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Vermicompost leachate in organic and conventional wheat production

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Abstract

Agriculture faces the challenge of increasing crop productivity while reducing the environmental impact associated with the intensive use of chemical fertilizers. This has driven interest in organic inputs and biostimulants in both organic and conventional production systems. Among these inputs, vermicompost leachate stands out as a derivative of vermicomposting containing soluble nutrients, humic substances, and beneficial microorganisms. The objective of this study was to evaluate the effect of vermicompost leachate on wheat yield under organic and conventional production conditions in the Yaqui Valley, Sonora, Mexico. The assessment was conducted over three cropping cycles: 2016–2017, 2023–2024, and 2024–2025. The first two cycles were managed organically, while the third cycle was managed conventionally. Two treatments were compared: control and vermicompost leachate application, using a randomized complete block design with four to six replicates, depending on the cycle. The evaluated variable was grain yield adjusted to 12% moisture. In all three cycles, leachate application showed a positive trend in grain yield compared to the control; however, no statistically significant differences were detected. The highest yields were recorded in the 2023–2024 cycle, which was associated with previous soil resting and prior compost application. In conclusion, vermicompost leachate can be considered a complementary input within an integrated soil management approach, with its effect on yield depending on management history, soil conditions, and production system.

Keywords: Vermicompost leachate; Wheat; Yield; Organic; Conventional

1 Introduction

Currently, agriculture faces the challenge of increasing crop productivity while simultaneously reducing the environmental impacts associated with the intensive use of chemical fertilizers. In this context, organic agriculture and sustainable production systems have gained prominence, driving the search for organic inputs that can complement or partially replace mineral fertilization in both organic and conventional crops [1]. Among these inputs, vermicompost and its derivatives stand out, produced through the vermicomposting process in which epigeic earthworms transform organic residues into products with high nutrient availability, humic substances, beneficial microorganisms, and bioactive compounds with growth-promoting effects on plants [2, 3]. One such derivative is vermicompost leachate, a liquid extract generated during the irrigation of worm beds, which contains soluble nutrients, humic and fulvic acids, and plant growth-promoting microbial communities [4].

Recent studies have shown that vermicompost leachate can positively influence the growth and development of various crops, although its effect depends on the applied dose, plant species, and environmental conditions [5]. It has been reported that the leachate can stimulate root growth and improve morphological traits during early developmental stages [4]; however, inappropriate applications or high concentrations may lead to negative effects, particularly under abiotic stress conditions [6]. Its effect on seed germination has also been documented as dose-dependent, showing beneficial responses at low concentrations and potential phytotoxicity at high concentrations [7]. Beyond its role as a fertilizer and biostimulant, vermicompost leachate can alter rhizosphere microbiological activity, which is key for the

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sustainability of agricultural systems and nutrient uptake efficiency [1]. Nevertheless, unlike solid vermicompost, leachate lacks specific regulatory standards governing its quality and characterization, limiting its standardization and large-scale agronomic use [8].

In wheat (*Triticum aestivum L.*) cultivation, conventional systems primarily rely on rapidly available mineral fertilizers, whereas organic systems depend on organic sources with gradual nutrient release. Consequently, organic wheat yields often differ from conventional yields, mainly due to nitrogen availability and agronomic management practices [4]. Recent studies suggest that, under certain management conditions, yields in both systems can be comparable, although productivity gaps persist under adverse climatic scenarios [9]. In the Yaqui Valley, Sonora, Mexico, nutritional analyses have been conducted on available soil amendments in the region, with the concentration of elements in the evaluated amendments reported in Table 1.

Table 1 Average chemical composition of manures available in the Yaqui Valley, Sonora, Mexico.

Element	Chicken manure	Pig manure	Compost	Manure
Total Nitrogen %	3.00	2.11	1.64	1.20
Total Phosphorus %	0.76	0.45	0.61	0.46
Potassium %	2.28	0.34	2.17	1.78
Calcium %	3.49	2.24	4.93	2.26
Magnesium %	0.42	0.17	0.48	0.38
Sodium %	2.69	0.90	3.12	3.46
Iron ppm	1841	3631	3440	4375
Manganese ppm	406	365	306	243
Copper ppm	41	221	145	36
Zinc ppm	279	853	160	147
Boron ppm	78	59	56	73

Fuente: [Cortés *et al.,* 10,11]

The agricultural use of these organic fertilizers, particularly in wheat, has provided an economically viable solution for managing the large amounts of manure generated by livestock activities in the Yaqui Valley, which were mostly left exposed to the environment. Their use has allowed for a reduction, or in some cases elimination, of chemical fertilizers [12]. The application of manure is well known among farmers, who quickly adopted this technology to the extent of using nearly all available product as a source of fertilization. As an alternative, vermicompost leachate can be used; however, there is limited information regarding its specific application in wheat production and its interaction with different fertilization schemes. In this context, it is necessary to generate scientific evidence to evaluate its potential as an alternative or complementary nutrient source in both production systems, contributing to the development of more sustainable management strategies for this globally important cereal. The objective of the present study was to evaluate the effect of vermicompost leachate on wheat yield under organic and conventional production systems.

2 Material and methods

The present evaluation was carried out at the Norman E. Borlaug Experimental Field of INIFAP, located in Block 910 of the Yaqui Valley, Sonora, at 27.36805° N and -109.92771° W, on a clay-textured soil. The site has a warm arid climate [BW(h)] with occasional extreme heat events, according to the Köppen classification modified by García [13]. Vermicompost leachate was evaluated during the 2016–2017, 2023–2024, and 2024–2025 cropping cycles; the first two cycles were under organic production, and the third cycle under conventional production.

2.1 Cropping cycle 2016–2017

The effect of vermicompost leachate applied through irrigation water on wheat yield was evaluated. Table 2 shows the average values from four vermicompost leachate samples analyzed at the Soil and Plant Nutrition Laboratory of CENEB-INIFAP. The amount of liquid vermicompost applied in this study was 2,000 liters per hectare, fractionated into four doses of 500 liters each, applied during four irrigations starting from the second supplemental irrigation.

Table 2 Average nutritional characteristics of vermicompost leachate obtained from worm beds in the Yaqui Valley, Sonora, Mexico.

Element	Value
Total Nitrogen %	0.061
Total Phosphorus %	0.558
Calcium %	0.580
Magnesium %	0.136
Sodium %	0.370
Potassium %	0.510
Copper ppm	4.275
Iron ppm	33.68
Zinc ppm	19.25
Manganese ppm	15.75

Sowing was carried out on November 26, 2016, with a seeding rate of 120 kg ha^{-1} of the CIRNO C2008 variety [14]. Five supplemental irrigations were applied. Sowing was performed in moist soil in double rows spaced 0.80 m apart to facilitate cultural weed control. The evaluation took place during the cycle when the field was being monitored for organic certification, after seven years without agrochemical applications and with manure fertilization since 2000. No chemical herbicides, insecticides, or fungicides were applied; weeds were controlled mechanically and manually. Leaf rust (Puccinia recondita) was observed and managed using a foliar application of a mixture of three microorganisms: Bacillus subtilis, Verticillium lecanii, and Trichoderma spp. The most important pest was aphids, which were monitored using yellow traps. Biological control was implemented through the release of approximately 3 g of lacewings every 8 m along the same row, in every 10 rows of the experimental plot. In addition to lacewing release, a 3% soap solution was applied 80 days after sowing, doubling the dose in infestation hotspots. The experimental unit consisted of eight rows, each 110 m in length, while the useful plot consisted of two rows, 3 m long and 0.80 m apart. Harvesting was performed manually using a sickle. The samples were subsequently threshed using a stationary Pullman-type thresher. The grain obtained was cleaned to remove straw and glume residues, weighed, and its moisture content determined. Two treatments were evaluated: T_1 = Control and T_2 = Vermicompost leachate application. A randomized complete block design with six replicates was used. The variable measured was grain yield adjusted to 12% moisture.

2.2 Cropping cycle 2023–2024

A single dose of 335 L ha^{-1} of vermicompost leachate was applied on November 28, 2023, prior to seedbed preparation. The application was performed using a commercial sprinkler mounted on a tractor (Figure 1).

Figure 1 Application of vermicompost leachate. CENEB-INIFAP, cropping cycle 2023–2024

Sowing was carried out on November 29, 2023, using the commercial variety Noroeste C2021 [15] at a seeding rate of 65 kg ha^{-1}. Fertilization was performed with 150 kg ha^{-1} of Compost Plus (Novedades Agrícolas DASA) [16]. Germination irrigation and four supplemental irrigations were applied. Pest management included one aphid control application using a tractor and two manual weedings.

The experimental plot consisted of 12 rows, each 110 m long and spaced 0.80 m apart. The useful plot comprised two rows, each 3 m long and 0.80 m apart, with four replicates. The field originated from a previous cycle that had been fertilized with 3 t ha^{-1} of Compost Plus and left fallow for one cropping cycle.

Harvesting was performed manually using a sickle. Samples were then threshed using a stationary Pullman-type thresher. The grain obtained was cleaned to remove straw and glume residues, weighed, and its moisture content determined. Two treatments were evaluated: T_1 = Control and T_2 = Vermicompost leachate application. The variable measured was wheat grain yield adjusted to 12% moisture.

2.3 Cropping cycle 2024-2025

A dose of 335 L ha^{-1} of vermicompost leachate was applied on December 4, 2024, at the time of seedbed preparation. The field was fertilized with 226 kg ha^{-1} of urea at the time of furrow preparation, plus 120 kg ha^{-1} of urea applied in bands before the first supplemental irrigation; no phosphorus was applied. Pre-sowing irrigation was performed on November 21, 2024. Sowing was carried out on December 5, 2024, using the Noroeste C2021 variety [15] at a seeding rate of 77 kg ha^{-1}. A second dose of vermicompost leachate was applied one day before the first supplemental irrigation. In total, pre-sowing irrigation and two supplemental irrigations were applied.

The experimental design was a randomized complete block with four replicates. The experimental unit consisted of 12 rows, each 110 m long and 0.80 m apart, while the useful plot consisted of two rows, each 2 m long, with 0.80 m between rows. Harvesting was performed manually using a sickle. Samples were then threshed using a stationary Pullman-type thresher. The obtained grain was cleaned to remove straw and glume residues, weighed, and its moisture content determined. Two treatments were evaluated: T_1 = Control and T_2 = Vermicompost leachate application. The variable measured was wheat grain yield adjusted to 12% moisture.

Figure 2 Appearance of the control plot on March 6, 2025. CENEB-INIFAP, cropping cycle 2024–2025

3 Results and discussion

In the three cropping cycles evaluated (2016–2017, 2023–2024, and 2024–2025), the application of vermicompost leachate consistently showed a trend toward increased wheat grain yield compared to the control; however, these differences were not statistically significant. This behavior is consistent with recent studies indicating that vermicompost leachates primarily act as plant growth biostimulants rather than as direct nutrient sources, and therefore their effect on yield may be moderate and dependent on soil conditions and agronomic management [17–18].

3.1 Cropping cycle 2016-2017

No significant differences ($P \geq 0.05$) were observed between the control and the vermicompost leachate treatment in any of the cycles. Figures 3 to 5 present the mean values of the evaluated treatments.

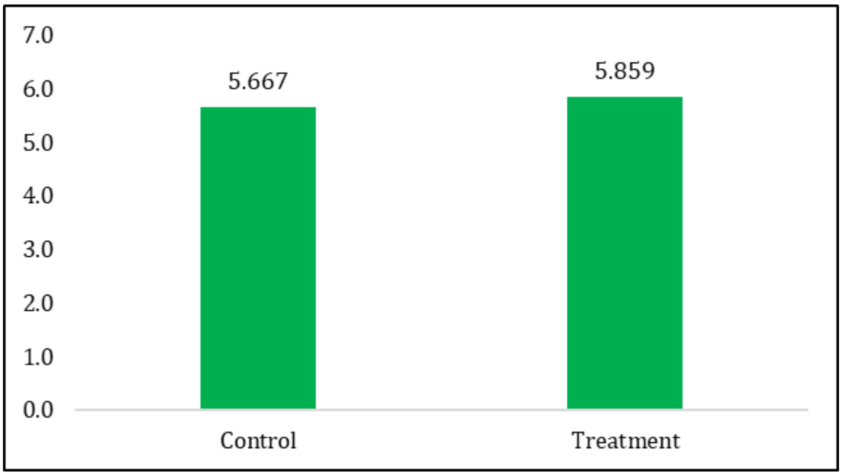

Figure 3 Response of wheat grain yield under organic production to the application of vermicompost leachate. CENEB-INIFAP, cropping cycle 2016–2017

In the 2016–2017 cycle, conducted under an organic production system with a long history of management without agrochemicals, the leachate treatment increased yield by 182 kg ha^{-1} compared to the control. The absence of significant differences may be explained by the high level of biological fertility of the soil, resulting from continuous use of organic amendments and the lack of synthetic fertilization over several years. Recent studies indicate that in soils with high organic matter content and established microbial activity, crop responses to additional liquid vermicompost applications are often limited, as the main benefits—improved nutrient availability, enzymatic activity, and soil structure—are already well established [19,20]. In these systems, the leachate may enhance physiological processes in the crop without necessarily translating into significant yield increases.

3.2 Cropping cycle 2023-2024

In the 2023–2024 cycle, the vermicompost leachate treatment exceeded the control by 365 kg ha^{-1} (Figure 4). This cycle exhibited the highest yields in the study, which can be attributed to the previous application of compost (3 t ha^{-1}) and the fallow period of the soil during the preceding cycle.

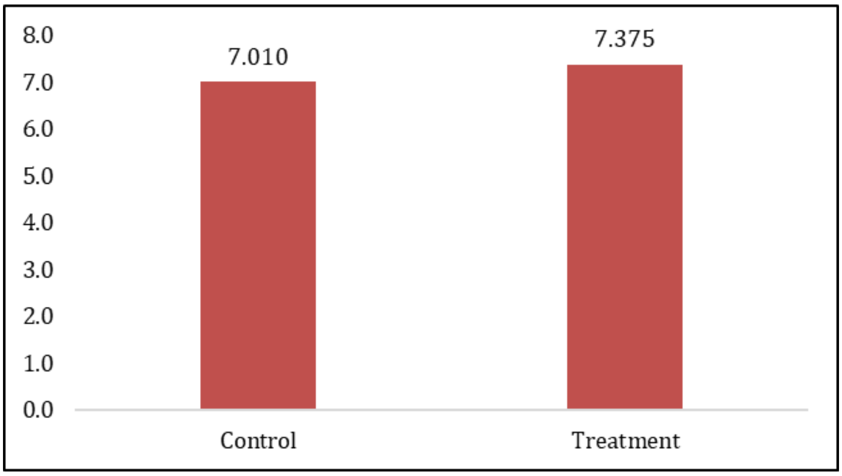

Figure 4 Response of wheat grain yield under organic production to the application of vermicompost leachate. CENEB-INIFAP, cropping cycle 2023–2024

Recent studies indicate that the combined application of solid organic amendments and liquid biofertilizers can generate synergistic effects, enhancing nutrient mineralization, beneficial microbial activity, and nitrogen uptake efficiency [21, 22]. In this context, vermicompost leachate may have acted as a physiological stimulant, improving crop vigor and contributing to the observed yield increase. Additionally, leaving the soil fallow for at least one cropping cycle allows for the reconstruction of microbial biomass, improved aggregate stability, and greater nutrient availability, particularly mineralizable nitrogen, resulting in a better response of the subsequent crop [23, 24].

3.3 Cropping cycle 2024-2025

In the 2024–2025 cycle, conducted under a conventional production system with nitrogen fertilization, the increase resulting from the applied treatment compared to the control was 204 kg ha^{-1} (Figure 5). Although the increase was modest, the positive trend observed in previous cycles was maintained.

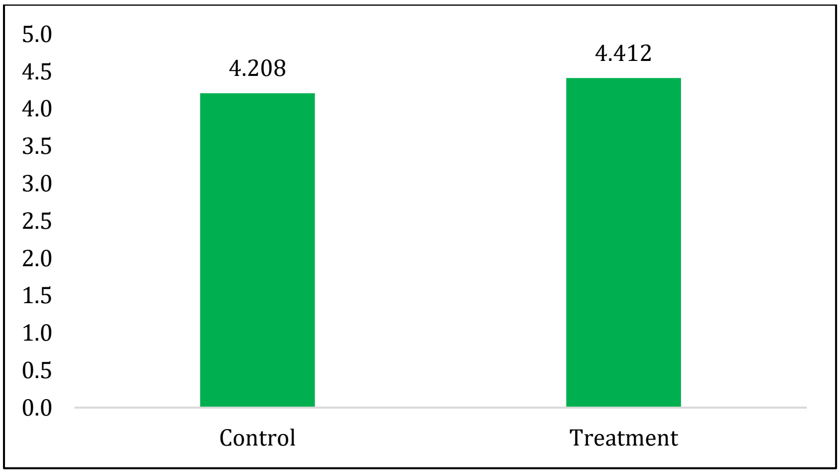

Figure 5 Grain yield response of wheat under conventional production to the application of vermicompost leachate. CENEB-INIFAP, 2024–2025 cycle

In conventional systems, recent research indicates that vermicompost leachate does not replace mineral fertilization but can enhance nitrogen use efficiency, root development, and stress tolerance, which is reflected in modest yet consistent yield increases [8, 9]. The overall reduction in yield observed in this cycle could be related to a lower number of supplemental irrigations and the possible incidence of environmental stress. The frequency and number of irrigations directly influence wheat yield, as reduced irrigation frequency limits water availability during critical crop stages, which can constrain spike and grain formation. An analysis from a study on irrigation regimes showed that higher irrigation frequency is associated with higher wheat yields, while treatments with fewer irrigations result in significantly lower yields due to water stress during sensitive stages [25]. The wheat yield response to the number of irrigations is closely related to water uptake efficiency and availability during key phenological stages. Studies show that when irrigation is reduced (to two or three events), water use efficiency may be maintained to some extent, but the water available for processes such as stem elongation and grain filling decreases, reducing total grain production [26].

Overall, the results indicate that vermicompost leachate did not produce statistically significant increases in wheat grain yield, although a consistent positive response was observed across the three agricultural cycles evaluated. Recent studies agree that the main benefits of vermicompost and its leachates are manifested in the medium to long term, through improvements in the physical, chemical, and biological properties of the soil, as well as in crop yield stability [3, 27].

4 Conclusion

The application of vermicompost leachate in wheat, evaluated over three agricultural cycles under different management systems (organic and conventional) in the Yaqui Valley, Sonora, did not result in statistically significant increases in grain yield; however, a consistent positive trend of the applied treatment compared to the control was observed in all cycles.

The results indicate that the crop response to vermicompost leachate was strongly influenced by soil management history, the production system, and the conditions of the agricultural cycle. In soils with long-term organic management and high biological fertility, the effect of the leachate was marginal, whereas in conditions with a history of fallow and organic amendments, the highest yields were recorded. In conventional systems, the leachate primarily acted as a supplementary input, without replacing mineral fertilization.

Overall, the findings suggest that vermicompost leachate should be considered as a support tool within an integrated soil management strategy, aimed at improving crop physiological efficiency and yield stability, rather than as a practice intended to immediately increase grain yield. Continued evaluation of this bio-input over the medium and long term is recommended, incorporating soil quality parameters and nutrient use efficiency to fully assess its contribution to the sustainability of wheat production systems.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that No conflict of interest.

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