re-educated about agriculture where food is grown where we live. Thus, the pursuit of sustainability in agriculture should derive from a continuous tuning among the needs, challenges and efforts of macroagriculture to shift away from a design that supports monocultures and high energy inputs to achieve food production.

Concurrently, microagriculture is connected, aware and informed about the issues which are typical of agriculture on a large scale. Its alternative design, management and localized resource base inspires macroagriculture to research more sustainable methods to maintain yields and achieve a more self-sustaining productivity. The flow of knowledge between the two food production models is centripetal (Figure 3), transparent, holistic and leads eventually to a unified paradigm of sustainable food production founded on the science of agroecology.

Figure 3. Interconnectedness between large-scale and small-scale agriculture



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