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Bibliographic review

Weeds as a microbiological soil indicator

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ABSTRACT

In the tropical zone, weed populations are generally high in crops, and yield losses can be irreversible if a set of measures for their timely management is not established, since they considerably increase the diversity of agricultural systems. The uptake of nutrients from the soil is fundamentally given by root growth and its interaction with the biotic and abiotic components of the soil, for which issues such as microbial biodiversity and its effect on soil quality are fundamental; that is why the importance of microorganisms in the rhizosphere of plants that facilitate the promotion of plant growth and its biotechnological use, as an alternative to promote the sustainability and quality of soils. The objective of this work was to analyze issues related to weeds, as microbiological indicators of the soil, as well as their importance in agroecosystems and their impact on agriculture.

Key words: microorganisms, rhizosphere, biodiversity and agroecosystem

INTRODUCTION

Weeds, in the agronomic sense, represent plants with no economic value or that grow out of place, interfering in the activity of crops, affecting their production capacity and normal development due to competition for water, light, nutrients and physical space or due to the production of substances that are harmful to the crop (1-3). In the tropical zone, weed populations are generally high in crops and if a set of measures for their timely management is not established, yield losses can be irreversible. Such adversities occur if weeds grow alongside economic crops (4,5).

This indicates that weeds represent one of the severe problems of world agriculture, since their invasive action facilitates their competition with crops, at the same time that they can behave as hosts of plagues and diseases. In Cuba, weed populations are generally high in crops and if a set of measures for their management is not established, they can cause great losses [(3)].

Nowadays it is considered that the presence of different weed species, within crops, has a deep impact on the composition and interactions of the crop entomofauna, to such an extent that predators and parasitoids are more effective in complex habitats; besides, beneficial insects have greater possibilities of finding alternative prey, shelter, reproduction sites and refuges for dormancy [(3,6)].

Soil microbial populations are immersed in a framework of interaction that affects plant development and soil quality. They are involved in fundamental activities that ensure the stability and productivity of both agroecosystems and natural ecosystems [(7)].

The microbial activity of the rhizosphere is largely responsible for the functioning of the ecosystem and the fertility of agricultural soils. Among the beneficial soil microorganisms, both arbuscular mycorrhizal fungi (AMF) and growth-promoting rhizospheric bacteria (GPRB), key constituents of the rhizosphere zone, contribute to improving plant development and nutrition, as well as increasing crop tolerance to certain biotic or abiotic stresses. The integration of these microorganisms in the systems guarantees sustainability, contributing to optimizing soil quality and health, limiting nutrient inputs and increasing yields [(8)].

On the other hand, the functions of weeds as improvers of host soils and multipliers of microfauna are aspects that have been little addressed in the international literature. In preliminary research on the subject, some authors suggest that there is a space of opportunity to develop research that explains the importance of weeds, due to their balancing presence in tropical agroecosystems [(5)]. Therefore, the objective of this work was to analyze issues related to weeds as soil microbiological indicators, as well as their importance in agroecosystems and their impact on agriculture.

Agroecosystems. Definition

In order to provide an answer to the serious environmental and socioeconomic problem caused by the indiscriminate use of pesticides, agroecology assumes, as its objective, the knowledge of the key elements and processes that regulate the functioning of agroecosystems and establishes the scientific basis for an effective management in harmony with the environment [(9)].

The agroecosystem is defined as an ecological system that has one or more populations of agricultural utility and the environment with which it interacts. The population is the basic unit for the study of the ecosystem and to understand how weeds function, it is necessary to know some essential facts about their structure (distribution of individuals by functional states) and their dynamic status (births, deaths, reproduction) [(3,10)].

On the other hand, it is defined as an ecological system that has one or more populations of agricultural utility and the environment with which it interacts [(10)]. The community of weeds present in a crop are only a part of a higher system: the agroecosystem, which is formed by very diverse components (crops, weeds, insects, microorganisms, soil, and climate) that are intimately related to each other and act as a unit [(11)].

Biodiversity in agroecosystems

Agroecology is a science that provides standards for understanding the nature of agroecosystems and their functioning; it also provides basic ecological principles for the study, design and management of agroecosystems that are, at the same time, culturally sensitive, socially just and economically viable [(5,12)].
The basic principles of agroecology include: recycling of nutrients and energy, substitution of external inputs; improvement of organic matter and soil biological activity; diversification of plant species and genetic resources of agroecosystems in time and space; integration of crops with livestock, through the use of rotational systems and optimization of interactions and productivity of the agricultural system as a whole, rather than isolated yields of different species [(5,13)].
An agroecosystem must have around 150 agricultural species to be considered of good diversity. The more diverse the productive systems are, the more complex and stable they are; the more biological components there are in the systems, the greater the self-regulation mechanisms, and the greater the self-regulation mechanisms, the greater the balance of the systems [(14-16)].
One of the basic principles of agroecology is biodiversity, within which weeds play a balancing and determining role for the good functioning of the agroecosystem [(5)].

Weeds in agriculture

A weed is any plant found in an inappropriate place, which by itself can be, in other situations, very valuable; that is, useful in certain conditions and undesirable at other times [(17)].
Weeds are considered to be all superior plants that, by growing next to or on cultivated plants, disturb or impede their normal development, make the crop more expensive and reduce its yields or quality [(3)].
In general, the species currently considered as weeds have led farmers to the permanent destruction of herbaceous and shrubby flora indiscriminately, without measuring benefits and consequences, since it is true that they increase management costs, hinder and delay agricultural work, are hosts of pests, reduce crop yields and reduce quality [(4)], reduce crop yields and product quality [(3)], but with their adequate management, they also protect soils against erosion, regulate runoff water, conserve genetic biodiversity and reduce weeding costs by up to 85 % [(18)].

In the last 40 years, weeds have been strongly combated as a strategy to intensify food production of different crop species in the tropics. As a result of this policy, international literature places them among the main or principal pests of economic crops and, therefore, they have been attacked without contemplation until their eradication by means of dissimilar methods, either by chemical means, manual activity of man, or with mechanical implements such as the powerful "machete", an instrument widely used by tropical farmers [19].

However, weeds seem to play a much more important role in the agroecosystem than is known to date. A proven example is that many of them develop in fallow areas and serve to prevent soil erosion and recycle its nutrients and minerals [3,20]. It has also been claimed that they serve as a reservoir of beneficial organisms for general pest control; therefore, the concept of weeds is relative and anthropocentric, but in no way constitutes an absolute category [3,21].

Weeds are part of a holistic vision and, due to their proven importance in the agroecosystem, they constitute a determining indicator of its sustainability. In this sense, it has almost been forgotten to classify weeds according to their benefits because this would imply accepting them as necessary. Such a proposal would promote acting contrary to the universalized logic, with adverse consequences, linked to censure and isolation [22].

Contribution of weeds to soil fertility

In nature there are no "weeds", but there are "invasive" plants that should be perceived as ecological indicators of great utility to understand the state of the physical, chemical and biological quality of soils, because they enhance the uptake of mineral elements by the plant, improve the physical, chemical and biological properties of the soil, as well as provide growth stimulating substances for plants [5,23].

These plants play an important role in the soil-weed relationship, since, through their ecological-physiological action, they can be shown as indicators of soil properties by different elements, whether phosphorus, potassium, nitrogen or humus.

The cultivated plant spent a lot of energy to establish itself, perhaps due to nutrient deficiency, because the soil was dominated by stoloniferous grasses (which have stems or stolons along the soil surface, roots at the nodes and produce new shoots), such as *Digitarias anguinalis* (L.) M. Scop, which represents a poor physical structure (Table 1) [5,24].

There is a diversity of weeds already reported in the literature capable of indicating soil quality through different parameters (Table 2) [5,25].

Table 1. Diseases. Indicator insects

Crop	Disease or insect that appears	Indicates deficiency of
Phaseolus vulgaris L	*Bemisia tabaci*, Bean Golden Yellow Mosaic Virus (BGYMV)	Calcium
Zea mays L	*Agrotis ípsilon*	Boron
Zea mays L	*Elasmo palpuslignosellus*	Zinc

Source: (17)

Table 2. Indicator plants

Scientific Name	Which indicates
Oxalis oxyptera Progel	Clayey soil, low pH, lack of calcium or molybdenum
Portulaca oleraceae L	Well-structured, moist and OM soil
Echino chloacrus-galli (L) *Beauv*	Anaerobic soil, with nutrients restricted to toxic substances
Carex ssp	Impoverished soil with extremely low calcium level
Amaranthuss sp	Presence of free nitrogen (OM)
Sida ssp	Very compacted soils
Bidens pilosus L	Medium fertility soils
Pteridium aquilinum Kuhn	Excess of toxic aluminum
Cyperus rotundus L	Acidic to thick, poorly drained soils

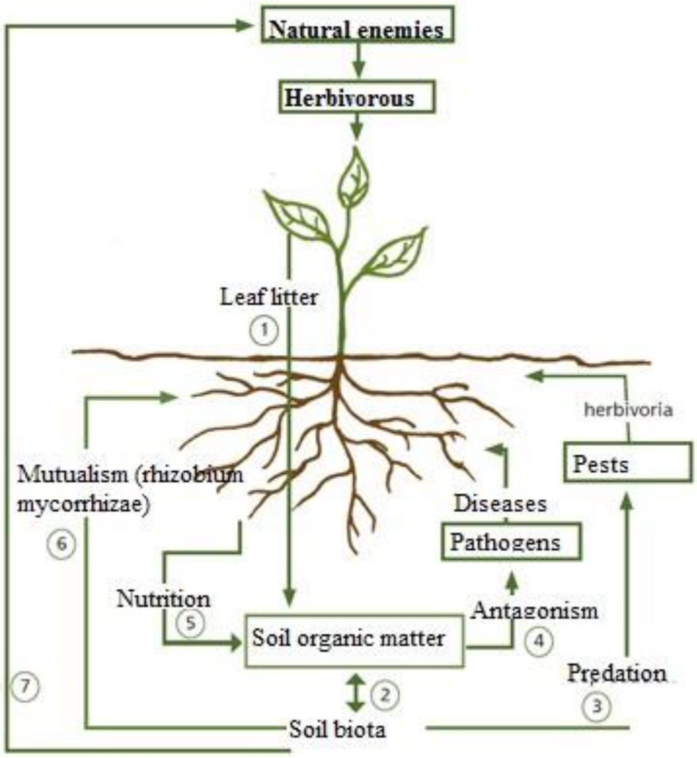
Source: (17)

Contribution to soil balance

Practices to improve soil fertility can directly impact the physiological susceptibility of the crop to insect pests, either by affecting the resistance to attack of individual plants or by altering the acceptability of some plants to certain herbivores (26).

Several investigations show that the ability of a crop to resist or tolerate insect pest attack and disease is linked to the physical, chemical, and particularly biological properties of the soil. Soils with high organic matter content and high biological activity generally exhibit good fertility, as well as complex food webs and abundant beneficial organisms that prevent infection. On the other hand, agricultural practices that cause nutritional imbalances, such as excessive application of synthetic nitrogen fertilizers, lower plant resistance to pests (27).

Plants function in a complex multi-trophic environment, where soil flora and fauna and above-ground organisms (crops, insects, others) generally interact in complex trophic networks, with a series of interactions that can favor or disfavor lower pest incidence (Figure 1).



Source: [5]

(1) Plant residues increase organic matter content (OMC).

(2) OMC provides substrate for soil micro-, meso- and macrofauna

(3) Soil predators reduce soil pests

(4) OMC increases antagonists that suppress soil pathogens

(5) Slow C and N mineralization that activates genes that promote crop tolerance to diseases

(6) Mutualists increase N fixation, P uptake, water use efficiency, others.

(7) Certain invertebrates (coloiboloids and detritivores) serve as alternative food for natural enemies in times of lower pest incidence.

Figure 1. Complex pathways in which aboveground biodiversity interacts in the agroecosystem

Aboveground communities are directly and indirectly affected by interactions with organisms in the soil food web [28].

The feeding activities of decomposers or detritivores (basically bacteria and fungi) in the food web stimulate the movement of nutrients, the addition of nutrients by plants, and the functioning of plants, indirectly influencing insects that feed on crops [23].

Examples of arbaceous plants as hosts of microorganisms in the rhizosphere

The presence of weeds in or around crop fields influences crop dynamics and associated biotic communities. Studies conducted over the last thirty years agree that manipulation of specific weeds are particular weed control practices or a cropping system that can affect the ecology of insect pests and associated natural enemies [5,29].

Weeds offer many important resources to natural enemies, such as alternative prey or hosts, pollen or nectar, as well as microhabitats that are not available in weed-free monocultures [5,30].

The microbial diversity associated with the rhizosphere of weeds is an extremely novel and interesting problem for work related to the application of agroecological principles aimed at management and conservation in agroecosystems, given the high diversity of microorganisms present in the soil and the complexity of their interactions [(5)].

Some authors have carried out studies on different species of weeds, of which five were shown to be the most integral in harboring edaphic diversity (bacteria, fungi and actinomycetes). These were: pata de gallina (*Eleusine indica* (L.)); Licorice weed (*Lepidium virginicum* (L.)); feverfew (*Parthenium hysterophorus* (L.)); gigantona (*Milleri aquinqueflora* (L.)) and yerba de Don Carlos (*Sorghum halepense* (L.) Pers.); while the rest were more selective. Species such as canutillo (*Commelina difusa* Burm.), guizazo (*Cenchru sechinatus* (L.)), estrella africana (*Cynodon plectostachyus* (K.SCHUM.) Pilg.), *Boerhavia* sp. and white rosemary (*Biden spilosa* (L.), only harbored bacteria, the cause could be of genetic origin [(5)].

The differences between the species in their ability to harbor microorganisms are evident. Thus, the weed *C. diffusa* presented higher populations of bacteria and total fungi, compared to *L. virginicum*; therefore, weed species can serve for the microbial reproduction of certain species or to identify their presence in agroecosystems, either for or against productive processes or as a reserve source for research of another nature [(5)] (Table 3).

Tabla 3. Microorganism counts in the rhizosphere of weeds

Weeds	Bacteria		Fungi		Actinomycetes	Total
	Quantity (UFC/g)	Morphotypes	Quantity (UFC/g)	Morphotypes	Quantity (UFC/g)	
B. pilosa	2×10^5	2	-	-	-	2×10^5
Boerhavia sp.	5×10^5	5	-	-	-	5×10^5
C. diffusa	8×10^6	7	5×10^4	4	-	$8{,}0\ 5 \times 10^6$
L. virginicum	2×10^5	1	6×10^4	4	$2{,}4 \times 10^5$	5×10^5
S. halepense	4×10^5	3	2×10^4	2	$1{,}2 \times 10^4$	$4{,}22 \times 10^5$
C. dactylon	-	-	1×10^2	2	$8{,}2 \times 10^4$	$8{,}2 \times 10^4$
M. quimqueflora	5×10^5	2	4×10^4	2	$1{,}7\ 9 \times 10^5$	$7{,}19 \times 10^5$
P. hysterophorus	6×10^5	3	4×10^4	2	$1{,}63 \times 10^5$	$8{,}03 \times 10^5$
E. indica	8×10^5	2	$1{,}1 \times 10^5$	2	$4{,}4 \times 10^5$	$1{,}35 \times 10^6$
P. oleraceae	$1{,}83\times 10^5$	8	1×10^4	1	-	$1{,}93 \times 10^5$
C. plectostachium	$1{,}41 \times 10^6$	7	-	-	-	$1{,}41 \times 10^6$
C. echinatus	$8{,}6 \times 10^4$	5	-	-	-	$8{,}6 \times 10^4$
C. rotundus	$5{,}1 \times 10^5$	3	10^5	1	-	$5{,}11 \times 10^5$
A. mexicana	$2{,}4 \times 10^5$	3	-	-	-	$2{,}4\times 10^5$
A. dubius	5×10^5	2	10^4	1	-	$5{,}1 \times 10^5$

Source: [(5)]

On the other hand, plant exudates can have a decisive influence on rhizosphere population dynamics [5,31]. The effect of plant species diversity on rhizosphere population dynamics may occur because plant species exhibit physiological differences and distinct biochemical compositions, which generate differential root exudates [5,32].

In the case of AMF, they are present in all tropical ecosystems, but their distribution is not homogeneous and there are soils and crops where the natural mycorrhizal potential of AMF is very low to promote plant development [5,33-35]; therefore, recognizing the areas where AMF populations are low and thus evaluating the contribution that could be made by the weeds that inhabit them, could be interesting information for this field of microbiological science.

The percentage of colonization and visual density (the variable that most clearly reflects symbiotic efficiency), according to the AMF distribution residing in the rhizosphere of the 10 species with the greatest ecological plasticity found in the research [5], are shown (Table 4).

Table 4. Distribution of resident AMF in the rhizosphere of different species of weeds

Weeds	Colonization percentage	Visual density
Cynodon dactylon (L.) Pers.	12,25 a	0,14 d
Lepidium virginicum (L.)	8,02 cd	0,31 a
Eleusine indica (L.) Gaertn.	2,00 ef	0,02 f
Chamaesy cehyssopifolia (L.) Small.	6,7 e	0,02 f
Argemone mexicana (L.)	1,22 f	0,02 f
Echino chloacolonum (L) Link	10,95 b	0,20 e
Amaranthus dubius Mart.	1,15 f	0,02 f
Sorghum halepense (L.) Pers.	9,20 c	0,27 b
Cyperus rotundus (L.)	7,05 d	0,11 e
Parthenium hysterophorus (L.)	9,12 c	0,31 a
ESx	1,23*	0,009*

Source: [5]

Although no AMF applications were made at the site where the research was conducted and, therefore, those found correspond to resident AMF, all the samples of the roots of the different species of arboresae showed mycorrhizal colonization. Although the visual density was low in all cases, the most significant weeds were *P. hysterophorus* and *L. virginicum* [5].

The result may be related to the characteristics of the root system of these vines, since in the case of *C. dactylon* it has a profuse root system. In general, species with non-pivoting roots tend to show greater colonization [36].

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Microorganisms in the soil

Soil is inhabited by an enormous variety of plant microorganisms (soil microflora) and animals (soil micro fauna) and even by animal organisms ranging from sub-microscopic to medium and even relatively large dimensions (macro fauna). So much so that their biomass normally exceeds that of all the animals living on the soil.

With the development of agriculture on agroecological bases, there has been an increased interest in the study of soil biological diversity, which includes two large communities of soil organisms: the microflora, composed of bacteria, fungi, actinomycetes, archaea, cyanobacteria, myxomycetes and yeasts (various trophic groups are found; for example, algae are primary producers (photosynthetic), while there are decomposer fungi and others, including predators, such as the carnivores of the "microfauna") and the fauna, which includes the microfauna: individuals between 0.02 and 0.2 mm in diameter (they are the smallest of the soil fauna, therefore, a microscope is needed to be seen. The two most important soil creatures are nematodes and protozoa. Nematodes occur widely in soils, especially in sandy soils, and depend on a thin film of water around the particles for their movement [36].

In the case of edaphic macrofauna, which are organisms larger than 5 mm in diameter (considered the "micro-engineers" of the soil), they contribute to the improvement of the physical and chemical properties of the soil, since they participate in aeration, porosity, water infiltration, decomposition of organic matter and nutrient recycling [37]. This is considered as the community of "engineers" of ecosystems, as mentioned, since they contribute notably in the transformation process of soil organic residues and as activators of the edaphic microfauna, generating a notable impact on the natural fertility of soils; that is, they determine the abundance and structure of other communities, besides being indicators of the health and quality of the soils [38].

Much of crop productivity is determined by soil fertility [39,40]. This fertility can be evaluated based on its physical (density, structure, porosity, etc.), chemical (clay activity, oxidation-reduction potentials, organic matter, etc.) and biological (microorganisms that make up the microflora and microfauna, in addition to the meso and macrofauna) characteristics. The interactions derived from these three characteristics produce significant changes in the biogeochemical cycles of the soil and in the availability of nutrients for plants; in addition, these interactions allow plant communities to contribute to soil stability as an integral component of the ecosystem or agroecosystem in question [40].

Role of soil microorganisms. Microbial biodiversity and its effect on soil quality

Soil quality is defined by its ability to function in a natural or modified ecosystem framework, sustain plant and animal productivity, maintain or improve water and air quality, and contribute to human health and habitability. Soil quality is strongly influenced by the microbial processes that occur in it and these, related to diversity; therefore, it is very likely that the maintenance of the microbial community structure has the capacity to serve as an early and highly sensitive indicator of soil degradation or impoverishment (41,42).

The interaction between plant root and microbial communities promotes the development of a dynamic environment known as the rhizosphere (43,44). It is defined as the portion of the soil that is adjacent to the root system of a plant and that, in turn, is influenced by the exudates of those roots (44-46).

Both the exudates and the soil organic material deposited by the biota itself provide the necessary strength for the development of the active microbial population around the roots, which is known as the rhizosphere effect (44,46,47). The rhizosphere community is mainly composed of non-pathogenic microorganisms (44,48), which can positively affect plant growth and development, nutrition, defense against diseases, tolerance to heavy metals, and resistance to xenobiotic degradation caused by natural or synthetic chemicals present in the environment (43,44).

It has been widely demonstrated that soil microorganisms interact with plant roots and soil constituents at the root-soil interface. This large set of interactions between soil, roots, and microorganisms results in the development of a dynamic environment known as the rhizosphere, where a variety of microbial forms can develop actively and in equilibrium. The rhizosphere constitutes one of those points sensitive to crop response, because it concentrates a great metabolic activity with nutrient exchange between the atmosphere and the soil, which is mediated by the action and interaction of plants and soil microorganisms (42).

Plants are considered to constitute complex ecosystems of eukaryotes and prokaryotes that determine the conditions of the surrounding habitat (42,49). Rhizosphere microorganisms contribute to plant growth, increasing the availability of limiting nutrients such as phosphorus and nitrogen and, in turn, the composition and activity of the bacterial community is strongly influenced by the type of vegetation present in the soil (42,50,51).

Use of beneficial microorganisms as a biotechnology that favors the sustainability of ecosystems

One of the factors that make it possible to achieve greater competitiveness in the world market for agricultural products is the reduction in the use of agrochemicals, whose cost depends, to a large extent, on the price of oil (especially nitrogen fertilizer) and whose effect can have harmful impacts on the environment. The partial or total substitution of agrochemicals by microorganisms, maintaining high crop yields, is a valuable alternative to achieve sustainable production and to conquer demanding markets (42).

The use of beneficial microorganisms has had a wide diffusion in the last years, due to their positive effect on the yield of many crops in different situations and to the feasibility of allowing the development of organic agriculture (42,52,53).

Beneficial microorganisms and their effect on productivity

A large number of microorganisms are found in the soil. Their diversity and number depend, to a large extent, on the composition and concentration of nutrients exuded by plant roots (54,55). The interaction between microorganisms and crops can be beneficial, harmful or neutral, and sometimes this can vary depending on soil conditions (55).

To understand the functioning of agroecosystems from the microbiological component, it is necessary to interpret biomass values and microbial activity in order to develop management strategies in production systems (45,56) and, in this way, contribute to the improvement of agricultural practices and biodiversity conservation methods (44,56).

Knowing the members of the microbial community associated to the crop of interest is an aspect of particular attention to develop an ecological floriculture, since it is possible to favor the application of inoculants without damaging the biological balance of soils. Also, the analysis of the behavior of fungi and bacteria to plant exudates is one of the basic principles of plant-microorganism interaction. Root exudates are used by microorganisms as a nutritive source, indirectly influencing the interrelationships between colonizing microorganisms through the selective action they exert on particular species or groups (55).

AMF are considered biological inputs of enormous potential in agriculture, due to their positive effects on the adaptation and growth of a wide variety of crops. In addition, these microorganisms are key components for the development of soil biota due to their great capacity to interact with different microbial species, while they can modify many aspects of the physical properties in the rhizospheric zone (Table 5) (55,57).

Table 5. Abundance of mycorrhizal fungi present in the rhizosphere of Gergera

Mycorrhizal fungi species	Spores g^{-1}
Glomus hoilike	10,47 a
Glomus mosseaelike	1,76 b
Glomus intraradices	1,08 b
Glomus sp.	0,84 b
Scutello spora sp.	1,27 b
ES(+/-)	0,37

Source: (48)

CONCLUSIONS

- For all the reasons explained above, it is necessary to develop research to demonstrate that weeds, which have always been considered as harmful because of their interference in economic crops, establishing a strong competition with them for light, water, nutrients, CO_2 and physical space, or by the production of harmful substances for the crop, also play a beneficial role within the agroecosystem. These and the microorganisms associated with their rhizosphere could be used as a tool in biotechnology to promote sustainability and soil quality, but also as a biofertilization alternative that will benefit the crop of interest and then in a benefit for producers.
- It has been possible to appreciate the importance of the activity of microorganisms in the different aspects that denote the fertility of a soil and the sustainability of agroecosystems, thus allowing agricultural systems to require fewer external applications and, thus, favoring the conservation of the soil resource.
- It is necessary to establish coexistence rules, through the adequate management of weeds in interspecific coexistence with crops, since it has been demonstrated that the presence of different species of weeds in them, maintains edaphic diversity.

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