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# Agroecology: Principles for the Conversion and Redesign of Farming Systems

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## Abstract

Modern agroecosystems require systemic change, but new redesigned farming systems will not emerge from simply implementing a set of practices (rotations, composting, cover cropping, etc.) but rather from the application of already well defined agroecological principles. These principles can be applied using various practices and strategies, each having different effects on productivity, stability and resiliency of the target farming system. By breaking the monoculture nature of farming systems, agroecological diversification aims at mimicking ecological processes leading to optimal nutrient cycling and organic matter turnover, soil biological activation, closed energy flows, water and soil conservation and balanced pest-natural enemy populations. All these processes are key for maintaining the agroecosystem's health, productivity and its self-sustaining capacity. By enhancing functional biodiversity, a major goal of the conversion process is achieved: strengthening the weak ecological functions in the agroecosystem, allowing farmers to gradually eliminate inputs altogether by relying instead on ecological processes and interactions.

**Keywords** Agroecology; Conversion; Diversified farming systems; Sustainability; Resilience

## Introduction

Modern agriculture has consisted in the replacement of natural plant communities with artificially supported crop communities. Human manipulation and alteration of ecosystems for the purpose of establishing agricultural production has turned modern agroecosystems into highly simplified systems, to the point that they are structurally and functionally very different from natural ecosystems. The self-regulation capacities of natural plant communities are lost when farmers modify them by promoting monocultures. The more intensely such communities are simplified, the more frequent and serious the ecological unbalances of simplified cropping systems [1].

Reliance on homogeneous monoculture production systems is no longer socially, economically and ecologically desirable as these systems compromise biodiversity, utilize resources inefficiently, are highly energy dependent, impose a major ecological footprint, are susceptible to pest outbreaks and are also vulnerable to climatic variability [2]. A recent analysis concluded that major grain crops are genetically uniform and thus extremely vulnerable to disease epidemics and climatic events [3]. This uniformity is linked to economic and legislative forces that favour monocultures and simplification [3]. In fact, increased demand for corn grain as a biofuel is altering diversity at the landscape level and consequently the ecosystem services they provide. For example, Landis et al. [4] concluded that recent biofuel-driven growth in corn monocultures in four US Midwest states resulted in lower landscape diversity, which in turn decreased habitat of natural enemies of soybean pests, thus reducing bio control services by 24%. Reduced biological control cost soybean farmers about $58 million per year due to reduced yield and increased pesticide use [4]. Similarly, Chinese researchers found in a two-year study of seventeen 1500 m-radius sites in China, that input of nitrogen fertilizer and cropland expansion compromised the ability of natural enemies to control cereal aphids leading to a disturbance of interspecific relationships thus enhancing reliance on pesticides [5].

Other than deploying new crop varieties and applying more than 5.2 billion pounds of pesticides worldwide, ecologically speaking, little has been done to reduce the pest susceptibility of industrial agroecosystems or to enhance their adaptability to changing climatic patterns [6]. Many agroecologists have suggested that agroecological strategies that break the nature of monocultures and favour field diversity as well as landscape heterogeneity are the most viable path to increase productivity, sustainability and resilience of agroecosystems [7,8]. This recommendation is based on observations and experimental evidence that assert the following trends: (a) when agroecosystems are simplified, key functional species are eliminated shifting the balance of the system from a desired to a less desired functional state, affecting the agroecosystem's capacity to respond to changes and provide ecosystem services and (b) the higher the vegetational diversity of agroecosystems, the greater the capacity of the agroecosystem to buffer against pest and disease problems as well as to shifting climatic patterns [9].

Research has shown that diversified agroecosystems can reverse yield reduction trends when a variety of crops and varieties are deployed in various temporal and spatial schemes as each responds differently to external shocks. In a recent review, researchers found that when compared to conventional monocultures, diversified agroecosystems supported greater biodiversity, better soil quality and water-holding capacity, and exhibited greater energy output/input ratios, and resilience to climate change. Diversified farming systems also enhance the regulation of weeds, diseases, and insect pests while increasing pollination services [10].

As farmers initiate the agroecological conversion of their farming systems, several beneficial changes in soil properties, microclimatic conditions, plant diversity and associated beneficial biota occur, slowly creating the foundations for enhanced plant health, crop productivity and resiliency [11]. Agroecosystems undergoing ecological conversion operate as complex systems with emergent properties, and therefore management decisions should take into consideration the special behaviors and properties of complex systems [12]. It is clear however that it is not diversity per se that enhances stability in agroecosystems but rather 'functional biodiversity', a set of biota clusters that play key roles in the determination of agroecosystem processes and in the provision of ecological services (soil fertility, pest regulation, etc.) thereby reducing the need for external farm inputs [7,13].

In this paper, we argue that modern agroecosystems require systemic change, but new redesigned farming systems will not emerge from simply implementing a set of practices (rotations, composting, cover cropping, etc.), but rather from the application of already well defined agroecological principles [7,13]. These principles can be applied by way of various practices and strategies, and each will have different effects on productivity, stability and resiliency within the farm system. Agroecological management leads to optimal nutrient cycling and organic matter turnover, soil biological activation, closed energy flows, water and soil conservation and balanced pest-natural enemy populations. All these processes are key for maintaining agroecosystem's health, productivity and its self-sustaining capacity [14]. The challenge to align agricultural systems with ecological principles is immense, especially in the current context of agricultural development where specialization, short-term productivity and economic efficiency are emphasized.

## The conversion of farming systems

The reversion of agroecosystems that have already undergone major ecological simplification implies a process of conversion from a high-input monoculture management system to a diversified system with very low external inputs [15]. Most farmers start the conversion process slowly, taking time to gain experience with a more diverse cropping system, experimenting on a small scale and thus reducing risk and to learn to be flexible enough to adapt to changing conditions.

**Stages in the transition:** The conversion to organic management affects the whole farming system, not only single enterprises. Crop rotations are the main management practices that overwhelmingly organic farmers utilize during conversion as these influence forage production, fertility building and are an integral part of weed, pest, and disease management strategies. A major emphasis during conversion is improving overall soil quality by incorporating organic matter into the soil via the application of animal manures or compost, as well as skillful cover cropping and well planned rotations. In most organic systems cover crops are the source of the vast bulk of organic carbon inputs needed for the desired soil microbial community and adequate nutrient pool [11]. Unfortunately pushed by market forces that privilege specialization, many organic farmers tend to replace practices such as rotations, cover cropping, etc. with a set of organic technology packages and input substitutions, making their operations dependent and intensive.

Many authors have conceptualized agroecosystem conversion as a transitional process with three marked phases [16]:

1. Increased efficiency of input use through integrated pest management or integrated soil fertility management.
2. Input substitution using environmentally benign inputs (botanical or microbial pesticides, bio fertilizers, etc.).
3. System redesign or diversification through optimal crop/animal assemblages which encourage interactions that allows the agroecosystem to sponsor its own soil fertility, natural pest control, and crop productivity.

Many of the practices that are currently being promoted as components of sustainable agriculture fall in categories 1 and 2. Both of these stages decrease agrochemical input use and offer benefits in terms of lower environmental impacts as well as economic advantages by reducing production costs. Incremental changes tend to be more acceptable to farmers as drastic modifications may be viewed as highly risky. But does the adoption of practices that increase the efficiency of input use or that substitute biologically based inputs for pesticides and fertilizers, while leaving the monocultural structure intact, have the potential to lead to the productive redesign of agroecosystems? A true agroecological conversion calls into question monoculture and the dependency on external inputs [15].

In general, the fine-tuning of input use through approaches such as Integrated Pest Management (IPM) or Integrated Soil Fertility Management (ISFM) does little to transition farmers toward an alternative system independent from external inputs. In most cases IPM translates to "intelligent pesticide management" emphasizing the selective use of pesticides according to a pre-established economic threshold, which pests often surpass in monoculture situations. Input substitution used by the large majority of organic farmers follows the same paradigm of conventional farming by trying to overcome the limiting factor with biological or organic inputs. Many of these "alternative inputs" have become commodified, therefore farmers are still dependent on input suppliers [17]. In California, many organic farmers cultivating grapes and strawberries apply between 12-18 different types of biological inputs per season. In addition to enhancing production costs, many products used for one purpose affect other aspects of the system. For example, Sulphur which is widely used to control foliar diseases of grapes, can also wipe out populations of Anagrus parasitic wasps, key regulators of leafhopper pests. Thus farmers become trapped in an "organic treadmill".

Gliessman [18] argues that improvements in efficiency of input use and input substitution are not enough to address the challenges facing modern agriculture. Instead, he argues that farming systems must be redesigned based on a new set of ecological relationships. This entails approaching conversion as an ecological transition of agriculture based on notions of agro-ecology and sustainability. System redesign arises from the application of agroecological principles that lead to the transformation of the structure and function of agroecosystems by promoting management guided to ensure the following processes [19]:

1. Increasing above and below ground biodiversity.
2. Increasing biomass production and soil organic matter content.
3. Efficient use of soil nutrients, water, solar energy, seeds, soil organisms, pollinators and natural enemies.
4. Optimal planning of plant-animal sequences and combinations.

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5. Enhancement of functional complementarities and interactions between soil, crop and biotic components.

Ultimately system redesign consists in the establishment of an ecological infrastructure that through plot to landscape-scale diversification, encourage ecological interactions that generate soil fertility, nutrient cycling and retention, water storage, pest/disease regulation, pollination, and other essential ecosystem services [20]. The associated cost (labor, resources, money) to establish the ecological infrastructure of the farm (living fences, rotation, insect habitats, etc.) during the redesign phase tends to be high in the first 3-5 years. Once the rotation and other vegetational designs (cover crops, polycultures, field borders, etc.) start lending ecological services to the farm, key ecological processes (nutrient cycling, pest regulation, etc.) are set in motion, the need for external inputs is reduced and thus maintenance costs start decreasing as the functional biodiversity of the farm sponsors ecological functions (Figure 1).

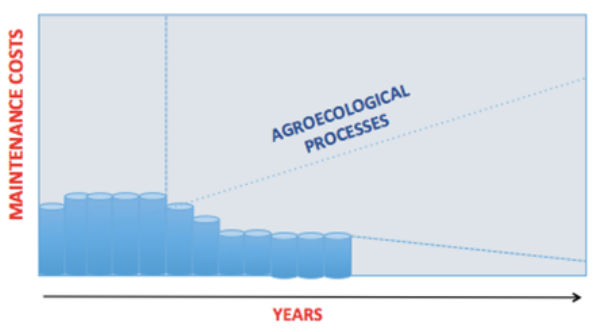


**Figure 1:** Maintenance costs during the transition towards system redesign.

Agroecology promotes principles rather than rules or recipes to develop an agroecological production system out of a conventional farm in a stepwise transition process. Farmers are increasingly challenged to make use of their intellectual and communication skills throughout this period of transition because they have to optimize conventional input-use efficiency, substitute synthetic with organic inputs, and re-design the production system. Such a transition is knowledge intensive and requires self-study, and ideally a reluctance to take major risks, demanding 3–5 years for the creation of an agroecosystem. Agroecology as a farming approach can be more labor-intensive, but benefits such as the development of capabilities, the services to neighboring ecosystems, and the provision of healthy food mostly justify the extra effort the farmer puts in redesigning her/his farming system [21].

## Changes in soil biology and crop productivity

After 3-4 years of conversion, changes on soil properties become apparent. In general, organically managed soils exhibit higher biological activity than soils managed conventionally. In a long term and well controlled study conducted in Switzerland researchers found root length of crops colonized by mycorrhizae in organic farming systems was 40% higher than in conventional monocultures [22]. Crop plants colonized by VAM usually exhibit significantly higher biomass and yields compared to nonmycorrhizal (NM) plants, under water stress conditions, as VAM colonization increases water use efficiency [23]. Biomass and abundance of earthworms were higher by a factor of 1.3 to 3.2 in the organic plots as compared with conventional ones [2]. Activity and density of predators such as carabids, staphylinids, and spiders in the organic plots was almost twice that of the conventional plots [22].

Percent nitrogen, phosphorus and potassium, pH, organic matter and some micronutrients increase with time, reaching values many times significantly higher than at the start of the conversion [24]. Many studies have revealed better performance of organic agriculture than conventional systems on various sustainability metrics, including species richness and abundance, soil fertility, nitrogen uptake by crops, water infiltration and holding capacity, and energy use and efficiency [10].

In terms to productivity, the Switzerland study showed that mean organic crop yield was only 20% lower over a period of 21 years indicating an efficient production. In the organic systems, the energy to produce a unit of crop dry matter was 20 to 56% lower than in conventional and also 36 to 53% lower per hectare [22]. Yields usually decline during the first 3-5 years of conversion, but as a recent metanalysis suggests, organic yields are only 19.2% lower than conventional yields, a smaller yield gap than previously estimated [25]. These researchers found that diversification schemes such as crop rotations and multiple cropping, reduced the yield gap when the methods were used by organic farmers.

Once agroecosystems reach the last stage of the conversion process (system redesign), and polycultural cropping systems are prevalent, total production output increases at the farm level. The mechanisms that explain higher productivity in polycultues are embedded in the process of facilitation. Facilitation occurs when one crop modifies the environment in a way that benefits a second crop, for example, by lowering the population of a critical insect pest, or by releasing nutrients that can be taken up by the second crop [26]. Thus mechanisms are related to the lower pest and pathogen incidence generally found in intercrops and to the higher resource use efficiency of crops with different root systems and leaf morphology. Resource capture and resource conversion efficiency and other concepts have also been suggested as mechanisms underlying polyculture yield advantages. A school of thought concerning the resource use of intercropping systems states that a combination of two contrasting species, usually legumes/cereals, would lead to greater overall biological productivity than each species grown separately because the mixture can use resources more effectively than under separate monocultures [27]. Huang et al. [28] explored how corn-faba bean, corn-soybean, corn-chickpea, and corn-turnip intercropping affected yields and nutrient acquisition in Chinese agricultural fields. The authors found that the intercropping systems more efficiently removed nitrogen from the soil – indicating increased resource use efficiency in the polycultures. Zhang and Li [29] propose a "competition-recovery production principle" based on several years of studies on intercropping of short-season/long-season species. They suggest that interspecific interaction increases growth, nutrient uptake and yield of dominant species, but decreases growth and nutrient uptake of the subordinate species during the co-existence stage of two crop species. After the dominant species is harvested, the subordinate species has a recovery or complementary process so that the final yields remain unchanged or even increase compared with corresponding sole species.

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## Agroecological principles for the conversion

As an applied science, Agroecology uses well established ecological principles for the design and management of diversified agroecosystems where external inputs are replaced by natural processes such as natural soil fertility, allelopathy and biological control (Table 1). Agroecology does not promote technical recipes but rather the above principles, which when applied in a particular region take different technological forms depending on the prevailing socio-economic and biophysical circumstances of farmers [7,13]. Each practice is linked to one or more principle thus contributing to its manifestation in the function of the agroecosystems (Table 2). The applied practices set in motion ecological interactions that drive key processes for agroecosystem function (nutrient cycling, pest regulation, productivity, etc.) (Figure 2).

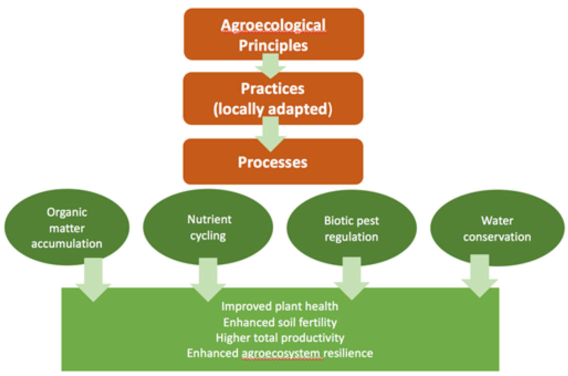


**Figure 2:** Agroecological principles for the conversion of farming systems.

| |
|---|
| Enhance the recycling of biomass, with a view to optimizing organic matter decomposition and nutrient cycling over time |
| Strengthen the "immune system" of agricultural systems through enhancement of functional biodiversity – natural enemies, antagonists, etc., by creating appropriate habitats |
| Provide the most favorable soil conditions for plant growth, particularly by managing organic matter and by enhancing soil biological activity |
| Minimize losses of energy, water, nutrients and genetic resources by enhancing conservation and regeneration of soil and water resources and agrobiodiversity |
| Diversify species and genetic resources in the agroecosystem over time and space at the field and landscape level |
| Enhance beneficial biological interactions and synergies among the components of agrobiodiversity, thereby promoting key ecological processes and services |

**Table 1:** Agroecological principles for the design of biodiverse, energy efficient, resource-conserving and resilient farming systems [7,13].

Agroecology does not promote a few magic bullet solutions divorced from local contexts and disseminated following top down approaches. Rather, it relies on a set of complex interactions that emerge when adequate combinations of various practices are operationalized on each farm [30]. The array of cultural practices used by each farmer result in functional differences that cannot be accounted for by any single practice. This is what Andow and Hidaka [31] called "a production syndrome" defined as a set of management practices that are mutually adaptive and when acting together lead to high performance. However, subsets of this collection of practices may be substantially less adaptive; that is, the interaction among practices leads to improved system performance not explained by the additive effects of individual practices. One of the frustrations of research in the organic/conventional yield gap has been the inability of low-input practices to outperform conventional practices in side-by-side experimental comparisons, despite the success of many organic and low-input production systems in practice. A consistent yield gap of 19-25% is reported when comparing organic and conventional agricultural systems, but interestingly the yield gap is reduced substantially when organic farmers adopt multi-cropping and complex crop rotations, evincing the "production syndrome" [25].

| Management practice | Principle to which they contribute* | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Compost application | x | | x | | | |
| Cover crops and/or green manures | x | x | x | x | x | x |
| Mulching | x | | x | x | | |
| Crop rotation | x | | x | x | x | |
| Use microbial/botanical pesticides | | x | | | | |
| Use of insectary flowers | | x | | | x | x |
| Living fences | | x | x | | x | x |
| Intercropping | x | x | x | x | x | x |
| Agroforestry | x | x | x | x | x | x |
| Animal Integration | x | | x | x | x | x |
| *Each number refers to an agroecological principle listed in Table 1 | | | | | | |

**Table 2:** Relative contribution of several management practices to one or more agroecological principles [32].

Depending on how it is concretely applied and complemented or not by other practices, one particular practice can sometimes act as an "ecological turntable" by activating various processes (nutrient cycling, biological control, antagonism, allelopathy, etc.), all essential for the health and productivity of a farming system. Cover crops for example can exhibit several multiple effects simultaneously including suppression of weeds, soil borne diseases and pests, protect the soil from rain and runoff, improve soil aggregate stability, add active organic matter, fix nitrogen and scavenge for nutrients [7]. Clearly, each production system represents a distinct group of management practices and by implication, ecological relations. This re-emphasizes the fact that agroecological designs are site-specific and what may be applicable elsewhere are not the techniques but rather the ecological principles that underlie sustainability. It is of no use to transfer technologies from one site to another, if the set of ecological interactions associated with such techniques cannot be replicated.

## Agroecological interactions in redesigned farming systems

System redesign is the last stage in the agroecological conversion process and consists in practical steps to break the monocultural structure by restoring agricultural biodiversity at the field and landscape level. Biodiversity enhancement is the cornerstone strategy of system redesign, as increasing diversity within functional groups promotes key processes (pest regulation, nutrient cycling, etc.) fundamental for agroecosystem function [33]. Higher plant diversity within the cropping system determines higher diversity of above and below ground associated biota which in turn leads to more effective pest control and pollination and to tighter nutrient cycling [19].

## Pest Regulation

Over the last 40 years, many studies have evaluated the effects of crop diversity on the abundance of insect pests. An early review by Risch et al. [34] summarized 150 published studies exploring the effects of diversifying an agroecosystem on insect pest densities. 198 total herbivore species were examined in these studies. Fifty-three percent of these species exhibited lower densities in the more diversified systems. Eight years later, Andow [35] analyzed results from 209 studies involving 287 pest species, and found that compared with monocultures, the population of pest insects was lower in 52% of the studies, and higher in 15% of the studies. Of the 149 pest species exhibiting lower densities in intercropping systems, 60% were monophagous and 28% polyphagous species [31].

The abundance of predators and parasitoids of pests was higher in intercrops in 53% of the studies and lower in 9%. Tonhasca and Byrne [36] analyzing 21 studies comparing pest suppression in polyculture versus monoculture, found that polycultures significantly reduced pest densities by 64%. In a later meta-analysis involving 148 comparisons Letourneau et al. [37] found that farms with species-rich vegetational schemes exhibited a 44% increase in abundance of natural enemies, a 54% increase in pest mortality, and consequently a 23% reduction in crop damage when compared to monoculture farms. Unequivocally, earlier reviews and recent meta-analyses suggest that crop diversification strategies lead to natural enemy enhancement, reduction of insect pest densities, and reduced crop damage, from a combination of ecological mechanisms.

Plant pathologists have also observed that mixed crop systems can decrease pathogen incidence by slowing down the rate of disease development and by modifying environmental conditions so that they are less favorable to the spread of certain pathogens [38]. For soil borne or splash borne diseases, Hiddink et al. [39] found that intercropping patterns and variety mixtures significantly reduced disease in comparison to monocultures. Host dilution was frequently proposed as the mechanism for reducing the incidence of pathogens. Other mechanisms, such as allelopathy and microbial antagonists, can also act to reduce disease severity in diversified farming systems [40]. Lower disease incidence contributes to less crop damage and higher yields in mixed crops as compared to corresponding monocultures.

Weed ecologists posit that many intercrops are often superior to monocultures in weed suppression, as crop combinations exploit resources more efficiently than sole crops, thus suppressing the growth of weeds more effectively through greater preemptive use of resources [41]. Alternatively, intercrops may still over yield sole crops without necessarily suppressing weeds. The latter situation arises if the yields of intercropping result from (1) better use of resources for which crops and weeds did not compete, or (2) other mechanisms such as increased efficiency of resource conversion, shifts in the partitioning of crop biomass, modifications of microhabitats, and decreased insect or disease pressures, none of which would necessarily result in the removal of nutrients, water or light from weeds [42].

### Yield stability in the midst of climatic variability

Intercropping is popular among small farmers in the developing world because they perceive this practice as more stable than monocropping, enabling them to produce various crops simultaneously while minimizing risks [43]. Data from several experiments on mixed cropping sorghum/pigeon pea showed that for a given 'disaster' (drought, frost, etc.), pigeon pea monoculture would fail one year in five, sorghum monoculture would fail one year in eight, but intercropping would fail only one year in thirty-six [44]. Many researchers have reported that polycultures exhibit more stable yields and less productivity declines during a drought than monocultures. For example, Natarajan and Willey [45] subjected polycultures of sorghum and peanut, millet and peanut, and sorghum and millet to water stress. They found that all the polycultures over yielded consistently at moisture availability levels ranging from 297 to 584 mm of water applied over the growing season. The rate of over yielding increased with water stress so that productivity differences between monocultures and polycultures became more accentuated as water stress increased [45]. One possible mechanism explaining the above observations is that polycultures tend to have higher levels of soil organic matter content [46] which in turn enhances the soil's moisture holding capacity, leading to higher available water for plants, which positively influences resistance of crop plants to drought conditions [47,48]. Hudson [49] showed that as soil organic matter content increased from 0.5 to 3%, soil water available to plants doubled. Several trials have shown that diversified farming systems exhibit greater water holding capacity than conventional farming systems. In northeastern US, five drought years occurred between 1984 and 1998 and in four of them organic maize out yielded conventional maize by significant margins. Organic maize yielded between 38% and 137% relative to conventional maize. The primary mechanism of the higher yield of the organic maize systems was the higher water-holding capacity of the soils in those treatments. Soils in the organic plots captured more water and retained more of it in the crop root zone than in the conventional systems [11].

In a 37-year trial, Reganold [50] found significantly higher soil organic matter levels and surface soil moisture content in soils managed organically than in soils managed conventionally. Many intercropping systems also improve the water use efficiency compared to monoculture. In China, water use efficiency in a potato-bean intercropping system was 13.5% greater than in monoculture (10.15 $kg/m^3$) [30]. Morris and Garritty [51] found that water-utilization efficiency by intercrops greatly exceeds that of crops grown in monocultures. They do so by promoting the full use of soil water by plant roots, increase the water storage in root zone, reduce the inter-row evaporation, but also by controlling excessive transpiration, and by creating a special microclimate advantageous to plant growth and development.

In hillside situations prone to tropical storms, intercrops can significantly provide soil erosion protection as their complex canopies afford a better soil cover. Under heavy rains more complex canopies and plant residues that cover the soil reduce the impact of raindrops whose impact can detach soil particles and promote erosion [52]. Surface runoff is slowed by the soil cover, allowing improved moisture infiltration. Not only does living and dead cover provide soil protection, but also the extensive root system of polycultures stabilize the soil by creating a complex mat in the profile thus holding the soil [50]. In Elora, Ontario [53] soil loss was significantly lower in a silage corn intercropped with red clover system than in the corn monoculture. Runoff reduction with the corn/clover system ranged from 45 to 87% and between 46-78% reduction of soil loss was achieved with the corn/clover system.

### Linkages between soil fertility and insect pest incidence

Although crop diversification strategies in the form of multi-species rotations, cover crops, agroforestry, and intercrops are key in the conversion process, when complemented by frequent applications of organic materials (crop residues, animal manures, and composts) surprising effects on plant health, soil quality and productivity can be noticed. These hidden connections have been totally missed by entomologists and other agricultural researchers who have explained pest outbreaks in agroecosystems solely as a consequence of the absence of natural enemies or development of pesticide resistance by insect pests or secondary pest outbreaks due to disruptions promoted by insecticides [54]. Western scientists have been largely unaware of the theory of trophobiosis offered by French scientist Francis Chaboussou [55] who as early as 1967 contended that pest problems were linked to nutritional unbalances of crop plants and destruction of soil biological activity. He explained that heavy applications of nitrogen (N) fertilizers, which are highly soluble, increase the cellular amounts of N, ammonia and amino acids, at a rate faster than plants can synthesize them into proteins. Reduction of protein synthesis leads to temporary accumulation of free N, sugars and soluble amino acids in the foliage, all substances needed for reproduction by certain insect pests and plant pathogens. Chaboussou's postulated that insect pests and diseases grow and multiply faster when plants contain more soluble free nutrients caused by the inhibition of protein synthesis. He also believed that a soil with a balanced microbial life was key for the uptake of micronutrients by the plants. This is important because a deficiency of micronutrients can also cause protein synthesis reduction which in turn leads to build-up in nutrients needed by pests and pathogens [55].

In the last 20 years a number of research studies have emerged corroborating Chaboussou's assertions, showing that the ability of a crop plant to tolerate insect pest and disease incidence is tied to optimal soil quality properties. Soils with high organic matter content and rich biological activity exhibit good soil fertility as well as complex food webs with many beneficial microorganisms that prevent infection [56]. In a series of controlled greenhouse experiments, when given a choice of maize grown on organic versus chemically fertilized soils collected from nearby farms, European corn borer (*Ostrinia nubilalis*) females significantly laid more eggs in the plants grown on chemically fertilized soils [57].

Although there was significant variation in egg laying among plants grown on conventionally managed soil, in plants grown in organic managed soil egg laying was uniformly low. Pooling results across all sampled farms showed that variation in egg laying was 18 times higher among plants grown in conventionally managed soil than among plants grown on organic soils [57]. In similar studies conducted in China by Hsu et al. [58] indicated that *Pieris rapae crucivora* butterflies preferred to lay eggs on foliage of chemically fertilized cabbage plants and the larvae grew faster on plants fertilized with synthetic fertilizer. The results of this study suggested that a proper organic treatment can increase plant's biomass production and exhibit a lower pest occurrence. This dampening of plant susceptibility to insects and disease led Phelan et al. [57] to propose the concept of biological buffering, which asserts that a more complex soil community supported by the influx of active organic matter tends to moderate fluctuation in the soil environment and promote greater ecological stability. During the conversion process additional mechanisms that transfer this stability above ground through greater plant resistance may include (a) modulation of plant mineral nutrient availability by the soil food web, and/or (b) an enhanced plant systemic defense induced by beneficial microbes interacting with plant roots [59].

## Conclusions

A key agroecological principle applied since the initiation of the conversion process, is the diversification of the agroecosystem by adding regenerative components such as combining plants in intercropping arrangements, crops and trees in agroforestry systems, animals and trees in silvopastoral systems, using legumes as cover crops or in rotations, etc. A community of organisms in an agroecosystem becomes more complex when a larger number of different kinds of plants are included, leading to more interactions among associated arthropods and microorganisms which are part of above and below ground food webs. As diversity increases, so do opportunities for coexistence and beneficial interactions between species benefitting agroecosystem sustainability [60]. Diverse systems encourage complex food webs, which entail more potential connections among plants, insects and microbes, creating alternative paths for energy and material flow. For this reason, a more complex community exhibits less fluctuation in the numbers of undesirable organisms and a more stable production [61]. By enhancing functional biodiversity, a major goal of the conversion process is achieved: strengthening the weak ecological functions in the agro-ecosystem, allowing farmers to gradually eliminate inputs altogether by relying instead on ecosystem functions [60].

The integrity of an agroecosystem undergoing conversion relies on synergies between plant diversity and the soil microbial community, to optimize organic matter decomposition and turnover. Soils with high organic matter and rich biological activity exhibit complex food webs populated by beneficial microorganisms that prevent pathogen infection and insect pest incidence [58]. It may be argued that diversified agroecosystems whose nutrient cycling is mediated by the soil food web possess greater ecological stability, as well as resilience to external perturbation [50]. Management should therefore be oriented to enhance the ability of a crop plants to resist insect pests and diseases by manipulating the biological properties of soils complemented by a vegetational infrastructure that harbors natural enemies of pests as well as pollinators [1]. Enhancing below-ground and above-ground positive ecological interactions through integration of soil and pest management practices constitutes a robust and sustainable path for optimizing agroecosystem function and productivity.

Basing the conversion process on particular practices tends to address components in isolation, focusing on the optimization of one component (soil fertility, plant nutrition, crop growth, etc.) failing to exploit the properties that emerge through the interaction of the various farm components. Input substitution thus becomes primarily reactive, shifting efforts to solving problems as they arise, ameliorating symptoms rather than addressing root causes. Agroecologists regard pest problems or nutrient deficiencies as a symptom of a failure of an ecological process (biological control or nutrient cycling) and thus endeavor to find out the root causes of such unbalance. Instead of focusing on one particular component of the agroecosystem, Agroecology emphasizes the interrelatedness of all agroecosystem components and the complex dynamics of ecological processes. Thus Agroecology is an alternative approach that transcends the use of alternative inputs to develop integrated agroecosystems that do not depend on external, off-farm inputs. The emphasis is on the design of complex agroecosystems in which synergisms between biological components replace inputs by promoting processes that through proper management allow farmers to naturally sponsor the soil fertility, productivity, and crop protection of their farming systems [7,13].

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