

# Can Biodiversity Improve Soil Fertility Resilience in Agroecosystems?

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## Introduction

Agricultural intensification has led to a widespread decline in agricultural biodiversity measured across many different levels, from a reduction in the number of crop and livestock varieties, to decreasing soil community diversity, to the local extinction of a number of natural enemy species. Monocultural agroecosystems typically display low resilience to perturbations such as drought, flooding, pest outbreaks, and invasive species and to uncertainties related to market fluctuations. These simplified intensive systems are also characterized by a loss of soil fertility, called soil sickness, which determines root dystrophy and specific replant diseases and finally precludes the continuous return of the same species in the same field (Zuconni, 2003). Large inputs of energy are then needed in the form of fertilizers, pesticides, herbicides, and irrigation. Agroecosystems typically are subjected to cyclical perturbations of variable intensity as a consequence of agricultural practices and to unpredictable events such as pest outbreaks and drought. However, the relationship between diversity and ecosystem function might change in a fluctuating environment.

There is a general agreement that a major role of biodiversity in relation to ecosystem services is insurance against environmental change (e.g., Holling, et al. 1995). A higher number of functionally similar species ensures that when environmental conditions have turned against the dominant species, other species can readily substitute for their functions, thereby maintaining the stability of the ecosystem (Yachi and Loreau, 1999) and enhancing ecosystem reliability (i.e., the probability that a system will provide a consistent level of per-

## Abstract

*The search for self-sustaining, low-input, diversified, and energy-efficient agricultural systems is now a major concern of many researchers, farmers, and policymakers worldwide. A key strategy in sustainable agriculture is to restore functional biodiversity of the agricultural landscape. Biodiversity performs key ecological services and if correctly assembled in time and space can lead to agroecosystems capable of sponsoring their own soil fertility, crop protection and productivity.*

*There is consensus that at least some minimum number of species is essential for ecosystem functioning under constant conditions and that a larger number of species is probably essential for maintaining the stability of ecosystem processes in changing environments. Determining which species have a significant impact on which processes in which ecosystems, however, remains an open empirical question.*

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formance over a given unit of time) (Naeem and Li, 1997). For example, diversity of pollinators is essential to food production systems, not only because pollen limitation to seed and fruit set is widespread but, most importantly, in the face of the ongoing trends of pollinator disruptions (Cane and Tepedino, 2001). Kremen et al. (2002) found that a diversity of pollinators was a de-

terminant for sustaining pollination services in conventional (versus organic) farms in California because of annual variation in composition of the pollinator community. Redundancy in soil microbial communities seems to be very common and crucial in maintaining soil resilience to perturbations. For example, experimental reductions of soil biodiversity through fumigation techniques show that soils with the highest biodiversity are more resistant to stress than soils with impaired biodiversity (Griffiths, et al. 2003).

Agrobiodiversity also serves as a capital in supporting agricultural sustainability by: (i) producing more and better quality food and fibre for a growing human population, (ii) protecting the natural resource based upon which agriculture as a cultural and economic sector depends and ultimately (iii) promoting social well-being of farming communities and society as a whole. Ecosystem services from agrobiodiversity, such as production of food and fibre are relatively well-understood, while other services are more difficult to identify and quantify, such as clean water, soil fertility, timber, habitat for fisheries, pest control, pollination and aesthetic values it is of great importance to develop adequate information and knowledge on these services, so that interest is encouraged rather than lost ([www.diversitas-international.org](http://www.diversitas-international.org)).

The main strategy in agroecology is to exploit the complementarities and synergisms that result from various combinations of crops, trees and animals in spatial and temporal arrangements such as polycultures, crop rotation, intercropping, agroforestry systems and crop-livestock mixtures. Throughout the world agroecologists should encourage those

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agricultural practices which increase the abundance and diversity of above and below-ground organisms, which in turn provide key ecological services to agroecosystems.

Farmers may avoid intensification and invest in agrobiodiversity utilization and conservation in heterogeneous environments, as shown for landraces of maize that are maintained in the mountains of Chiapas, Mexico (Brush and Perales, 2007). In contrast, in landscapes with less environmental and cultural heterogeneity, farmers usually disinvest in agrobiodiversity as an asset due to the lack of incentives offered by markets and other institutions at both local and larger scales, especially when synthetic inputs are available as low cost alternatives (Pascual and Perrings, 2007).

## Biodiversity and soil fertility

Biodiversity may also play a role in preserving fertile soils by reducing the losses of soil to erosion by wind and rain. By removing the most fertile topsoil which forms at a rate of few centimetres per century, erosion reduces productivity. Especially on slopes, vegetation cover, plant litter and root systems can greatly reduce the risk of erosion by trapping sediment and enhancing infiltration. While in principle vegetation cover can reduce erosion problems irrespective of its diversity, a multi-species assemblage is more likely to provide year-round cover, because the timing of litterfall and rates of disappearance will vary by species (Swift et al., 2004).

Recent years have shown increasing interest in the development of productive farming systems with a high efficiency of internal resource use and thus lower input requirement and cost. In this context, the importance of soil biota for the improvement of soil fertility and land productivity through biological processes becomes a key component of a strategy towards agricultural sustainability (Swift et al., 2004).

Soil organisms perform a number of vital functions (Paoletti et al., 1994): decomposing litter and cycling nutrients, converting atmospheric nitrogen into organic forms, and reconvertng the nitrogen contained in organic residues to soluble forms and gaseous nitrogen, suppressing soil-borne pathogens through antagonism, synthesizing enzymes, vitamins, hormones, vital chelators and allelochemicals that regulate populations and processes, altering soil structure, directly interacting with plants through mutualism, commensalisms, competition, and pathogenesis. From an agronomical point of view, the processes of decomposition, immobilisation and mineralization liberate nutrient elements according to plant growth, but the synchronization is not always matched with the cultivated plant needs. Thus, losses by leaching are limited as plants absorb necessary elements, but crop control can be improved by appropriate external nutrient inputs.

The soil not only houses a large proportion of the Earth's biodiversity but also provides the physical substrate for most human activities. Although soils have been widely studied and classified in terms of physical and chemical characteristics, knowledge of soil biodiversity and function is far from complete (Swift and Anderson, 1993; Swift et al., 2004). This knowledge gap is partly due to the limited recognition that soil biota plays a key role in determining the physical and chemical properties as

well as productivity of soils, and partly due to the huge diversity of soil organisms and the difficulties faced for their identification and for the study of their direct linkages to soil function. A healthy soil community has a diverse food web that keeps pests and diseases under control through competition, predation, and parasitism. There is a strong relationship between soil biota, soil fertility and plant health (Altieri, 1994).

The loss of a stratified soil microhabitat due to physical disturbance of the soil caused by tillage and residue management causes a decrease in the density of species that inhabit agroecosystems. Such soil biodiversity reductions are negative because the recycling of nutrients and proper balance between organic matter, soil organisms and plant diversity are necessary components of a productive and ecologically balanced soil environment. Soil biomass consists of microbes (fungi, bacteria and actinomycetes) and animals such as nematodes, mites, collembola, diplopoda, earthworms and arthropods. A square meter of an organic temperate agricultural soil may contain 1000 species of organisms with population densities in the order of  $10^6/m^2$  for nematodes,  $10^5/m^2$  for micro arthropods and  $10^4/m^2$  for other invertebrate groups. Energy, carbon, nitrogen and other nutrient fluxes through the soil decomposing subsystem are dominated by fungi and bacteria, although invertebrates play a certain role in N flux (Swift and Anderson, 1993).

Losing functionally redundant soil organisms may alter a soil's ability to resist and recover from stress. Early studies of biodiversity and stability have produced evidence that diversity enhances a system's ability to provide consistent levels of performance, and reduces its temporal and spatial variation (McGrady-Steed et al., 1997; Naeem and Li, 1997). The importance of biodiversity for the stability of soil processes has been investigated by Griffiths et al. (2003). The first study provided some support for the notion that diversity contributes to stability: they observed that in those soils where biodiversity had previously been reduced soil processes were less stable in the face of different types of perturbation. These findings, however, may have been driven by the technique that was used in order to reduce soil biodiversity. Indeed, their follow-up study, in which soil communities were altered using a more neutral methodology, observed no direct effects of diversity on the variability of the processes. However, even though individual studies might have overstated the importance of biodiversity for stability due to the effects of confounding variables (Hooper et al., 2005), the general consensus appears to be that soil diversity is important for resilience to stress and disturbance.

Loss of nutrients applied to agricultural soils causes environmental harm. Off-site problems caused by over-application of nutrients are better recognized than are problems caused on-site. Excess nutrients can also increase plant susceptibility to pathogens and arthropod pests and can also lead to increased weed competition (Wander, 2010).

## Species richness and ecosystem functioning

There has been substantial debate over both the form of the relationship between species richness and ecosystem processes and the mechanisms underlying these relationships (Johnson et

al., 1996). Theoretically, rates of ecosystem processes might increase linearly with species richness if all species contribute substantially and in unique ways to a given process—that is, have complementary niches. This relationship is likely to saturate as niche overlap, or ‘redundancy’, increases at higher levels of diversity (Vitousek and Hooper, 1993). Several experiments indicate such an asymptotic relationship of ecosystem process rates with species richness. An asymptotic relationship between richness and process rates could, however, arise from a ‘sampling effect’ of increased probability of including a species with strong ecosystem effects, as species richness increases (Hooper and Vitousek, 1997).

The sampling effect has at least two interpretations. It might be an important biological property of communities that influences process rates in natural ecosystems (Hooper and Vitousek, 1997), or it might be an artefact of species-richness experiments in which species are randomly assigned to treatments, rather than following community assembly rules that might occur in nature (Huston, 1997).

Finally, ecosystem process rates may show no simple correlation with species richness. However, the lack of a simple statistical relationship between species richness and an ecosystem process may mask important functional relationships. This could occur, for example, if process rates depend strongly on the traits of certain species or if species interactions determine the species traits that are expressed (the ‘idiosyncratic hypothesis’) (Lawton, 1994).

This mechanistic debate is important scientifically for understanding the functioning of ecosystems and effective management of their biotic resources. Regardless of the outcome of the debate, conserving biodiversity is essential because we rarely know *a priori* which species are critical to current functioning or provide resilience and resistance to environmental changes.

Evaluations of diversity have more often than not been assessments of the value of biological resources as such rather than assessments of the value of diversity *per se* (Nunes and van der Bergh, 2001). For instance, if the interest lies in the functional roles of the community these may depend on the ‘structure’ of the vegetation and the relationships between different ‘functional groups’, rather than on diversity as such (Woodward, 1993). In the case of agroecosystems, whilst the dominant crops or livestock are human choices, by far the majority of the species (as soon as one takes the below-ground part of the system into consideration) are self-selected. So, are we asking the right question about the relations between biodiversity and ecosystem services? (Swift et al., 2004).

Apart from *intrinsic* (sometimes called ‘non-use’), *utilitarian* (also called direct use, contributory, primary or infrastructure) and *serendipitous* (‘option’ or bequest) values, biodiversity also contributes to ecosystem life support functions and the preservation of ecological structure and integrity. We refer to these functions as the *functional* value of diversity. This category of value has only been relatively recently recognised in the economic literature as an important category *per se* which overlaps partially with concepts such as that of ‘indirect use’

value (Kerry-Turner, 1999). Part of this functional significance may result in direct utilitarian value for *Homo sapiens* in the production of goods and services that can be priced. Beyond this lie a range of ecosystem services that are of acknowledged benefit to humans but which generally lie outside the boundaries of recognised direct utilitarian benefit.

As explored in the theory of island biogeography, the diversity within any ecosystem at any point in time is the result of a ‘self-selection’ process that involves co-evolution of the species comprising the biological community within a given ecosystem by interactions among them and with the abiotic environment through time. This is not an isolated process. New species may enter an ecosystem from neighbouring areas, some establishing themselves and others failing to do so. Partly as a result of successful newcomers or new adaptations emerging in existing ones (be they competitors, predators, pests or diseases) and partly as a result of fluctuations in abiotic environmental conditions, some of the existing species may become (locally) extinct over any period of time. The species richness of any given ecosystem or land unit is therefore a dynamic property. In agroecosystems, farmers take a dominant role in this dynamic by the selection of which organisms are present, by modifying the abiotic environment and by interventions aimed at regulating the populations of specific organisms (‘weeds’, ‘pests’, ‘diseases’ and their vectors, alternate hosts and antagonists). The dynamic nature of the (local, patch level) diversity of any system, whether natural or agricultural, is often underrated, as is the importance of the selection pressure and process.

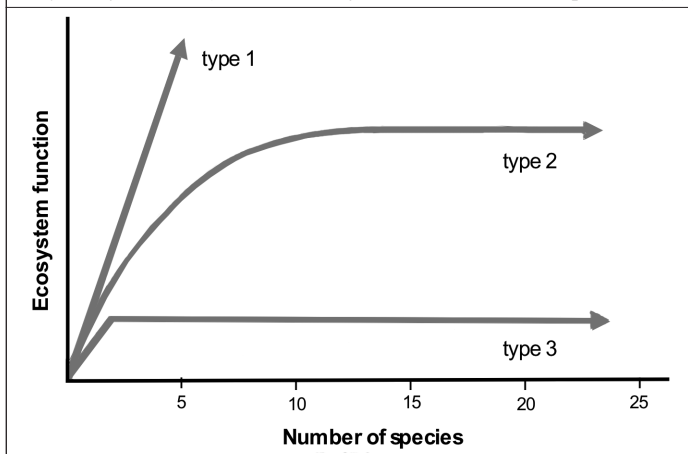
Vitousek and Hooper (1993) hypothesized three different possible relationships between plant diversity and broad-based ecosystem functions such as the rate of primary production which led them to propose that the asymptotic relationship shown as Curve 2 in Fig. 1 was the correct one. This suggests that whilst the essential functions of an ecosystem, such as primary production, require a minimal level of diversity to maximize efficiency this effect is saturated at a relatively low number. Swift and Anderson (1993) proposed that this relationship could also apply to the decomposer system.

During agricultural intensification the diversity of crops and livestock is reduced to one or a very few species of usually genetically homogenous species. The varieties are selected or bred for yield (e.g. high plant harvest index), taste and nutritional quality. Plant arrangement is commonly in rows, fallow periods are bare, sequences may be monospecific (varietal) or of two or rarely more species. This is in contrast to natural ecosystems where the genetic diversity of plants (both within and among functional groups) is high but varies in relation to environment.

## Natural and Agricultural ecosystems

Natural ecosystems are mostly large areas that are perceived as a rather homogeneous matrix, consisting of various micro-habitats with different species associated but still clearly part of the same system. Instead, agroecosystems

Figure 1 - Possible relationships between number of species and ecosystem functions (re-elaborated from Vitousek and Hooper, 1993).



consist of three intermingled and strongly interacting sub-systems: the managed fields, referred to as the productive sub-system, the semi-natural or natural habitats surrounding them and the human sub-system composed of settlements and infrastructures. Biodiversity conservation is mostly focused on the semi-natural subsystem. Human settlements and infrastructures are rarely considered for their biodiversity, and their impact on biodiversity in the surrounding natural, semi-natural or productive areas is generally ignored. The productive sub-system instead, is often perceived to have a negative impact on biodiversity in the surrounding areas (Moonen and Barberi, 2008). Secondly, agroecosystems exist by the grace of humankind and are managed with a clear scope: to produce food, feed, goods such as timber, fibres and other natural products for own use and/or for the market. Analogously to a natural ecosystem, any benefit humankind derives from an agroecosystem is referred to as an 'ecosystem service'.

Diversity of agroecosystems in a same territory is like having an 'insurance' for income production on at least part of the territory in case changing environmental or political (socio-economic) conditions are unfavourable for some production systems. In agroecosystems, on the other hand, communities are not mainly formed by processes of natural competition and dispersal because agricultural management heavily interferes with the nature and intensity of these processes and introduces new, exotic species to the community which can out-compete local species. The agroecosystem services for production provided by the functional groups can be divided into soil-related processes (e.g. increased nutrient cycling, decomposition rate, aggregate stability, organic matter formation and water regulation, allelopathic interaction), food web services, gene flow and the direct crop production service. The crop production service is strictly speaking the result of increased soil related processes, food web services and gene flow.

The study of biodiversity in relation to agroecosystem functioning is only useful when it is linked to the role that clusters of functionally similar elements and/or their state of

diversity play in ecosystem functioning (Loreau, 2000; Bengtsson, 1998), when the spatial (Gurr et al., 2003; Yamamura, 2006) and temporal (Davidson and Grieve, 2006) scales of the interactions are clearly defined and taken into account (Symstad et al., 2003) and when aspects of ecosystem resilience and stability and/or of the processes (fluxes of material, energy and nutrients) are taken into account (Srivastava and Vellend, 2005).

No direct link was found between soil resilience and microbial diversity, but there remains the possibility that reduced diversity leads to reduced functions, such as with the insurgence of soil sickness due to the repeated replant of the same species, and that both the intensity and temporal length of a stress will have effects. Is there some stress threshold beyond which a soil's functions will be irretrievably impaired? Are there particular 'key-stone' species which perform unique functions and which, if killed, will irreversibly damage the soil? If the answer to these questions is 'yes', then the conservation of the richness of the soil's biota is essential for the sustainable use of soils (Usher, 2005).

## Biodiversity in the agricultural landscape and its ecological functions

The insurance hypothesis of biodiversity, i.e., that higher numbers of species increase resilience and reorganization after disturbance, may be most relevant at the landscape level (Swift et al., 2004). Agricultural landscapes that are composed of a mosaic of well-connected early and late successional habitats may also be more likely to harbour biota that contribute to regulating and supporting services for agriculture, compared to simple landscapes (Bengtsson et al., 2003; Swift et al., 2004).

The potential for biodiversity to provide ecological resilience, i.e., the capacity to recover from disruption of functions, and the mitigation of risks caused by disturbance (Swift et al., 2004) is compelling, but poorly documented. The functional significance of biodiversity is likely to be most profound at larger spatial and temporal scales, by providing insurance value, especially when dispersal abilities of organisms allow for immigration within the landscape. This would also imply that the 'realized niche' of organisms may shift, such that they occupy greater or different habitats within the landscape. The insurance hypothesis proposes that species or phenotypes that appear to be functionally redundant for a specific ecosystem process at a given time may actually diverge in response to environmental fluctuations, thereby stabilizing the aggregate ecosystem function through time. On the short-term, this may essentially be an expansion of the 'realized niche' through genotype-environment interactions, but selection for plasticity could be a likely evolutionary outcome if environmental fluctuations become the norm. Heterogeneous composition of ecosystems in agricultural landscapes may thus provide insurance value that is not detected by the local-scale experiments that are typical of most agricultural research. While some theoretical analysis of the economic relevance of the insurance value exist (e.g.,

Folke et al., 1996; Perrings, 1998;), there are few empirical studies of the insurance value of agrobiodiversity (e.g., Di Falco and Perrings, 2005).

By maintaining landscape mosaics composed of different sets of ecosystems, the potential for resilience from biodiversity is expected to increase. Given that agricultural landscapes are prone to disturbance, succession can be more rapid when some indigenous plants remain, seed banks exist, and/or neighbouring intact biodiversity-rich vegetation still serves as a source of dispersing organisms (Lamb et al., 2005).

The general trend towards further intensification based on uniformity and the increased use of external inputs raises real questions as to how agrobiodiversity can realistically be utilized to achieve similar or higher yields, support human livelihoods, and reverse the trend toward lower environmental quality. In other words, what research is necessary to determine where and how agrobiodiversity can make positive contributions to productivity, sustainability, and resilience of human livelihoods? One example is the use of diverse traditional varieties of crops. It has been suggested *inter alia* that traditional varieties provide yield stability, are resistant to biotic and abiotic stress, have good resilience, and are adapted to low input agriculture. Hence, they constitute a key component of the natural resources assets of the rural poor in many parts of the world (Altieri and Merrick, 1997).

## Relationship between biodiversity and soil resilience

Examining diversity-function relationships under stable or equilibrium conditions will not tell us very much. Under such conditions it is likely that a small number of key species have considerable effects on ecosystem functions. The crucial question is whether more diverse ecosystems are more resistant or resilient when environmental conditions change (Folke et al., 1996). Hence Tilman and Downing (1994) asked the right question, although they did not use a good system to test it (as is evident when reading Tilman et al., 1996). In the context of a changing global climate and other large-scale environmental perturbations, the important questions pertain to whether the resistance or resilience of ecosystem processes, or other aspects of ecosystem function, depend on diversity. However, this imposes some difficulties for the whole enterprise of relating diversity to ecosystem function. It is impossible to know what changes in climate or what large-scale perturbations that natural and managed ecosystems will experience in the future. Hence it is difficult to predict which species will be of importance in the future. This was elegantly shown in a 10-year experiment on lake acidification (Frost et al., 1995). Secondary production remained fairly constant as pH dropped from 6.1 to 4.7, but zooplankton species composition changed dramatically. It was not possible to predict the few dominant species under acidified conditions from knowledge about the initial conditions when these species were rare.

This crucial question of resilience and diversity should be given the highest priority. Field experiments are highly de-

sirable whenever they are possible to carry out, but in many cases controlled manipulations of diversity and perturbations of the system will have to be performed in the laboratory. Both soil microcosms and larger climate chambers would be appropriate. Problems with manipulating diversity have been discussed above, and can be avoided. Choosing perturbation is probably a matter of taste, although it is likely that different perturbations, such as freezing (Allen-Morley and Coleman, 1989), drying, heating, or application of pesticides or heavy metals, will yield different results when measuring resistance and resilience. The ideal experiment would be using the same soil system, crossing functional diversity and species richness with several perturbation treatments, and examining the effects at both the community and ecosystem levels.

Bengtsson (1998) concluded that diversity does not play a role for ecosystem function, and there is no reason to expect that it does. Species may be important for ecosystem function, but diversity is an abstract aggregated property of species in the context of communities or ecosystems—there is no mechanistic relationship between diversity and ecosystem function, but through the species and functional groups whose interactions provide most of the mechanisms for ecosystem functions. One single number—species richness, a diversity index, the number of functional groups, or connection may not be able to capture the complex relationships and interactions between many species and the functions performed by these interactions.

A focus on functional groups and species such as keystone species or ecosystem engineers (earthworms and termites) is probably the most efficient way of providing more mechanistic explanations (at the community, population and individual levels) of ecosystem processes and stability.

A sustainable management of ecosystems will require knowledge of the effects that key species have in ecosystems, i.e. mechanistic explanations of ecosystem processes, not non-mechanistic correlations between diversity and ecosystem processes.

Theoretical predictions concerning the effects of species or functional groups on process rates may be possible, and can be tested empirically. This seems unlikely in the case of diversity. A tentative to include biodiversity for predicting the stability of an agroecosystem was carried out by Zuconi (2003). The question was: when organic residues degradation may undergo through humification? In temperate climatic zones the increase of soil fertility is related to the accumulation of humified organic matter. The consequent creation of vegetal soil (Zuconi, 2003) is the main way to expand the biomass production per unit of acreage. Nature does this process efficiently by humification of organic matter but in agriculture this process is completely neglected, thus impoverishing soil quality. Humification processes are more important in temperate climates and less in tropical ones, even though it may be discussed for these climates as well.

Humus is able to modify chemical (cation exchange capacity, water holding capacity), physical (structure, porosity), biological (diversified microbial life), and allelopathic (organic

residues evolution) soil property. The humification process and the crop residues action on saprophytic growth are also the key to understand natural suppressiveness of the soil pests (Zuconni, 2003) and the disease incidence of soil borne plant diseases (Bonanomi et al., 2006).

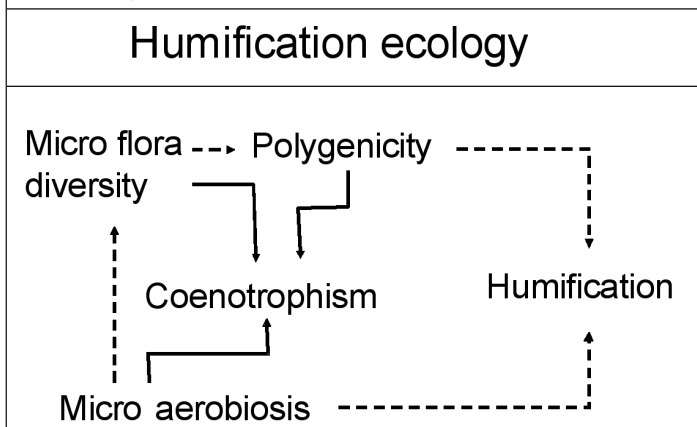
The accumulation of residues from a sole crop disrupts the humification process, inducing odd decompositions that delay stabilization and release toxic metabolites (Giorgi et al 2008, 2010). These, in turn, may induce specific allelopathic effects (dispathy) accounting for ‘soil sickness’ (Neri et al., 2005; Zuconni, 2003; Giorgi et al., 2007), an event recorded in rice too (Neri et al., 1996). Root absorption, in particular, may be hindered by these toxins (Zuconni, 2003) ensuing dystrophies and root die-back.

Humification is a direct result of processes which may happen only in the presence of some factors and conditions (effectors, figure 2). It needs polygenicity (a substrate with very diverse origins), diverse populations of microorganisms, and microaerobic conditions. All together these conditions determine coenotrophism (to have nutrition functions in a group of individuals).

When coenotrophic conditions are set it is possible to create humic compounds with a great efficiency (low carbon loss). The process starts from degradation, but with low production of soluble molecules, and very rapidly goes through polymerisation and polycondensation to create more complex structures.

The creation of humic compounds is very important to enrich the soil of stable (lasting up to 100 years) organic matter with colloid properties, so to improve physical-chemical, biological and allelopathic characteristics.

Figure 2 - Humification requires a diversified microflora and polygenicity of the substrates in presence of microaerobic conditions (re-elaborated from Zuconni 2003).



## Biodiversity as Insurance

Even when high diversity is not critical for maintaining ecosystem processes under constant or benign environmental conditions, it might nevertheless be important for maintaining them under changing conditions. The insurance hypothesis (Yachi and Loreau, 1999) and related hypotheses (Doak Tilman, 1999; Ives et al., 2000) propose that biodiversity pro-

vides an “insurance” or a buffer, against environmental fluctuations, because different species respond differently to these fluctuations, leading to more predictable aggregate community or ecosystem properties. In this hypothesis, species that are functionally redundant for an ecosystem process at a given time are no longer redundant through time. In a way, this is the old stability-versus complexity debate resurfacing in a new form (McCann, 2000). Several problems, however, have confused this historical controversy: (i) The general concept of “stability” actually covers a wide array of different properties (Pimm, 1984); (ii) the relationship between these properties and diversity may change across ecological levels of organization such that large variability at the population level may not imply large variability of ecosystem processes (Tilman, 1999 and Pimm, 1984); and (iii) stability has been approached mainly within a deterministic, equilibrium theoretical framework. Recent theoretical work has attempted to remove these obstacles and has provided support for the insurance hypothesis. As diversity increases, the variability of individual populations may increase as a result of the destabilizing influence of strong species interactions internal to the system, but the variability of aggregate ecosystem properties often decreases because of the stabilizing influence of asynchronous species responses to intrinsic or extrinsic environmental fluctuations (Yachi and Loreau, 1999). What remains unclear, however, is whether this stabilizing effect saturates at low or high diversity, which depends on model conditions (Schwartz, et al., 2000; Yachi and Loreau, 1999; Tilman, 1999). Whereas experimental work has played a leading role regarding short-term effects of biodiversity on ecosystem functioning, theory has been prominent in the diversity stability debate, both historically and recently. A number of empirical and experimental studies have shown decreased variability of ecosystem processes as diversity increases. These studies, however, have been based either on diversity gradients established naturally or after other treatments (Tilman, 1999), or on microcosm experiments in which variability among replicates was also considered (McGrady-Steed, et al., 1997 and Naeem and Li, 1997), which does not fully preclude alternative interpretations (Huston, 1997). Experiments in which both diversity and environmental fluctuations are controlled are now needed to perform rigorous tests of the insurance hypothesis. Theory too should evolve to provide better guidance for experiments. Most of the classical equilibrium approaches may be inadequate to understand stability properties such as resilience and resistance at the ecosystem level. New approaches should be developed that take into account the dynamics of diversity and the potential for adaptation through phenotypic plasticity, evolutionary changes, and species replacement.

## Conclusion

Conservation of wild biodiversity (genes, species and ecosystems) is considered by many to be an ethical imperative. At the same time, conservation also supports ‘ecosystem services’—ecological processes and functions that sustain and improve human wellbeing. The conservation community is

moving towards an 'ecosystem approach' to conserving biodiversity, in light of the dependence of protected areas on a supportive matrix of land and water use, and creation of biological corridors (Convention on Biological Diversity, 2000).

The search for self-sustaining, low-input, diversified, and energy-efficient agricultural systems is now a major concern of many researchers, farmers, and policymakers worldwide. A key strategy in sustainable agriculture is to restore functional biodiversity of the agricultural landscape (Altieri, 1994). Biodiversity performs key ecological services and if correctly assembled in time and space can lead to agroecosystems capable of sponsoring their own soil fertility, crop protection and productivity.

There is consensus that at least some minimum number of species is essential for ecosystem functioning under constant conditions and that a larger number of species is probably essential for maintaining the stability of ecosystem processes in changing environments. Determining which species have a significant impact on which processes in which ecosystems, however, remains an open empirical question.

### Does diversity is of less importance?

The answer is certainly *NOT* because the main importance of diversity is not that it in itself has a function in ecosystems, but that high diversity implies that there is a source of new species performing functions or ecosystem services as human needs or environmental conditions change (Frost et al., 1995; Folke et al., 1996). Although it is possible to regard this provision of 'natural insurance capital' (Folke et al., 1996) as a functional role of diversity, such an argument lacks scientific content unless diversity is linked to what species do in ecosystems.

It is also difficult to affirm which species is needed for the ecosystem functioning as environmental conditions changes. But even if we could predict this, it would be arrogant to expect that we can predict all future environmental conditions. Hence, preserving biodiversity as an insurance is a matter of caring for the future, in addition to the present. Finally, a certain amount of biodiversity is necessary to obtain a sustainable crop production, to avoid soil sickness and to prevent soil decline, enhancing the natural suppressiveness against pest and diseases.

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