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The role of red californian earthworms (Eisenia fetida) in polymer waste decomposition

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Abstract. This study delves into an in-depth exploration of the physiological and behavioral characteristics of Eisenia fetida, also referred to as the red Californian earthworm, thriving within the arid climate of Turkmenistan. The investigation encompasses an extensive assessment of their growth rates across different seasons, shedding valuable insight into the exceptional adaptability of these earthworms in diverse environmental conditions. Furthermore, it endeavors to elucidate the remarkable potential of red Californian earthworms in effectively consuming polyethylene film and plastic particles, thereby accentuating their substantial and pivotal role in the degradation of polymer waste within ecosystems. The current global production of polyethylene and plastic waste amounts to an astounding 2 billion tons daily, of which a mere 20% undergoes recycling for the production of new goods. The disproportionate amount of unrecycled waste is released indiscriminately into the ecosystem, posing a formidable environmental challenge. Polymer waste exhibits an exceptionally slow decomposition rate, spanning over 400-500 years [1, 2], or emits hazardous compounds, such as dioxins, when subjected to incineration. Hence, the integration of red Californian earthworms in the natural decomposition of polymer waste, facilitating the conversion of hazardous material into a beneficial, waste-free by-product, emerges as a critical and pressing consideration. This investigation represents an inaugural exploration into the capacity of red Californian earthworms to decompose polyethylene and plastic waste, shedding illuminating light on their potential pivotal role in fostering ecologically sustainable waste management practices and furthering our understanding of ecosystem restoration.

1. Introduction

The pursuit of augmenting agricultural productivity while addressing the escalating environmental challenges posed by polymer waste has instigated a dedicated inquiry into the potential impact of the red Californian earthworm, Eisenia fetida, in biodegradation, particularly within the arid environmental landscapes of Turkmenistan. As part of an endeavor to optimize plant growth through the production of environmentally friendly fertilizers, the cultivation of vermicompost, facilitated by red Californian earthworms, has emerged as a principal objective. This necessitates a thorough investigation into the bioecological characteristics and developmental dynamics of the red Californian earthworm within arid climates, not only to advance scientific understanding but also to address practical implications in waste management and agricultural sustainability within the region.

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The potential of red Californian earthworms to efficiently biodegrade and convert organic waste, specifically polymer residues, presents an encouraging avenue for mitigating the challenges posed by polymer waste accumulation [3]. While acknowledging the promise of their capability, a scarcity of extensive scientific inquiry into the specific mechanisms and the extent of polymer waste degradation by red Californian earthworms is distinctly noticeable. Filling this knowledge gap warrants a comprehensive exploration of the earthworms' capacity to sustain and break down various polymer residues, contributing to the generation of environmentally preferable organic vermicompost.

Understanding the bioecological intricacies of red Californian earthworms in polymer waste biodegradation holds significance not only at a local level but also carries global relevance. The limited scientific literature concerning the study of these earthworms in the specified region underscores the novelty and potential impact of this investigative undertaking. While existing literature predominantly focuses on the application of vermicompost produced by Californian earthworms in agricultural contexts, the comprehensive exploration of red Californian earthworms' direct role in polymer waste decomposition and vermicompost generation remains an underexplored domain of research.

Recent studies have evinced a growing interest in the potential applications of vermicompost, particularly those produced by earthworm species such as Eisenia fetida, across various agricultural settings. Despite the paucity of research on red Californian earthworms in arid conditions, related studies highlight the positive impact of vermicompost incorporation on crop yield enhancements. Works by *Artykov, Ibragimov et Khabibova (2014)* [4], *Orazov (2014)* [5], *Bazarova (2005)* [6], *Bazarova et Allekov (2015)* [7], *Kaipova (2016)* [8], *Kurbanov et Ibragimov (1997)* [9], and *Ibragimov (2015)* [10] delve into the utilization and effects of vermicompost in agricultural settings, providing insights into its potential contribution to enhanced agricultural productivity. However, the dedicated exploration of the red Californian earthworms' capacity in polymer waste biodegradation and vermicompost generation necessitates further investigation in this underexplored research domain.

Furthermore, other pertinent studies have explored the potential applications of vermicompost and the utilization of earthworms in waste management. For instance, research by *F. de Jesús Rodríguez-Flores (2021)* [11] shed light on the growth and adaptability of the Californian red worm (Eisenia fetida) in a medium contaminated with diesel, indicating the capabilities of earthworms in challenging environmental conditions. Additionally, studies by *A.I. Amouei (2017)* [12] elucidated the capacity of earthworms to decompose various types of waste, including municipal solid waste, household waste, garden waste, and sewage sludge, highlighting the versatility of earthworms in waste management. Moreover, the work of *H. Khalid (2023)* [13] focused on the use of earthworms for solid waste management through the process of vermicomposting, further indicating the potential of earthworms in waste decomposition.

Through this comprehensive review of related studies, it becomes evident that red Californian earthworms, particularly Eisenia fetida, hold substantial potential in waste management practices, stimulating further examination into their role in polymer waste biodegradation and vermicompost generation within specialized environmental settings such as arid climates.

2. Materials and Methods

Research on the ecological characteristics, growth, and nutrition of red Californian earthworms within arid conditions in Turkmenistan from 2014 to 2023 was conducted at a vermicompost production farm located on the outskirts of the city of Turkmenabat and the Laboratory of Agrochemistry and Soil Science of the S.A. Niyazov Turkmen Agricultural University under the guidance of Candidate of Biological Sciences Peyzulla Hydyrov. Worm collection and observation from samples were carried out using the MBS-9 stereomicroscope, following methods adopted in helminthology.

At the red Californian earthworm cultivation site, the pH of nutrients was determined by inserting a litmus test into the solution and fixing its level on the appropriate scale. Furthermore, the temperature inside the pit and the environment was measured using specialized thermometers. Rotted cow manure served as earthworm feed, and 700 earthworms per 1 m^2 were initially released into the pit. For the experimental studies, the earthworms were provided with 10 kg of cow manure as feed, which was rinsed with a strong jet of water. The earthworms were fed and watered every 14 days, while corresponding pH, temperature, and humidity levels were monitored every 10 days in the concrete pit. Over time, the earthworms proliferated and spread across the entire pit area.

The numerical values of the earthworms were determined using a special stereomicroscope, and different stages of earthworm development were studied using the same equipment. The moisture content of the soil and vermicompost was evaluated according to a formula to determine moisture content (1). The collection of earthworm samples from manure was carried out, using the MBS-9 stereomicroscope and following methods adopted in helminthology. A total of 370 samples were selected and studied during the research period.

$$W = \frac{(a-b)\cdot 100}{b-w} \tag{1}$$

Here *W* is the moisture content of manure; *a* is the weight of a box with wet manure, (g);*b* is the weight of a box with dry manure, (g); *w* is the weight of an empty box, (g).

Observations revealed that the red Californian earthworm, a saprophytic hybrid, predominantly feeds on various organic substances. This distinctive earthworm strain, obtained through hybridization and selection of various forms of earthworms (Eisenia fetida) at the University of California, USA, in 1959. The research indicated that a temperature ranging from +15 to +30°C creates ideal conditions for the normal growth of the red Californian earthworm, while lower temperatures slow down their growth and temperatures below -4 to -6°C lead to their demise. Additionally, it was observed that these earthworms avoid light and burrow into the lower layers of manure.

Furthermore, the study uncovered that the composition of vermicompost primarily contains humus, nitrogen, phosphorus, potassium, calcium, and various trace elements, indicating its suitability as an organic fertilizer. The moisture content of the earthworm's feed manure played a crucial role in their reproduction, with the ideal humidity level for their growth being 70-85%. However, excessive humidity was shown to have adverse effects on earthworm reproduction.

Moreover, the study revealed the exceptional adaptability of red Californian earthworms in various applications, including the destruction of organic waste collected in industrial wastewater tanks and testing soils for pesticide contamination. The earthworms also played a significant role in soil biotesting and were proven to be effective as a dietary supplement for birds, as a means for soil fertility enhancement, and as a bait for fish.

The research also explored the dispersion of polyethylene fragments by red Californian earthworms and their potential in the biodegradation of polyethylene and plastic waste, providing unprecedented insights in a previously unexplored area. The findings underline environmental concerns and the potential role of red Californian earthworms in scattering polyethylene particles, which could have significant implications on waste management practices and environmental conservation.

In conclusion, the in-depth exploration conducted through this research provides valuable insights into the ecological dynamics and applications of red Californian earthworms within the arid conditions of Turkmenistan.

3. Results and Discussion

The red Californian earthworm, a saprophytic hybrid, was developed through the hybridization and selective breeding of various earthworm forms, particularly the Eisenia fetida species, by George Barrett at the University of California in 1959 [14]. Our investigation determined an optimal air temperature range of +15°C to +30°C for the normal growth of red Californian earthworms under natural conditions. At temperatures of +5°C to +10°C, earthworm growth decelerates, and at -4°C to -6°C, earthworms perish. Additionally, these earthworms shun light exposure and burrow into lower layers of manure.

The esophageal wall of these earthworms incorporates three pairs of calcifying glands furnished with extensive blood vessels, aiding in the elimination of surplus carbonate salts in the earthworm's blood fluid. These glands discharge a calcium carbonate solution into the earthworm's esophagus through a specific jet. This solution interacts with humic acid, a high-molecular organic substance present in the ingested, decomposed material within the manure's anterior intestine. As a result, gummites, the primary component of vermicompost, form from the organic matter assimilated by the earthworm. Typically, surpluses of humic acids accumulate in vermicompost and act as accelerators for plant growth when utilized as soil fertilizer. The nourishment intensity of the red Californian earthworm is also contingent on the pH level (hydrogen index) of the substances contained in the manure. Essentially, earthworms abstain from consuming highly acidic manure. Thus, it is recommended to rinse the manure in water to slightly diminish its acidity before utilizing it as earthworm feed. In our experiments, the pH value of the solution was 6 when we added water to the manure prepared for earthworm feeding. After rinsing it with a strong water stream, the pH value rose to 6.2. This rinsing process to some extent ameliorates the acidity of the manure. Worms perish if the pH level in their feed falls below 5 or exceeds 9. Typically, earthworms commence feeding from the lower manure layer, gradually ascending to the upper layer after depleting the nutrients. When a significant portion of the earthworms is concentrated in the upper 2-3 cm manure layer, an additional 8-10 cm layer of feed manure is required.

Vermicompost composition comprises 20-30% humus, 2-4% nitrogen, 3-4% phosphorus, 1-2% potassium, and 4-6% calcium [15]. Additionally, vermicompost contains trace elements such as iron, zinc, copper, boron, magnesium, and manganese, essential for plant growth. It also encompasses various beneficial microorganisms that enhance soil fertility [16].

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Table 1. Average Number and Biomass of Earthworms (2015-16) in Vermicompost Production Pit Samples (100 g)

№	Number of mature worms	Weight of mature worms (g)	Number of young worms	Weight of young worms (g.)	Number of young worms	Weight of young worms (g.)	Number of cocoons	Cocoon weight (g)	Total number	Total biomass (g.)
1.	6	2,256	4	0,408	154	0,770	6	0.054	170	3,488
2.	18	6,768	12	1,224	54	0.270	9	0.081	93	8,343
3.	12	4,512	12	1,224	33	0,165	12	0,108	69	6,009
4.	25	9,400	45	4,590	60	0,300	5	0,045	135	14,335
5.	12	4,512	4	0,408	20	0,100	8	0.072	44	5,092
6.	20	7,520	36	3,672	36	0,180	4	0,036	96	11,408
7.	15	5,640	15	1,530	21	0.105	-	-	51	7,275
8.	18	6,768	39	3,978	9	0,045	9	0.081	75	10,872
9.	24	9,024	17	1,734	40	0,200	10	0,090	91	11,048
10.	34	12,164	52	6,035	90	0,350	67	0,195	243	18,734
11.	19	7,144	30	3,060	52	0,260	14	0,126	115	10,590
12.	47	14,556	14	1,009	87	0,330	62	0,185	210	16,100
13.	21	7,560	86	17,372	70	0,147	10	0,200	187	15,279
14.	9	3,140	17	2,045	50	0,264	42	0,128	118	5,567
15.	84	21,000	126	19,200	162	0,750	18	0,090	390	41,040
16.	50	18,000	96	11,120	150	0,309	42	0,130	338	29,759
17.	14	4,620	7	1,540	35	0,107	70	0,209	126	6,576
18.	20	7,708	5	1,489	39	0,116	10	0,048	74	9,361
19.	60	15,120	114	17,934	60	0,096	4	0,032	238	33,182
20.	42	14,960	98	19,574	18	0, 035	56	0,340	214	35,909
21.	11	4,518	35	3,678	40	0,200	16	0,120	102	8,516
22.	11	4,536	86	17,400	-	-	27	0,358	124	22,294
23.	90	30,567	25	3,160	50	0,254	6	0,050	171	34,031
24.	17	6,700	50	6,257	95	0,389	12	0,125	174	13,471
25.	90	25,230	150	18,630	66	0,205	2	0.016	308	45,081
26.	28	10,080	90	18,180	14	0,028	59	0,079	191	28,367
27.	19	6,740	-	-	200	0,400	90	0,180	309	7,320
28.	3	0,580	5	0,175	2	0,007	6	0,036	16	0,798
29.	18	7,480	84	15,120	30	0,180	48	0.090	180	23,870
30.	9	3,150	42	7,569	15	0,100	24	0,109	90	10,928
31.	24	8,640	67	14,740	54	0,324	80	0,169	225	23,873
32.	4	1,480	33	5,940	20	0,140	5	0,035	62	7,595
33.	4	1,079	37	6,800	7	0,042	1	0,001	49	7,922
34.	6	2,280	48	8,640	24	0,168	42	0,120	120	11,208
35.	14	4,060	40	8,000	16	0,097	30	0,180	100	12,337
36.	18	6,120	66	14,200	30	0,210	12	0,096	126	20,626
37.	65	23,400	9	1,980	140	0,980	5	0,012	219	26,272
38.	-	-	42	10,500	18	0,127	18	0,086	78	10,713
39.	7	2,100	49	12,250	21	0,156	30	0,200	107	14,706
40.	53	15,900	17	2,650	90	0,540	10	0.010	170	18,100
41.	6	2,098	54	9,720	12	0,087	12	0,025	84	11,930
42.	22	16,460	7	0,840	6	0,025	5	0,040	40	17,365
43.	8	2,960	56	9,520	87	0,609	16	0,047	167	12,136
44.	4	2,540	52	9,457	70	0,558	8	0,044	134	12,599
45.	12	4,080	102	18,360	30	0,120	12	0,048	156	22,608
46.	6	1,800	97	19,400	-	-	4	0,030	107	21,230
47.	17	5,100	60	12,000	40	0,280	25	0,125	142	17,505
48.	36	12,240	85	17,000	100	0,640	9	0,018	230	29,858
49.	17	5,230	54	10,070	98	0,690	21	0,084	190	16,74
50.	40	14,000	34	7,480	6	0,050	19	0,076	99	21,606

Appropriate moisture levels in the feed manure are crucial for the active reproduction of the red Californian earthworm, with 70-85% humidity being optimal for normal earthworm growth. Our observations indicate a decrease in earthworm vitality at humidity levels of 30-50%, necessitating periodic water spraying in the earthworm breeding areas to heighten humidity. During dry periods with elevated air temperatures (+35°C to +40°C), daily spraying of the earthworm feed substrate is essential. Excessive humidity, however, negatively impacts earthworm reproduction. High humidity levels cause a discoloration of the earthworm larvae from bright yellow to reddish, leading to their gradual decay and obstructing the emergence of new larvae, resulting in a 25-30% decline in young larvae formation.

As per our findings, the combination of temperature (+15°C to +30°C) and humidity (70-85%) establishes the optimal conditions for earthworm growth. With adequate nutrition, the earthworms propagate vigorously, reaching high population levels. Table 1 presents the number of earthworms in individual test samples acquired under optimal conditions.

As depicted in Table 1, the highest quantity of earthworms found within 100 grams of manure was 390. Among these, approximately 21.54% were mature, 32.30% immature, 41.53% young earthworms, and about 4.61% larvae. The lifespan of a worm can extend to several years, with an average of 4-6 breeding cycles annually. A mature earthworm can yield up to 20 cocoons per breeding season, each cocoon producing 4 to 18 young larvae after 20-21 days, and commencing their own reproduction within 30-35 days under normal conditions. It is estimated that a mature pair of earthworms can generate approximately 1.5 thousand offspring annually (Fig. 1).

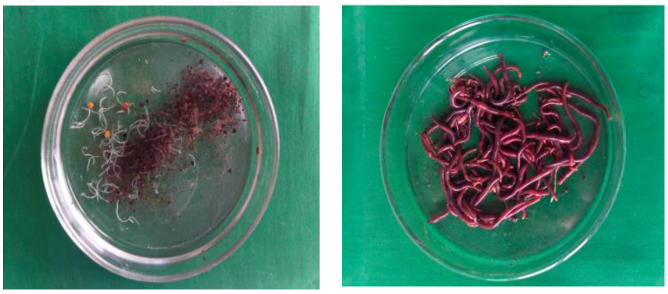

Fig. 1. Sexually Mature and Immature Red Californian Earthworms

Our observations reveal that young caterpillars congregate in dense clusters of soft grass and litter, forming localized focal points and dispersing as they mature. In our dry climate, it has been determined that earthworms reproduce most vigorously during the spring months of April and May, as well as in autumn during September and October. Worms intended for overwintering should be situated in environments with temperatures of 18-20°C.

During the preparation of vermicompost for utilization as organic fertilizer, a portion of the earthworms remains within it, continuing to survive for a specific duration, eventually integrating into the soil alongside the manure and feeding on various decomposing organisms [17]. When vermicompost is applied to crops such as tomatoes and bell peppers grown in greenhouses, the red Californian earthworms contained within it maintain their high level of activity in the soil for 50-60 days.

As indicated in Table 1, the biomass of red Californian earthworms per 100 grams ranged from approximately 3488 to 45081 grams, demonstrating the potential for high earthworm population levels within a specific quantity of cattle manure. In our investigations, we discovered that when plastic films were mixed with cattle manure, a primary food source for the red Californian earthworm, the worms were able to consume them.

Due to the enduring nature of various polyethylene products, they impede the natural progression of metabolic processes. When these products are incinerated in landfills, they release carcinogenic dioxin compounds into the atmosphere [18]. There is scientific evidence suggesting that red Californian earthworms can serve purposes beyond fertilizing cultivated plants. For instance, excess produced earthworms are introduced into fish ponds, where they can survive in water for 10-12 days and serve as sustenance for fish. Moreover, technologies have been developed for the production of dry protein flour from red Californian earthworms. The flour obtained from dried earthworms contains 60-70% protein and 20% fat, along with 8% lysine and 3% amino acids. Adding this protein flour to the primary fish diet significantly increases the fish's weight, particularly benefiting young fish, as evidenced by a 1.5 times weight gain over 40 days when 2 grams of dry earthworm meal per 1 kilogram of feed. The red Californian earthworm is utilized by anglers for baiting hooks. When employed for this purpose, the earthworms can remain viable on the hook for up to 6 hours. Unlike other earthworm species, they do not exude an unpleasant odor, which positively impacts the avoidance of fish being deterred.

Red Californian earthworms are also employed to decompose organic waste present in industrial wastewater tanks. For this application, sawdust is spread over the residues and coated to release the earthworms. In these instances, the earthworms transform these residues into vermicompost [19].

Red Californian earthworms are utilized in soil biotesting when soil is contaminated with diverse pesticides. When monitored over a specific duration, in environmentally uncontaminated soil, the earthworms do not perish and exhibit a tendency to burrow into the soil. However, in the presence of toxic compounds in the soil, over 50% of the earthworms perish within a designated timeframe, with the majority remaining on the soil surface and refraining from burrowing into the soil [20, 21, 22].

Red Californian earthworms are employed not only in vermicompost production but also in the formulation of feed additives for avian nourishment. Scientists have observed that incorporating red Californian earthworms into the feed of artificially reproducing endangered chicken-like species notably augments their reproduction in controlled environments. Furthermore, when live red Californian earthworms are administered to poultry, a rapid increase in their weight and egg production is observed. Administering 5 grams of live earthworms to chickens and 30 grams to adult chickens daily has proven to be beneficial [23].

In our investigation, we noted that domestic chickens actively seek out red Californian earthworms in vermicompost and consume them. Providing birds with earthworms as a dietary supplement enhances the quality of their meat and accelerates the maturation of chicks.

Furthermore, a crucial environmental consideration is the role of red Californian earthworms in the breakdown of polyethylene film. The identification of polyethylene particle breakdown in our study is particularly noteworthy, as no previous research has been conducted in this domain. The incineration of used polyethylene alongside waste carries significant environmental harm.

The incineration of polyethylene leads to the formation of acetylene volatile cyclic and acyclic hydrocarbons, along with other environmentally hazardous compounds [24]. Toxic dioxin compounds are generated during the incineration of metals and chlorine-containing organic and inorganic substances.

When dioxin compounds infiltrate the human body, they disrupt the immune system, leading to liver cell destruction and infertility. Inhalation of 0.06 ml/g of dioxin compounds per 60 kg of human body weight is sufficient to poison the body. These gases bind to cellular proteins, enter the nucleus, and stimulate gene activity accelerating oxidation processes, resulting in rapid aging, cardiovascular disease, and tumorous conditions. Dioxin compounds, formed during polyethylene and plastic combustion, are highly toxic and remain intact for 25-30 years. Upon release into the atmosphere, they form highly mutagenic and toxic carcinogens. Polyethylene compounds transform into dioxins under high-temperature conditions. Burning polyethylene and plastic particles stored in waste release various toxic compounds, including 1,4-dioxin, into the atmosphere.

An essential preventative measure against dioxin atmospheric contamination involves dispersing residues from the utilization of dioxin-forming polymer compounds in various applications without converting them into toxic compounds.

The primary objective of our research is to assess the biodegradation level of polyethylene and plastic waste when incorporated into the diet of red Californian earthworms. Furthermore, we investigate the role of red Californian earthworms in the breakdown of polyethylene film. The observed dispersion of polyethylene particles in our research is particularly noteworthy given the lack of prior studies in this area. Incinerating used polyethylene with waste is highly detrimental.

Over the course of a 9-year research endeavor, it was discovered that earthworms consume and break down polyethylene particles, integrating them into vermicompost as an inorganic substance. Consequently, the utilization of this method for processing polyethylene precludes the formation of toxic dioxin compounds. Our ongoing experiments focused on examining the capacity of red Californian earthworms to decompose polyethylene. At a red Californian earthworm breeding facility situated on the outskirts of the city of Turkmenabat, we supplied the earthworms with 0.130 mm thick polyethylene, commonly used as greenhouse covering material. Once again, it was unequivocally established that red Californian earthworms can consume and break down polyethylene of substantial thickness.

The conversion of various plastic products into recyclable materials after their useful lifespan represents a critical environmental concern. Notably, plastic products, including polyethylene, persist for many years without degrading and, in the case of incineration, can result in the release of toxic compounds into the atmosphere.

In our scientific investigations, we explored the ability of red Californian earthworms to decompose used plastic products. This involved the pulverization of the plastic in the laboratory using specialized equipment. Subsequently, the plastic powder was immersed in a Petri dish with water for a duration of 2 days (refer to Fig. 1).

We combined the moist plastic powder with cattle manure, the primary sustenance for red Californian earthworms, and fed it to them (refer to Fig. 2). After 14 days, it was observed that the worms had ingested the plastic particles and converted them into humus.

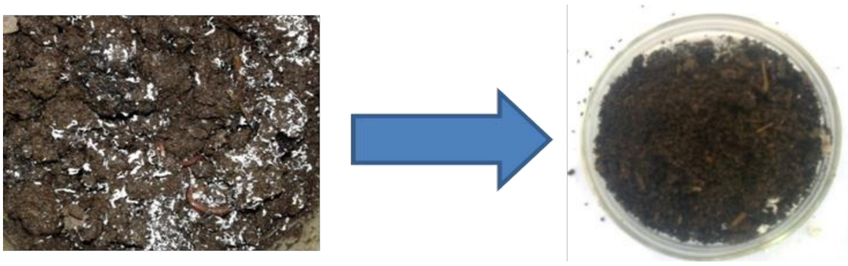

Fig. 2. Feeding Behavior of the Red Californian Earthworm on Polymer Waste

In the subsequent phase of the experiments, 1 kg of vermicompost, wherein the biohumus formation process continues, was enriched with 0.500 g of moistened plastic residue. The experimentation was replicated 5 times within 4 glass vessels (06/14/2016 – 12/15/2016). Consequently, the processing duration for 0.500 grams of plastic residue in the earthworm bed was observed to be 12-14 days, during which a significant population of juvenile earthworms efficiently decomposed the plastic residue.

Owing to the abundance of microorganisms producing bioactive substances within the fertilizer, plant resilience against pests and diseases is heightened [25]. Furthermore, the sprouting and maturation of grasses sown in specifically designed natural strips are accelerated. The flowering period of plants is also extended. Upon applying vermicompost to the soil within orchards, shrubs, and grassy areas, their growth cycle is prolonged, their foliage adopts a lusher hue, the flowers exhibit an increased diameter, and the roots are supple and robust. Substantially positive effects on the growth of fruit-bearing trees become apparent within 7-8 days.

Vermicompost encompasses a habitat for a distinctive array of microorganisms that contribute to elevating soil fertility. It is devoid of pathogenic microflora, helminth eggs, pathogenic protozoa cysts, or larvae of synanthropic mosquitoes. Additionally, the quantity of Escherichia coli bacteria present within it is notably lower in comparison to ordinary manure. Different plant species assimilate vermicompost in diverse manners. For instance, tomatoes demonstrate the highest uptake of vermicompost among green crops. Following spring plowing, when a layer of humus measuring 1-2 cm in thickness is formed, fruits and vegetables mature prematurely within 7-10 days, yielding abundant, exquisite, and substantial produce.

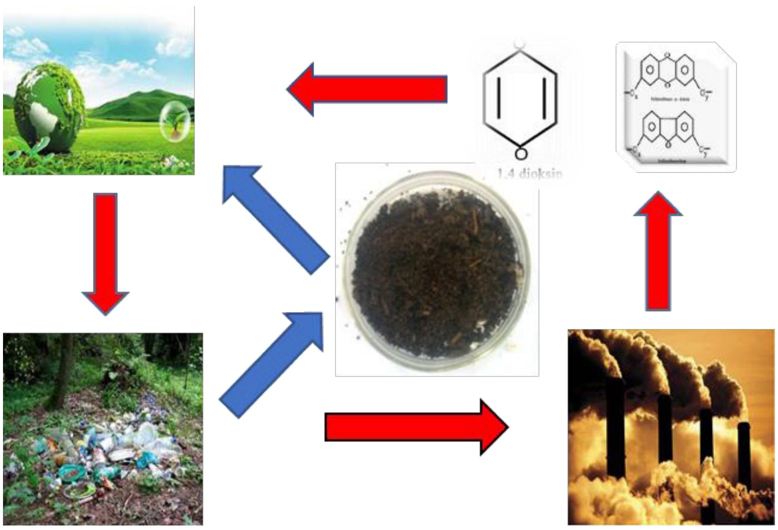

Fig. 3. Cycle of Polymer Residue Utilization by Red Californian Earthworms in Nature

Vermicompost, a high-quality organic fertilizer, contains 60-80 kg of highly nutritious plant nutrients per dry ton. In our context, the utilization of vermicompost as a fertilizer is deemed highly advantageous. Typically, humus content ranges from 0.6-0.9% in pasture soils and 0.1-0.4% in sandy soils. In ordinary manure, humus comprises 3-5%, while in vermicompost, it accounts for 10-30%. Vermicompost exerts varied impacts on different phases of plant growth. For instance, its application is optimal for watermelon with 4-5 leaves and wheat during the germination phase. Consequently, in agriculture, the application of vermicompost to crops influences plant growth, enhances yield, and promotes high-quality produce. This fertilizer provides adequate water and air to plant roots in the soil and facilitates efficient water utilization without polluting the environment, soil, or water. Additionally, vermicompost, as a biologically active substance for plants, serves as a biostimulant containing numerous compounds that accelerate plant growth, diverse enzymes, and soil antibiotics. The germination of plant seeds soaked in a biosulfate solution is substantially enhanced. It is acknowledged that vermicompost-enriched soil halts the growth of pathogenic microflora and enhances plant resistance to cold and drought while diminishing weed population. Biohumus exhibits technological traits including incombustibility, moisture resistance, and hydrophilicity, alongside high mechanical particle strength and fertilizing properties. It distinguishes itself from other organic fertilizers through selectivity, moisture egulation, advantages in production, and convenience in transportation and application.

Within vermicompost reside microorganisms that convert toxic metal compounds and impede the transmission of radionuclides to plants. Humic acid in biosulfate forms stable humic salts upon combining with heavy metals, preventing enzymatic hydrolysis by the plant root system. Consequently, harmful radionuclides are absorbed by humic salts, averting harm to the environment and wildlife. Physiologically active substances stored in soil enriched with vermicompost activate vital biochemical and physiological processes in plants, augment metabolism, and enhance nutrient absorption. The greater the quantity of vermicompost in the soil, the superior its buffering properties. The application of biohumus fertilizer proves highly beneficial for various crop types grown in our country, particularly concerning the limited humus content in Turkmenistan's soils. In monitoring the effectiveness of vermicompost in sandy desert soils of Gularyk village in the Amyderya River valley from 2014-2019, it was observed that meadow irrigated, sandy-desert, and meadow-alluvial soils are prevalent in the Amu Darya valley. The natural humus content in irrigated meadows, extensively utilized in agriculture, is evenly distributed, with humus content ranging from 1-3% in irrigated meadow soils and 0.4-0.8% in sandy desert soils.

Increasing the humus content in the soil is imperative for achieving a bountiful harvest. The introduction of vermicompost into the soil stands as a primary requisite for amplifying fertility levels several-fold. Humus formation in the soil arises from the decomposition of various plant residues, including dried roots, stems, leaves, manure, and animal carcasses. Assorted bacteria, unicellular organisms, fungi, saprophytic insects and larvae, as well as earthworms, partake in organic waste degradation and humus generation. Notably, earthworms play a pivotal role in the humus formation process.

To facilitate the cultivation of tomatoes in greenhouses using vermicompost, the process involved applying vermicompost to cover the cultivation area and adding additional soil between two 40-meter rows of tomatoes at depths of 30 cm and 20 cm. This procedure included the incorporation of 500 kg of humus into the bed. After applying the vermicompost, the beds were watered with tap water and then covered with soil. It's noteworthy that the seedlings grown in the vermicompost-fertilized tomato beds did not require nitrogen, potassium, and phosphorus fertilizers. Emphasis was placed on regular irrigation and weeding. The "Chelbars" variety of tomatoes thrived in the greenhouse environment, yielding 8-10 kg of tomatoes per bush. Post-harvest observations revealed that the lateral roots of the tomatoes had proliferated within the vermicompost after the stems were removed, indicating enhanced nutrient absorption and root network development.

When transplanting seedlings of bell peppers (specifically the "Lastochka" variety) into greenhouses, individual cylindrical wells were dug under each base, and 0.5 kg of vermicompost was added, then covered with a layer of soil. This approach significantly contributed to the prolific branching and blossoming of bell pepper plants. Interestingly, the application of vermicompost enhanced the seedlings' resistance to root rot and wilting compared to conventional soil fertilization methods. Bell pepper treated with vermicompost exhibited resistance to root rot, likely due to the absence of various pathogens in vermicompost in comparison to conventional cattle manure.

The introduction of vermicompost between rows of flowers in both greenhouse and outdoor gardening settings proved to be advantageous (refer to Fig. 4). The use of vermicompost resulted in increased size of pepper fruits and a yield of 3.0-3.5 kg per bush without requiring additional nitrogen, phosphorus, and potash fertilizers. The primary focus was on weeding, soil aeration, and periodic watering. Overall, vermicompost emerged as a crucial fertilizer for both greenhouse and outdoor gardening environments.

Fig. 4. Application of Vermicompost to Greenhouse-Grown Roses

Upon the application of vermicompost to various cultivars of Dutch white roses in controlled greenhouse conditions, substantial changes were observed. These changes included an increase in the size of the rose petals and significant elongation of the stems. Additionally, it was found that filling half of the flower pot with vermicompost led to a reduction in the water demand of the roses. Furthermore, it was observed that red Californian earthworms, present in the vermicompost, not only thrived in the greenhouse but also continued to consume diverse organic waste present in the soil.

Ideally, the introduction of vermicompost into gardens in autumn is recommended, coinciding with the shedding of leaves. During this period, the earthworm larvae and mature earthworms existing in the vermicompost continue to thrive in the outdoor environment, feeding on fallen leaves beneath the layer of vermicompost. Following the autumn rains, the fallen leaves undergo decomposition under the vermicompost, providing sustenance for the earthworms, thereby promoting the transformation of the organic matter into vermicompost.

Introducing vermicompost into orchards during the autumn season has been associated with significant flowering of trees in early spring, yielding large fruits, and enhancing the resistance of the trees to various diseases. Moreover, the application of vermicompost has been found to be beneficial for indoor plants such as Kalanchoe, cacti, and aloe. These indoor flowers exhibit improved growth and enhanced blooming when cultivated with vermicompost fertilizer, without producing any unpleasant odor. Research is underway in our country to investigate the impact of red Californian earthworms on various harmful flies and moths as they consume larvae within the precincts of young seedlings in shady and coniferous gardens

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Fig. 5. Polyethylene Decomposition by Red Californian Earthworms (Eisenia fetida)

The process of vermicompost formation results in earthworm excreta that is rich in ammonia, produced within the intestinal wall, effectively meeting the nitrogen requirements of plants. Furthermore, vermicompost finds widespread application in mitigating soil salinization and enriching unproductive soils with organic matter. When seeds are soaked in an aqueous solution of vermicompost, their germination is significantly enhanced. Additionally, plants fertilized with vermicompost exhibit increased resistance to diseases. Notably, the use of biohumus fertilizer is crucial in the cultivation of ornamental plants in specialized areas near commercial and recreational establishments. The application of vermicompost as a fertilizer for ornamental trees, shrubs, and herbs does not result in a foul odor or soil contamination. Furthermore, the presence of vermicompost fertilizer contributes to increased humidity levels around ornamental trees and grasses.

4. Conclusions

The findings of this study provide valuable insights into the role of red Californian earthworms (Eisenia fetida) in the decomposition of polymer waste, particularly focusing on their ability to consume and break down polyethylene particles and plastic ash. Through rigorous experimentation, several key conclusions have been drawn, shedding light on the optimal environmental conditions for the development of red Californian earthworms and their efficacy in transforming polymer waste into sustainable, eco-friendly resources.

First and foremost, it has been established that the optimal humidity level for the thriving development of red Californian earthworms in arid conditions lies within the range of 70-85%, while the air temperature conducive to their growth falls between +15°C and +30°C. Furthermore, the pH value of the nutrient medium has been identified as a critical factor, with an optimal range of 6.0-6.2 conducive to the well-being and productivity of the earthworm population. These parameters provide essential guidelines for the establishment of favorable conditions for red Californian earthworm cultivation in arid environments.

Moreover, the investigation delved into determining the biomass of red Californian earthworms across various age groups, elucidating the quantity of vermicompost produced under arid conditions. This data contributes to a comprehensive understanding of the earthworm population dynamics and their vermicomposting output, essential for practical applications and scaling up vermicomposting operations in arid regions.

The pivotal discovery that red Californian earthworms exhibit the capacity to consume polyethylene particles and plastic ash, subsequently decomposing these materials, marks a significant breakthrough. This digestion process not only mitigates the accumulation of polymer waste but crucially prevents the release of toxic compounds into the atmosphere that typically result from the incineration of polyethylene and plastic. Thus, these findings have profound implications for waste management practices and environmental conservation efforts, offering a sustainable solution to the challenges posed by polymer waste disposal.

Furthermore, the study underscores the potential of vermicompost as an environmentally friendly, economically efficient, and organic fertilizer suitable for a wide range of plant species. The versatile applicability of vermicompost in agriculture as a nutrient-rich soil conditioner with the ability to enhance plant growth and vitality has been reaffirmed. These findings open avenues for the widespread adoption of vermicompost as a sustainable alternative to chemical fertilizers, promising beneficial outcomes for agricultural productivity and environmental sustainability.

In conclusion, the results of this study highlight the instrumental role of red Californian earthworms in polymer waste decomposition, offering valuable insights into their environmental requirements, waste management capabilities, and the agricultural utility of the vermicompost they produce. These findings pave the way for the implementation of sustainable practices in waste management and agriculture, with significant potential for addressing environmental challenges and promoting sustainable development.

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