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REVIEW

Liquid vermicompost as a biostimulant in chili pepper nurseries: Morphophysiological evaluation and impact analysis

Vermicompost líquido como bioestimulante en viveros de ají: Evaluación morfofisiológica y análisis de impacto

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ABSTRACT

Introduction: the present study addressed the need to find sustainable alternatives in agricultural production, highlighting the role of organic agriculture as an ecological agroecosystem management system. The importance of using natural inputs such as organic fertilizers to maintain soil fertility, protect biodiversity and reduce pollution was recognized. Among these inputs, vermicomposting was positioned as an effective technique for transforming organic residues into useful products for agriculture, with special interest in its application to horticultural crops such as chili peppers (Capsicum annuum L.) in the nursery stage.
Development: during the development of the study, it was explained that vermicompost, being the result of the activity of earthworms and microorganisms, offered a stable product, rich in nutrients, and capable of improving the physical, chemical and biological conditions of the soil. It was described that this compost stimulated seedling emergence, as well as root growth, stem height and number of leaves, thanks to the release of hormonal compounds and beneficial microorganisms. The advantages of liquid vermicompost over synthetic fertilizers were also mentioned, as it is an accessible and environmentally friendly solution.
Conclusions: the use of vermicompost leachate proved to be an effective agroecological alternative in chili bell pepper nursery production. It was concluded that it promoted early plant development, improved the substrate and reduced the time to transplanting, directly benefiting small and medium producers interested in sustainable agricultural systems.

Keywords: Vermicompost; Chili; Organic Agriculture; Organic Fertilizers; Nursery.

RESUMEN

Introducción: el presente estudio abordó la necesidad de encontrar alternativas sustentables en la producción agrícola, destacando el papel de la agricultura orgánica como un sistema de manejo ecológico del agroecosistema. Se reconoció la importancia de emplear insumos naturales como los abonos orgánicos para mantener la fertilidad del suelo, proteger la biodiversidad y reducir la contaminación. Entre estos insumos, el vermicompostaje se posicionó como una técnica eficaz para transformar residuos orgánicos en productos útiles para la agricultura, con especial interés en su aplicación en cultivos hortícolas como el ají (Capsicum annuum L.), en su etapa de vivero.
Desarrollo: durante el desarrollo del estudio se explicó que el vermicompost, al ser resultado de la actividad de lombrices y microorganismos, ofrecía un producto estable, rico en nutrientes, y capaz de mejorar las condiciones físicas, químicas y biológicas del suelo. Se describió que este abono estimulaba la emergencia de

plántulas, así como el crecimiento radicular, la altura del tallo y el número de hojas, gracias a la liberación de compuestos hormonales y microorganismos benéficos. Asimismo, se mencionaron las ventajas del vermicompost líquido frente a los fertilizantes sintéticos, al tratarse de una solución accesible y amigable con el ambiente.
Conclusiones: el uso del lixiviado de vermicompost demostró ser una alternativa agroecológica eficaz en la producción de ají en vivero. Se concluyó que promovió el desarrollo vegetal temprano, mejoró el sustrato y redujo el tiempo hasta el trasplante, beneficiando directamente a pequeños y medianos productores interesados en sistemas agrícolas sostenibles.

Palabras clave: Vermicompost; Ají; Agricultura Orgánica; Abonos Orgánicos; Vivero.

INTRODUCTION

In recent decades, the search for sustainable alternatives for agricultural production has driven interest in agroecological practices that promote a balance between productivity, environmental health, and social well-being. In this context, organic agriculture has established itself as a production system that excludes synthetic inputs and prioritizes integrated agroecosystem management, focusing on conserving soil fertility, protecting biodiversity, and preventing environmental pollution. According to the FAO,[1] it is a holistic approach that encourages the use of practices adapted to each region, based on cultural, biological, and mechanical methods, instead of agrochemicals.

One of the fundamental pillars of this type of agriculture is the use of organic fertilizers, derived from animal and plant waste. These fertilizers provide essential nutrients and improve the soil's physical, chemical, and biological properties. These inputs improve the soil's structure, porosity, and water retention capacity while increasing fertility through the release of nutrients such as nitrogen, phosphorus, and sulfur. They also stimulate microbial activity, which is vital for the decomposition of organic matter and the absorption of nutrients by plants.

Within this approach, vermicomposting has emerged as an efficient and environmentally friendly technique for transforming organic waste through the combined action of earthworms and microorganisms. The resulting product, vermicompost or worm humus, is a stable, fine material with a high concentration of nutrients and beneficial organisms. This process can be carried out on different scales and has proven effective in improving the yield of various crops.

In the particular case of chili pepper cultivation (Capsicum annuum L.), a plant with high commercial demand, using vermicompost can positively impact its initial development phase, especially during the nursery stage. This phase is critical for obtaining vigorous and healthy seedlings with characteristics suitable for transplanting, such as good root development, optimal height, stem diameter, and number of leaves.

Therefore, it is essential to study the effect of vermicompost leachate on the physiological and morphological variables of chili pepper cultivation. This will validate its use as a sustainable, economical, and accessible alternative for small and medium-sized horticultural producers seeking to reduce the use of chemical inputs without compromising crop productivity.

DEVELOPMENT

Theoretical basis

Organic agriculture

There are currently many explanations and conceptualizations of organic agriculture, but they all agree on ecosystem management rather than agricultural inputs. A system that takes into account site-specific management practices that maintain and increase long-term soil fertility and prevent the spread of pests and diseases, replacing the potential environmental and social consequences of using agricultural inputs such as synthetic fertilizers and pesticides, veterinary drugs, genetically modified seeds and species, preservatives, and additives. Synthetic fertilizers, pesticides, veterinary drugs, genetically modified seeds and species, preservatives, and additives.

According to the Food and Agriculture Organization of the United Nations (FAO),[1] the conceptualization of organic agriculture is as follows:

It is a holistic production management system that promotes and enhances the health of the agroecosystem, particularly biodiversity, biological cycles, and soil biological activity. It emphasizes using management practices rather than off-farm inputs, considering that regional conditions will require locally adapted systems. This is achieved by using, whenever possible, cultural, biological, and mechanical methods, as opposed to synthetic materials, to fulfill each specific function within the system.Three causes of organic agriculture can be understood:

- The promotion of organic agriculture by consumers or the market. Thanks to their certification and labeling, organic products are clearly recognized. Consumers choose products that are produced, processed, handled, and marketed in a specific way.
- The promotion of organic agriculture through services. In countries such as the European Union (EU), subsidies for organic agriculture produce environmental goods and services, such as reducing groundwater pollution or creating a landscape with greater biodiversity.
- Promotion of organic agriculture by farmers. Some producers consider conventional agriculture unsustainable and have created other production methods to improve the health of their families, the economy of their farms, and their self-sufficiency. In many developing countries, organic agriculture is adopted to improve household food security or reduce input costs. Similarly, in developed countries, small farmers are increasingly creating direct channels to supply uncertified organic products to consumers.

Organic fertilizers

Organic fertilizers are all animal and plant waste from which plants can obtain significant amounts of nutrients; as these fertilizers decompose, the soil is enriched with organic carbon and improves its physical, chemical, and biological characteristics (Nicaraguan Institute of Agricultural Technology (INTA).[2] This is obtained through the degradation and mineralization of organic materials, which increases the soil's microbial activity and makes it rich in organic matter, energy, and microorganisms.

Origin of organic fertilizers

Organic fertilizers can come from natural ecosystems with permanent vegetation or from agricultural ecosystems, although the main sources are animal, plant, and mixed waste.[3]

Physical properties of soil improved by organic fertilizers

Organic fertilizers tend to favor soil's physical properties, specifically its structure, aeration, porosity, aggregate stability, infiltration, hydraulic conductivity, and water retention capacity. Murray et al.[4] stated that the values of soil organic matter and bulk density present in the agroforestry system improved soil structure in the first 20 cm.

In this sense, annual vegetation cover contributions led to changes in soil structure by increasing infiltration rate and improving bulk density, total porosity, and moisture retention capacity.

Chemical properties of soil improved by organic fertilizers

In organic farming, soil needs are met by using organic fertilizers with natural options, such as rock phosphate, rock flour, dolomite lime, orykta (a natural fertilizer extracted from mines rich in silicon dioxide 59 % and 22 other minerals), borax (sodium tetraborate, extracted naturally from evaporite deposits), Kmag (natural fertilizer extracted from mines and containing 22 % K2O, 18 % MgO, 22 % S), potassium sulfate, magnesium sulfate, calcium sulfate, zinc sulfate, copper sulfate, manganese sulfate, and animal sources such as fish or bone meal, eggshells, among others. These alternatives make it possible to address fertility deficiencies in each soil or according to the crop's needs.[5]

The benefits of organic fertilizers on soil chemical properties are detailed below: They help increase soil fertility by releasing several essential nutrients for plants, including: nitrogen (N), phosphorus (P), sulfur (S), and some minor elements such as copper (Cu) and boron (B); increase in the soil's cation exchange capacity (CEC), which manifests itself in greater retention and supply of mineral elements to plants and, of course, an increase in the soil's buffer capacity, which is directly reflected in the ability to resist sudden changes in soil pH when substances or products that leave acidic or alkaline residues are added.[6,7,8]

Biological properties of soil improved by organic fertilizers

Microorganisms are considered to mainly influence soil properties and directly affect plant growth. Organic fertilizers promote soil aeration and oxygenation due to the decomposition of soil particles caused by the generation of biochemical reactions that occur there, resulting in greater activity of aerobic microorganisms.[9,10] They also produce growth-inhibiting and growth-activating substances and considerably increase the development of beneficial microorganisms to degrade organic matter in the soil and promote crop development.[6]

The quality of compost for a given use is usually determined in two different ways, among others:

- Through field experiments, plants' response under real growing conditions to different doses of compost is measured in terms of biomass production, root growth, number of leaves or flowers, among other aspects.[11,12,13]
- By measuring a set of properties, some of which, such as organoleptic properties (odor, color, particle size, presence of inappropriate elements such as plastics, glass, etc.) can be evaluated sensorially, while physical, chemical, and biological properties (density, porosity, aeration, pH, electrical

conductivity, nutrients, heavy metals, bacteriological contamination, etc.) are usually determined in the laboratory.[14,15,16]

Vermicomposting

Vermicomposting is a process of bio-oxidation, decomposition, and stabilization of organic matter through the activity of earthworms and microorganisms. In this process, a stabilized, homogeneous, fine-grained final product is obtained called vermicompost, worm compost, worm humus, or worm humus.[7]

Vermicompost is the biological material resulting from the decomposition of organic waste through the activity of earthworms, mainly those of the genus Eisenia, the most commonly used being the California red worm (Eisenia foetida). This is carried out in beds, where organic waste is placed as a substrate for the worms. This species transforms the organic matter through ingestion and excretion into a compost rich in nutrients and microorganisms, conditions that make mineral elements such as phosphorus, calcium, potassium, magnesium, and microelements assimilable by plants.[17,18]

Historical advances in the vermicomposting process

The first reference to the benefits of vermicomposting, understood as the use of worms for the elimination of organic waste, was made by the Benedictine monk Augustus Hessing in the 1930s, when he used worms to eliminate organic waste produced in the monastery. In the mid-1940s, intensive worm farming began with the aim of obtaining vermicompost or worm humus. The species Eisenia foetida, also known as the California red worm, was initially used. However, for reasons related to breeding, reproduction, and the variety of organic waste it ingests, this species has proven to be the most suitable worm for vermicomposting processes and vermiculture systems.[21,22,23]

Vermicomposting was a common practice in ancient Egypt, where worms were considered “the intestines of the earth.” This activity is known to have begun in the United States in the late 1940s and early 1950s, later reaching Europe with significant development in Italy. It started to develop in Latin America in the 1980s, successfully establishing itself in Ecuador, Cuba, Chile, and Peru. This activity is being carried out successfully throughout Latin America, the United States, and the Caribbean Islands.[8,9]

Vermicomposting system and technique

Vermicomposting processes can be carried out on different scales, depending on the scientific objectives pursued.[10] Three scales have been established:

- Microcosm scale: Microcosm-scale experiments aim to determine the viability of problematic organic waste, either alone or conditioned, as food for worms and to select the most suitable substrates for vermicomposting on a larger scale. The experiments are carried out under controlled temperature and humidity conditions and generally use Petri dishes of different sizes as receptacles.[24]
- Laboratory or mesocosm scale: The objective is to provide information on the scientific basis of the vermicomposting process and on the viability of using new organic waste, alone or mixed with others, selected at the microcosm scale, for biodegradation by the combined action of worms and microorganisms. The environmental conditions in these processes are controlled, with humidity and temperature kept constant, and they are usually located in extraordinary chambers for this purpose.[25]
- The type of receptacle used is generally a cylindrical, open PVC tube of varying diameter and height. A thin sponge is placed at the bottom to facilitate drainage. The organic waste to be tested is deposited on the sponge and covered with a layer of mature vermicompost, into which the worms are introduced. Finally, the container is covered, top and bottom, with a cloth with small holes to facilitate gas exchange and drainage of excess water.[26]
- Pilot scale or macrocosm: This scale aims to develop, optimize, and monitor the vermicomposting process under environmental conditions and on a large scale that allows its transfer to the business sector. In addition, it aims to generate profitable organic fertilizers or amendments that can be used in the agricultural industry or as soil regenerators/bioremediators. In non-continuous systems, slightly inclined (5 %) beds between 1 and 2 m2 facilitate drainage. The problem waste is placed in the center, and a buffer zone (mature vermicompost) is placed on both sides, where the worms are inoculated.[27,28]

In continuous systems, reactors (4-8 m^2) are used, with a layer of mature manure placed at the base, which is inoculated with epigeal worms. The reactor is periodically fed with the problem waste.[29]

Raw materials used in the vermicomposting process

The substrate is made from crop residues, household waste, brushwood, horse, goat, rabbit, cattle, and chicken manure. Although fresh materials are used, it is always important to pre-compost and place layers no more than 10 cm thick to prevent the bed from overheating. If manure is used, it should be mixed with carbon-

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rich waste such as coffee husks, sawdust, granules, and fruit scraps to achieve an optimal C/N ratio for the process, always ensuring that the moisture content is around 70 %.[30]

It is important to emphasize that pre-composting is done to eliminate human pathogens and phytopathogens, so temperatures of around 65°C must be reached. The process must be carried out with optimal moisture in the mixture, so water should be added, without excess, if necessary. Pre-composting should be maintained with weekly turning for at least 22 days. Once this period has elapsed, the mound should be lowered to allow it to cool.[31,32]

Crop growth and development

Growth is generally defined as an irreversible increase in the dimensions of the plant.[11] Thus, Fontúrbel et al.[12] describe it as a phenomenon of biomass increase, due to the processes of cell division and protein synthesis that increase the organism's size.

In this sense, Martínez and Torres.[13] refer to growth as an increase in size. Multicellular organisms grow from the zygote, increasing not only in volume but also in weight, number of cells, amount of protoplasm, and complexity.

Thus, Brukhin et al.[14] consider it the increase in the volume and/or mass of plants with or without the formation of new structures such as organs, tissues, cells, or cell organelles.

Increases in volume (size) are often quantified approximately by measuring expansion in only one or two directions, such as length (stem height), diameter (of a branch, trunk), or area (of a leaf). Volume measurements can be non-destructive, so it is possible to measure the same plant several times.[33]

On the other hand, Di Benedetto et al.[33] indicate that it is usually determined by weight accumulation, variations in height or diameter, or changes in leaf area.[34]

Growth is often associated with development (cell and tissue specialization) and reproduction (production of new individuals).[35]

Crop growth phases

According to the Asian Vegetable Research and Development Center (AVRDC), 1990, growth and development occur in vegetative and reproductive phases. The growth period that occurs as soon as the seed germinates until the plant is ready to flower is considered the vegetative stage. The period from flowering to fruit harvest is the reproductive stage, which is the maturation period or adult phase when the plant can reproduce.[36]

The final stage of a plant's life is called senescence, although it also refers to the terminal stage of leaves, seeds, flowers, or fruits. Senescence is the aging process when irreversible changes lead to the death of the plant or part of the plant. In root, bulb, and tuber crops, the reproductive phase is replaced by the storage organ development phase. We are only interested in the vegetative growth of leafy vegetables, unless they are grown for seeds. We are interested in the reproductive stage in legume, cucurbit, and solanaceous crops. However, the vegetative stage is equally important because the leaves produce the carbohydrates and other compounds that support the growth of flowers, fruits, and seeds.[37]

Crop development

Two fundamental phenomena can be distinguished in plants: growth and development. Development refers to the differentiation of structures during growth to produce an adult organism. This begins at an early stage, when the embryo divides to form the seed. This seed remains dormant (latent) until the conditions necessary for germination are found (these conditions are highly variable and depend on the type of plant). Once the seed has found optimal conditions for development, it begins to mobilize its energy reserves and break down the protective coverings around the embryo. The key step in this phase is inhibition, a process by which cells absorb water and activate cellular metabolic processes.[38]

Segura[15] defines development as the events that contribute to the progressive elaboration of the plant's body and enable it to obtain food, reproduce, and fully adapt to its environment. Similarly, he indicates that it comprises two fundamental processes: growth and differentiation. Growth denotes the quantitative changes during development, while differentiation refers to qualitative changes. Therefore, development can be defined as the set of gradual and progressive changes in size (growth), structure, and function (differentiation) that enable the transformation of the zygote into a complete plant.[39]

Chili pepper cultivation

Chili peppers are perennial plants, but they are grown commercially annually, which is much more profitable. The classification of cultivated Capsicum is complex due to the lack of distinctive characteristics between particular species. Five (5) species are known to be cultivated: Capsicum annuum, C. chinense, C. frutescens, C. baccatum, and C. pubescens.[16]

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Root system

The chili pepper is characterized by a short but highly branched primary root. Secondary roots can extend up to 1.20 m in diameter, and most roots are located between 5 and 40 centimeters deep.[16]

Stem and leaves

Although chili peppers are considered herbaceous, they are unique because their lower part is woody. They can be cylindrical or angular prismatic in shape, glabrous, erect, and vary in height depending on the variety (mostly 0,30–1,2 m).[16]

This plant has pseudodichotomous branching, always with one branch more than another (the area where the branches join causes them to break easily). This type of branching gives the chili pepper an “angular” umbelliform shape.[40]

The leaves of the chili pepper are simple and alternate. They have an oval-lanceolate blade with smooth edges, dark green in color, and compressed petioles.

Flowers

They are located at the points where the stem branches, with 1-5 flowers per branch. In large-fruited varieties, a single flower is formed per branch, and more than one in small-fruited varieties.[16]

The flowers are hermaphroditic, with six sepals forming a persistent calyx, six petals, and six stamens. They have a superior ovary, which can be bi- or trilocular. In most cases, the stigma is at the level of the anthers, which facilitates self-pollination. In most small-fruited varieties, the percentage of self-pollination is high, generally exceeding that of large-fruited varieties.

Fruit

The fruit consists of a berry with 2-4 locules, which form lower cavities with visible divisions in elongated peppers but not in rounded ones. The anatomical structure of the fruit is represented by the pericarp and the seed.[16]

In sweet fruits, the pericarp has a mesocarp approximately 1 mm thick and a somewhat dry texture. The pericarp develops best when most of the ovules are fertilized, contributing to a better fruit shape. In cases of insufficient pollination, deformed fruits are obtained.

There is a diversity of fruit shapes and sizes. However, they are generally grouped into round and elongated, with weights ranging from a few grams to 100 grams (the lower weights correspond mainly to the spicy fruit varieties and the higher weights to the sweet fruit varieties).[42]

When botanically ripe, the fruit is reddish primarily, although there are also varieties with yellow or orange fruit. Depending on the intended use, harvesting is done at botanical or technical maturity for consumption.[43]

Seeds

The seeds are generally depressed, reniform, smooth, and yellowish or yellowish-white. Their absolute weight (1,000 seeds) depends on the variety, varying from 3,8 to 8 g.[16]

The germination rate is generally high (95-98 %) and can be maintained for 4-5 years if kept under good storage conditions.[44,45]

Table 1. Operationalization of variables

Variables	Dimension	Indicators
Independent		
Vermicompost leachate	0	%
	25	
	50	
	75	
Shop assistant		
Emergency capacity	Emerged seedlings	nro
Growth	Height	cm
	Root length	cm
Development	Number of blades	nro
	Blade diameter	cm
	Stem diameter	mm

CONCLUSIONS

The study on the effect of vermicompost leachate on chili pepper (Capsicum annuum L.) cultivation reaffirmed the importance of the agroecological approach in horticultural production systems, especially in

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the early stages of plant development. It was concluded that the use of organic fertilizers, particularly liquid vermicompost, contributed significantly to improving the soil's physical, chemical, and biological conditions, which positively impacted the growth and development of chili pepper seedlings in nurseries.

From a physiological perspective, vermicompost leachate favored seedling emergence and increased height, root length, number of leaves, and stem diameter, demonstrating its potential as a natural biostimulant. These results were associated with essential nutrients, beneficial microorganisms, and hormonal compounds (such as auxins, gibberellins, and cytokinins) that are generated in the vermicomposting process through the action of earthworms and aerobic microorganisms.

In addition, it was determined that vermicomposting, due to its low environmental impact, represents a viable alternative to the intensive use of synthetic fertilizers, whose negative consequences have been widely documented. In this sense, it was demonstrated that properly treated organic waste can be transformed into high-value, accessible, and sustainable agricultural inputs, promoting the self-sufficiency of small and medium-sized producers.

Liquid vermicompost not only fulfilled a nutritional function but also improved substrate structure, increased moisture retention, and promoted a favorable environment for root development, thus facilitating earlier and more successful transplanting. These characteristics are essential in nurseries where plants with optimal characteristics must be obtained in the shortest possible time.

Finally, the need to continue promoting research that delves deeper into the relationship between types of waste, composting conditions, and their impact on different crops was highlighted. The aim is to optimize leachate formulations and adapt their use to diverse agroclimatic realities. Vermicompost emerged as a key tool for advancing toward a more sustainable and resilient agriculture committed to soil health, food security, and the conservation of the agricultural environment.

REFERENCES

1. Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO). Agricultura orgánica. 2015. Disponible en: http://www.fao.org/organicag/oa-faq/oa-faq1/es/

2. Instituto Nicaragüense de Tecnología Agropecuaria (INTA). Elaboración de abonos orgánicos. 2018. Disponible en: https://inta.gob.ni/project/elaboracion-de-abonos-organicos/

3. Cajamarca D. Procedimientos para la elaboración de abonos orgánicos. Cuenca: Universidad de Cuenca, Facultad de Ciencias Agropecuarias. 2012. Disponible en: http://dspace.ucuenca.edu.ec/bitstream/123456789/3277/1/TESIS.pdf

4. Murray R, Bojórquez J, Hernández A, Orozco M, García J, Gómez R, et al. Efecto de la mate-ria orgánica sobre las propiedades físicas del suelo en un sistema agroforestal en Nayarit, México. Rev Bio-Ciencias. 2011;1(3):27-35.

5. Garro J. El suelo y los abonos orgánicos. San José, Costa Rica: Instituto Nacional de Innova-ción y Transferencia de Tecnología Agropecuaria (INTA); 2016.

6. Mosquera B. Abonos orgánicos: protegen el suelo y garantizan alimentación sana. Manual para elaborar y aplicar abonos y plaguicidas orgánicos. FONAG-USAID. 2010. Disponible en: https://issuu.com/frederys1712doc/docs/abonos_org__nicos_-_protegen_el_sue

7. Mendoza D. Vermicompost y compost de residuos hortícolas como componentes de sustratos para la producción de planta ornamental y aromática. Valencia, España: Universidad Poli-técnica de Valencia. 2010. Disponible en: https://riunet.upv.es/handle/10251/8685?show=full

8. Martínez C. Potencial de la lombricultura: elementos básicos para su desarrollo. Texcoco, México: Lombricultura Técnica Mexicana; 1996.

9. Larco E. Desarrollo y evaluación de lixiviados de compost y lombricompost para el manejo de sigatoka negra (Mycosphaerella fijiensis Morelet), en plátano. Tu-rrialba, Costa Rica: CATIE. 2004. Disponible en: http://repositorio.bibliotecaorton.catie.ac.cr/handle/11554/4776?show=full

10. Nogales R. Vermicompostaje en el reciclado de residuos agroindustriales. XII Congreso Ecuatoriano de la Ciencia del Suelo. 2010. Disponible en: http://www.secsuelo.org/wp-content/uploads/2015/06/4.-Rogelio-Nogales.-Vermicompostaje.pdf

11. Di Benedetto A, Tognetti J. Técnicas de análisis de crecimiento de plantas: su aplicación a cultivos intensivos. Rev Investig Agropecu. 2016;ISSN 1669-2314.

12. Fontúrbel F, Achá D, Mondaca D. Manual de introducción a la botánica. La Paz, Bolivia: Editorial Publicaciones Integrales; 2007.

13. Martínez D, Torres J. Manual teórico: fisiología vegetal. Puebla: Benemérita Universidad Autónoma de Puebla, Escuela de Biología. 2013. Disponible en: https://www.academia.edu/5198464/

14. Brukhin V, Morozova N. Plant growth and development - basic knowledge and current views. Math Model Nat Phenom. 2011;6(2):1-53.

15. Segura J. Introducción al desarrollo: concepto de hormona vegetal. En: Azcón J, Talón M, editores. Fundamento de fisiología vegetal. Barcelona: McGraw-Hill Interamericana; 2007. p. 349-76.

16. Fundación de Desarrollo Agropecuario. Cultivo de ají. Boletín N°20. Santo Domingo, República Dominicana: Fundación de Desarrollo Agropecuario INC; 1989.

17. Ansorena J, Batalla E, Merino D. Evaluación de la calidad y usos del compost como componente de sustratos, enmiendas y abonos orgánicos. Insurumen Eta Nekazal Laborategia. 2014. Disponible en: https://issuu.com/horticulturaposcosecha/docs/140711evaluar_compost_ansorena

18. Agencia Chilena para la Inocuidad y Calidad Alimentaria (ACHIPIA). Uso y manejo de abonos orgánicos. Fondo de Cooperación Chile-México. 2017. Disponible en: https://www.gob.mx/cms/uploads/attachment/file/290745/Gu_a_Abonos_Org_nicos_.pdf

19. Arias F. El proyecto de investigación: introducción a la metodología científica. Caracas: Edi-torial Episteme; 2012.

20. Asian Vegetable Research and Development Center (AVRDC). Vegetable production training manual. Tainan, Taiwán: AVRDC Publication; 1990.

21. Domínguez J, Lazcano C, Brandon M. Influencia del vermicompost en el crecimiento de las plantas. Acta Zool Mex. 2012;26(2):359-71.

22. González-Solano K, Rodríguez-Mendoza M, Sánchez-Escudero J, Trejo-Téllez L, García-Cué J. Uso de té de vermicompost en la producción de hortalizas de hoja. Agro Productividad. 2018;7(6).

23. González K, Rodríguez M, Trejo L, Sánchez J, García J. Propiedades químicas de tés de vermicompost. Rev Mex Cienc Agríc. 2013;(Pub Esp 5):901-11.

24. Jiménez V. Efecto de aplicación de diferentes fuentes de fertilizantes en 3 genotipos de chi-le (Capsicum annuum L.) a nivel plántula [tesis de grado]. México: Universidad Autónoma Agraria, División de Agronomía; 2010. Disponible en: http://repositorio.uaaan.mx:8080/xmlui/handle/123456789/44832

25. López Baltazar J, Méndez Matías A, Pliego Marín L, Aragón Robles E, Robles-Martínez M. Evaluación agronómica de sustratos en plántulas de chile 'onza' (Capsicum annuum) en in-vernadero. Rev Mex Cienc Agríc. 2013;6:1139-50.

26. Martínez D, Torres J. Manual teórico: fisiología vegetal [Internet]. Puebla: Benemérita Uni-versidad Autónoma de Puebla, Escuela de Biología. 2013. Disponible en: https://www.academia.edu/5198464/BENEMERITA_UNIVERSIDAD_AUTONOMA_DE_PUEBLA_ESCUELA_DE_BIOLOGIA_MANUAL_TE%C3%93RICO_FISIOLOG%C3%8DA_VEGETAL

27. Melgar R, Benítez E, Nogales R. Bioconversion of wastes from olive oil industries by ver-micomposting process using the epigeic earthworm Eisenia andrei. J Environ Sci Health B. 2009;44(5):488-95.

28. Melo O, López L, Melo S. Diseño de experimentos: métodos y aplicaciones. Colombia: Universidad Nacional de Colombia, Centro Editorial de la Facultad de Ciencias; 2020.

29. Moreno A, Rodríguez N, Reyes J, Márquez C, Reyes J. Comportamiento del chile Húngaro (Capsicum annuum) en mezclas de vermicompost-arena bajo condiciones protegidas. Rev Fac Cienc Agrar. 2014;46(2):97-111.

30. Monge A. Evaluación del crecimiento y desarrollo de plántulas de tomate y chile dulce mediante seis sustratos y tres métodos de fertilización. Costa Rica: Instituto Tecnológico de Costa Rica. 2007. Disponible en: https://core.ac.uk/download/pdf/60991235.pdf

31. Mundarain S, Coa M, Cañizares A. Fenología del crecimiento y desarrollo de plántulas de ají dulce. Rev UDO Agrícola. 2005;5(1):62-7.

32. Organización Mundial de la Salud (OMS). Consecuencias sanitarias del empleo de plaguicidas en la agricultura. Ginebra: OMS. 1992. Disponible en: https://apps.who.int/iris/handle/10665/39175

33. Palella S, Martins F. Metodología de la investigación cuantitativa. Caracas: Fondo Editorial de la Universidad Pedagógica Experimental Libertador (FEDUPEL); 2017.

34. Pérez-Espinosa A, Camiletti J, Pérez-Murcia M, Agulló E, Andreu J, Bustamante M, et al. Bio-transformación de residuos orgánicos de distinta naturaleza combinando compostaje y ver-micompostaje. En: López R, Cabrera F, editores. V Jornadas de la Red Española de Compos-taje. Red Española de Compostaje; 2017. p. 88-92.

35. Rodríguez P. Impacto del lixiviado de humus de lombriz sobre el crecimiento y productivi-dad del cultivo de habichuela (Vigna unguiculata). Ciencia en su PC. 2017;(2):44-58.

36. Rosario M, Camacho C. Apuntes de metodología de la investigación. Santa Bárbara de Zulia, Venezuela: Dirección de Publicaciones UNESUR; 2015.

37. Santiago A, Nahuat J. Efecto de la dosificación del lixiviado de lombriz (Eisenia foetida) en el cultivo de chile habanero (Capsicum chinense). México: Instituto Tec-nológico de la Zona Maya. 2016. Disponible en: http://www.itzonamaya.edu.mx/web_biblio/archivos/res_prof/agro/agro-2016-11.pdf

38. Solomon E, Berg L, Martín D. Biología. México: Cengage Learning; 2014.

39. Solórzano A. Efecto de quitosano, hongos micorrízicos y ácidos húmicos sobre el crecimiento y desarrollo en variedades de pimiento (Capsicum annuum) [trabajo de grado]. Ecuador: Universidad Técnica Estatal de Quevedo, Facultad de Ciencias Agrarias. 2019. Disponible en: https://repositorio.uteq.edu.ec/handle/43000/3848

40. Torres A, Cué J, Hernández G, Peñarrieta S. Efectos del BIOSTÁN en la altura y masa seca de Phaseolus vulgaris, genotipo criollo. Rev La Técnica. 2015;15:18-25.

41. Trevisan S, Ornella F, Quaggiotti S, Serenella N. Humic substances biological activity at the plant-soil interface. Plant Signal Behav. 2010;5(6):635-43.

42. Valadez L. Producción de hortalizas. México: Limusa, S.A.; 1998.

43. Vázquez E, Teutscherová N, Fernández E, Benito M, Masaguer A. La combinación del vermi-compostaje y compostaje mejora las propiedades agronómicas del producto final respecto al solo compostaje de los residuos. En: López R, Cabrera F, editores. V Jornadas de la Red Española de Compostaje. Reciclando los residuos para mejorar los suelos y el medioambien-te. Red Española de Compostaje; 2017. p. 277-81.

44. Yuni J, Urbano C. Técnicas para investigar: recursos metodológicos para la preparación de proyectos de investigación. Argentina: Editorial Brujas; 2014.

45. Zambrano J. Efecto del vermicompost sobre el crecimiento y rendimiento del cultivo de pi-miento (Capsicum annuum L.) bajo sistema protegido. Ecuador: Univer-sidad Técnica de Manabí, Facultad de Ingeniería Agronómica. 2018. Disponible en: http://repositorio.utm.edu.ec/bitstream/123456789/1277/1/EFECTO%20DEL%20VERMICOMPOST%20SOBRE%20EL%20CRECIMIENTO%20Y%20RENDIMIENTO%20DEL%20CULTIVO%20DE%20PIMIENTO%20%28Capsicum%20annuum%20L.%29%20BAJO%20SISTEMA%20PROTEGIDO.pdf

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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