Sustainable Development Research; Vol. 7, No. 4; 2025
ISSN 2690-9898 E-ISSN 2690-9901
https://doi.org/10.30560/sdr.v7n4p1

Comparative Environmental Effects of Lithium, Nickel, Lead, and Zinc-based Battery Waste on Seed Germination and Early Plant Growth

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Received: September 11, 2025 Accepted: October 7, 2025 Online Published: October 14, 2025

Abstract

Batteries serve as crucial components of modern life yet they create major environmental risks when people dispose of them incorrectly. The heavy metals like lithium, nickel and lead present in batteries can escape into soil and water bodies which damages plant ecosystems and causes harm to vegetation. This study examines the effects of four battery-derived metals, lithium, nickel, lead, and zinc, on plant development and seed starting processes. Cauliflower plants and spinach seeds were used as test subjects and exposed to controlled concentrations of each metal compound through four weeks. The study demonstrated that lithium and nickel exposure resulted in complete plant death and complete seed germination failure. The plant growth was severely limited by lead exposure which also blocked seed germination, but zinc exposure produced no adverse effects on plant health and enhanced seed germination rates above control levels. The research demonstrates that proper battery disposal methods require specific approaches based on battery chemical composition. Specialized recycling facilities should process lithium-ion batteries and nickel-metal hydride batteries and lead-acid batteries, but alkaline and zinc-carbon batteries can go to general waste disposal when handled correctly.

Keywords: battery-derived metals, plant development and seed germination, battery disposal methods

1. Introduction

The rapid expansion of portable electronics, renewable energy systems and electric vehicles during the past few decades has led to a massive increase in battery usage. The increasing number of batteries in use requires immediate attention to their life cycle management because of disposal methods and environmental effects after use. The disposal of spent batteries leads to environmental problems because they end up in landfills and unregulated waste sites where their materials can migrate into nearby water and soil. Batteries consist of different metals which include vital trace elements and dangerous substances that become toxic when they accumulate in nature. The environmental release of lithium (Li) and nickel (Ni) and lead (Pb) from rechargeable batteries creates significant ecological problems because these heavy metals are found in standard battery compositions. The environmental release of these elements creates biological disruptions and decreases soil fertility while blocking root absorption and generates extended contamination threats for agricultural lands and biodiversity.

The two primary battery categories consist of primary non-rechargeable batteries and secondary rechargeable batteries. The environmental risk from primary batteries such as zinc-carbon and alkaline cells is lower because they contain zinc and manganese dioxide which serve as essential micronutrients at trace levels. The disposal of these batteries becomes problematic when they accumulate for extended periods or when disposed of incorrectly. The environmental risks from secondary batteries including lithium-ion and nickel-metal hydride (NiMH) and lead-acid chemistries are more severe because they contain toxic and reactive substances. The two primary lithium-ion battery materials used in consumer electronics and EVs consist of lithium cobalt oxide (LiCoO2) and lithium nickel manganese cobalt oxide (NMC). The biological systems face toxicity risks from transition metals which are present in these materials. Lead-acid batteries used in various industrial and automotive applications contain lead which serves as a proven neurotoxin that harms the environment.

The disposal of batteries faces inconsistent management practices throughout different geographic areas. The practice of informal battery recycling through open burning and basic acid extraction methods spreads across various regions while creating dangerous levels of contaminants that threaten both human settlements and natural environments. The disposal of batteries in industrialized nations often results in their placement in domestic waste streams which then experience accelerated metal release through landfill conditions. The lack of proper disposal knowledge among consumers exists because different regions have different regulatory approaches to battery disposal. The environmental guidelines sort batteries by their chemical composition but fail to show direct biological effects on plant survival and seed growth.

Multiple scientific investigations have analyzed battery leaching behavior and studied how specific metals affect soil microbes and aquatic organisms. Research about how battery-derived metals affect early-stage terrestrial plant development remains scarce especially when using controlled laboratory settings for exposure studies. The critical ecological development phases of seed germination and seedling growth face disruptions which create a chain reaction that affects food webs and hinders habitat recovery.

This research investigates the effects of four metals, lithium, nickel, lead and zinc, which are common battery components. Brassica oleracea cauliflower plants and Spinacia oleracea spinach seeds are used to study how these metals affect plant development and seed germination and plant health when exposed to uniform conditions. The combination of quantitative measurements with visual health signs enables us to develop an operational bioassay system for determining toxic substance levels. The research findings provide scientific knowledge and practical applications which help develop improved battery disposal systems and spread knowledge about the environmental dangers of incorrect e-waste disposal.

2. Methods and Procedure

The research design aimed to duplicate natural environmental contact with battery-generated metal pollutants to study their biological impacts on plant life and seed development. The study used 10 cauliflower (Brassica oleracea) plants and 25 spinach (Spinacia oleracea) seeds because cauliflower plants grow quickly and show obvious signs of stress when contaminated while spinach seeds work well for germination studies because of their established developmental patterns.

The design of experiment included five experimental groups which received lithium (Li) and nickel (Ni) and lead (Pb) and zinc (Zn) treatments alongside one distilled water control. Chemical solutions were prepared by dissolving 15g of each chemical metal salts into half a cup (~150mL) of purified water. Fresh solutions were made each week to maintain chemical stability. Standard potting mix filled plastic cups with 1 cup each served as containers for plant growth. Two cauliflower plants were assigned to each metal treatment group and two plants to the control group.

Spinach seeds were planted into labeled seed starter trays with five seeds per treatment group. All cups and trays were placed under identical outdoor conditions to provide equal exposure to sunlight and wind and natural temperature fluctuations. All containers were rotated weekly to minimize microclimate effects on results. Each metal group received 10 mL of solution daily for maintaining proper soil saturation without waterlogging. The study duration spanned more than 30 days to enable researchers to observe various growth stages and stress reactions in the plants.

Measurements were taken weekly and included plant height (cm), number of leaves, visual health notes (leaf discoloration, curling, wilting, stem rigidity), and seed germination counts. Photographs were captured at each checkpoint to create a visual time series. Height was measured from the soil surface to the tallest leaf tip using a metric ruler. Germination was defined as the emergence of the radicle from the seed coat and recorded on a per-tray basis. Plants that showed no measurable growth or complete loss of turgor by week four were deemed non-viable.

All measurements and observations were noted manually in a spreadsheet for comparative analysis. Results were presented in terms of average plant height per group, relative change from day zero, and total seed germination percentage. These metrics facilitated both quantitative and qualitative comparisons across the five treatment groups, aiding in isolating the effects of each metal on early plant development, stress response, and seed germination rate.

Figure 1. Materials: Cauliflowers, Spinacia seeds, Potting mix, Metal salts, Cups

3. Results and Analysis

The research demonstrated that each metal substance produced major and distinct impacts which affected plant wellness (Fig.2) and seed germination success rates (Fig.3). All plants maintained similar height ranges between 11.6–14.7 cm during the first week of observation before metal-specific effects started to appear in week two.The control plants demonstrated typical development through their initial slow growth of 2-4% followed by continuous fast growth reaching 42-66% during the first month.

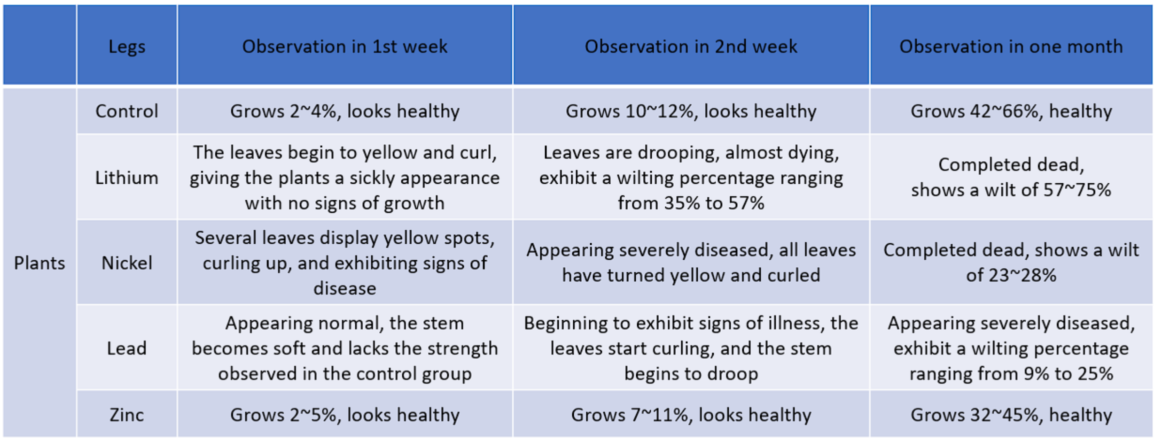
The plants exposed to lithium treatment showed the most severe and fastest deterioration in their health status. All treated plants developed chlorosis symptoms and their leaves curled up and stems became soft during the second week of the study. Both plants experienced complete collapse starting from week two until week four when their leaves turned brown and their stems turned dry. The lithium-treated plants showed a net growth reduction of 75% when compared to control plants. The existing scientific evidence shows lithium disrupts chloroplast operation while blocking essential nutrient absorption between plant roots and soil.

The toxic effects of nickel exposure became visible after two weeks of no noticeable impact. The nickel-treated plants maintained identical growth patterns to control plants throughout the first two-week observation period. The nickel-treated plants started showing leaf curling and grey spots during week three before their complete collapse occurred in week four. The toxic effects of nickel accumulated with time because the substance builds up in biological systems and disrupts enzyme operations. The plants experienced severe height reduction and scientists declared them non-viable after thirty days of observation.

The plant growth inhibition caused by lead exposure took longer to develop than the effects of other tested metals. The plants under lead treatment experienced decreased vitality throughout all measurement periods but survived without death. The lead-treated plants reached an average growth of 2.0–2.8 cm which represented 20% of the control group's total growth. The plants showed drooping leaves and minor yellowing but did not develop the fatal necrotic damage which affected lithium and nickel-treated plants. Lead functions as a long-term stress factor which damages metabolic processes and disrupts calcium signaling pathways without triggering immediate cell death.

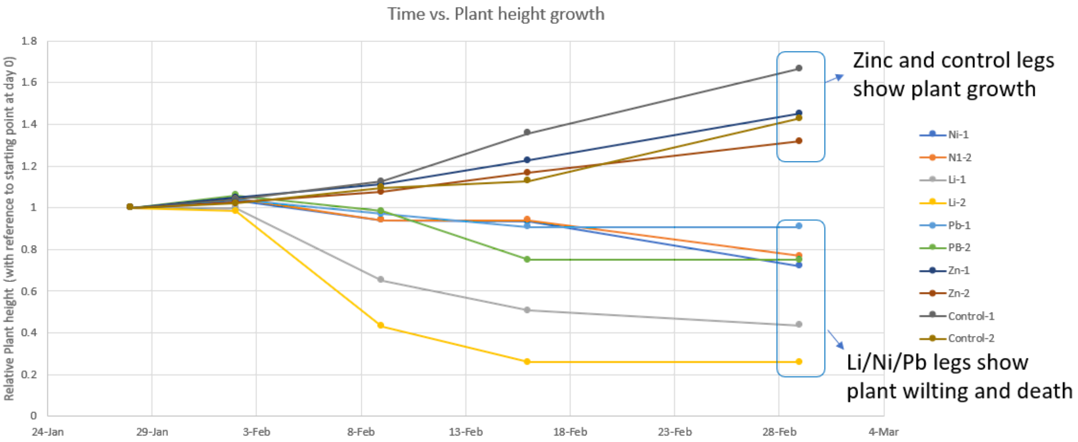
The plants treated with zinc achieved results which either matched or exceeded the outcomes of the control group. The zinc-treated plants showed weekly growth between 1.8 and 2.5 cm which resulted in final heights between 18–19 cm that matched or surpassed the control range. The plants treated with zinc showed no toxic symptoms including chlorosis or wilting and demonstrated increased leaf growth and denser leaf structures. The results confirm zinc functions as a micronutrient which helps plants control enzymes and produce auxin.

(a)



	Legs	Observation in 1st week	Observation in 2nd week	Observation in one month
Plants	Control	Grows 2~4%, looks healthy	Grows 10~12%, looks healthy	Grows 42~66%, healthy
	Lithium	The leaves begin to yellow and curl, giving the plants a sickly appearance with no signs of growth	Leaves are drooping, almost dying, exhibit a wilting percentage ranging from 35% to 57%	Completed dead, shows a wilt of 57~75%
	Nickel	Several leaves display yellow spots, curling up, and exhibiting signs of disease	Appearing severely diseased, all leaves have turned yellow and curled	Completed dead, shows a wilt of 23~28%
	Lead	Appearing normal, the stem becomes soft and lacks the strength observed in the control group	Beginning to exhibit signs of illness, the leaves start curling, and the stem begins to droop	Appearing severely diseased, exhibit a wilting percentage ranging from 9% to 25%
	Zinc	Grows 2~5%, looks healthy	Grows 7~11%, looks healthy	Grows 32~45%, healthy

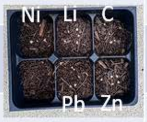
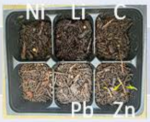
(b)



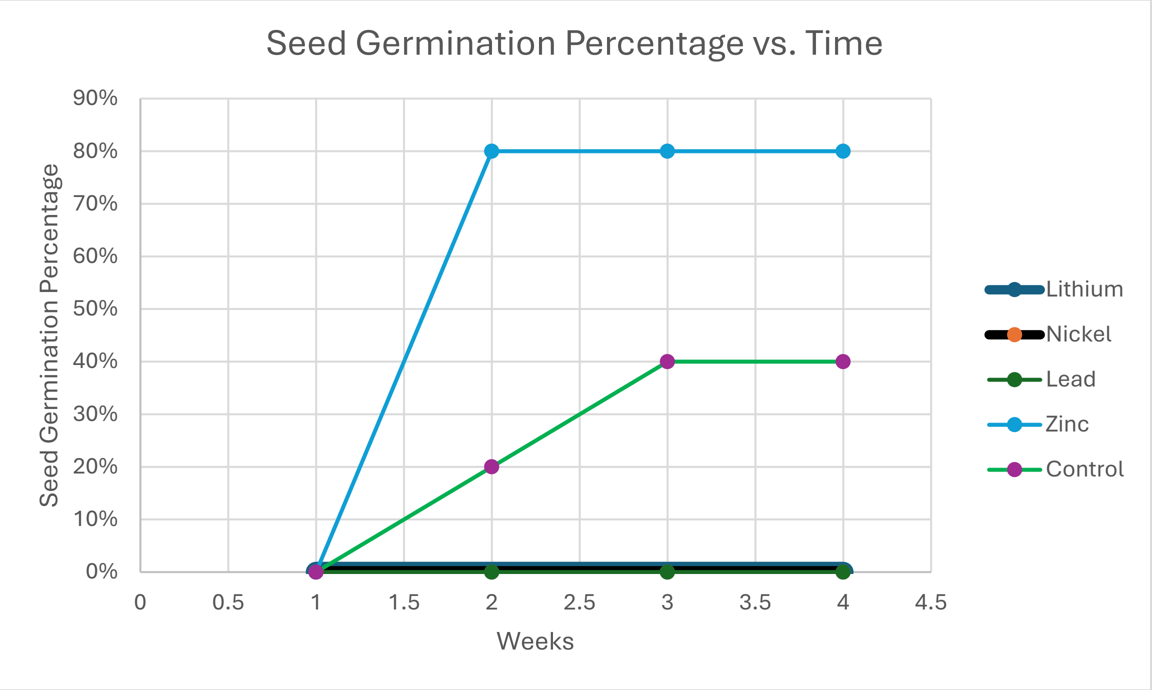
(c)

Figure 2. Plant growth results. (a) Raw images of plants from each group (b) Plant health observations (c) Plant height over time

The seed germination results confirmed the observed patterns in plant development. The lithium and nickel and lead-treated spinach seeds failed to germinate throughout the entire thirty-day study period. The seeds in the zinc treatment group reached 80% successful germination during the second week and continued their growth process. The control group showed moderate seed germination at 40% while their roots developed normally. The results demonstrate that early developmental stages show extreme sensitivity to heavy metal stress while zinc proves to be a beneficial factor for seed germination.

	Legs	Observation in 1st week	Observation in 2nd week	Observation in 4th week
Seeds	Control (W)	No spout	One out of five seeds has sprouted	Two out of five seeds have sprouted
	Lithium (Li)	No spout 	No spout 	No spout 
	Nickel (Ni)	No spout	No spout	No spout
	Lead (Pb)	No spout	No spout	No spout
	Zinc (Zn)	No spout	Four out of five seeds has sprouted and grow faster than control leg	Four out of five seeds has sprouted

(a)



(b)

Figure 3. Seed germination results. (a) Raw images and observations (b) Seed germination percentage chart

The data presented in Fig. 2 and 3 shows how each plant group grew in height throughout the weeks and how germination rates accumulated across different treatment groups. The control and zinc-treated plants kept their stems upright with green leaves but lithium and nickel-treated plants showed stem failure and complete loss of turgor pressure and necrotic tissue. The plants treated with lead maintained their upright position but displayed clear signs of stress.

The study demonstrated that different metals produce distinct biological effects which directly relate to their chemical identity. The study showed lithium and nickel caused immediate toxic death of plants but lead caused long-term growth suppression and zinc showed no harmful effects and possibly some beneficial effects. The consistent results from plant and seed measurements confirm that different battery materials create specific and quantifiable effects on soil-plant ecosystems while showing that not all battery materials create equal environmental threats.

4. Discussion and Conclusion

This study provides strong experimental evidence that different battery-derived metals exert varying levels of toxicity on terrestrial plants and seeds. Among the four metals tested, lithium and nickel caused the most severe biological damage, while lead imposed moderate suppression, and zinc appeared neutral to slightly beneficial. These distinctions are important because not all batteries pose equal environmental risks. Although public messaging often lumps batteries into general e-waste categories, the actual impact of improper disposal depends greatly on the underlying chemistry.

The most dramatic results were observed with lithium-treated plants. Both cauliflower plants exposed to lithium exhibited complete collapse by the fourth week. Early yellowing, curling, and drying of leaves were visible within the first 7–10 days, suggesting that lithium's effects occur rapidly and disrupt fundamental cellular processes. This aligns with known literature that shows lithium can interfere with photosynthesis, chloroplast structure, and the ionic balance in plant root membranes. The fact that seed germination was also completely suppressed further supports the idea that lithium can damage meristematic tissues at early growth stages, preventing even the initiation of developmental pathways.

Nickel produced delayed but equally fatal outcomes. The plants initially seemed unaffected, showing near-normal height gains in the first two weeks. However, signs of distress such as spotted leaves and curling began to manifest in week three, followed by plant death in week four. This trajectory indicates a bioaccumulative effect which is consistent with nickel's well-known tendency to disrupt enzymatic functions involved in nitrogen metabolism and to generate oxidative stress over time. Nickel is also known to displace essential nutrients such as magnesium and calcium, contributing to gradual system-wide failure.

Lead-treated plants exhibited a different pattern. Unlike Li and Ni, Pb did not kill the plants outright but rather slowed growth and induced visible signs of stress such as leaf drooping and discoloration. Final height measurements showed roughly 20% of the control group's average gain, indicating long-term inhibition of cell elongation and possibly disrupted transpiration due to root damage. Lead's well-documented toxicity includes its interference with water channel proteins and calcium signaling pathways. Its chronic toxicity may not immediately kill plants, but over time, it limits the capacity for nutrient transport and photosynthesis.

Zinc, in contrast, showed no toxicity under the exposure levels tested. In fact, plants in the zinc group displayed equal or slightly superior growth compared to the control group. Spinach seeds exposed to zinc also germinated at a significantly higher rate (80%) than the control group (40%). These observations reflect Zinc's essential role as a micronutrient in many enzymatic processes including auxin metabolism, protein synthesis, and membrane stabilization. However, it should be noted that excessive zinc can be toxic at higher concentrations, and the positive effects seen here are likely due to the zinc dose aligning with optimal nutrient thresholds.

From an ecological and waste management perspective, these findings underscore the importance of battery chemistry-specific disposal strategies. Currently, many recycling or disposal systems do not distinguish between battery types, and public understanding of the environmental risks associated with improper disposal remains limited. Our results suggest that regulatory agencies should implement clearer labeling requirements and promote differential handling practices: lithium-ion and nickel-metal hydride batteries should never be sent to landfill and must be routed to e-waste centers with containment capabilities. Lead-acid batteries already benefit from take-back programs, but continued public engagement is necessary to keep them out of general trash systems. Zinc-carbon and alkaline batteries, while less hazardous, still require guidance on bulk accumulation and regional landfill permeability.

Another key insight from this experiment is the vulnerability of seeds compared to mature plants. Germination was completely halted in the Li, Ni, and Pb groups, indicating that the early stages of development are particularly sensitive to even low-level contamination. For conservationists, urban gardeners, and agricultural professionals, this suggests that soils contaminated by battery metals are not safe for crop starting, revegetation efforts, or ecological restoration. Efforts to reclaim post-industrial or landfill-adjacent plots for planting should include heavy metal screening—especially for lithium and nickel.

Limitations of this study include its 30-day time frame, single-soil composition, and a limited number of plant species. While cauliflower and spinach are useful indicator organisms, broader ecological relevance would be improved by including native grasses, legumes, or flowering plants that represent different photosynthetic strategies and root architectures. Additionally, this study focused solely on the biological outcomes of metal exposure. It did not directly measure the metal concentrations in soil or plant tissue, nor did it analyze leachate chemistry over time. Future work should incorporate spectrometric techniques like ICP-MS to quantify actual metal uptake and use geochemical modeling to understand metal speciation under field conditions, which is one of the research topics that I'm currently working on at Sustainable Materials and Energy Laboratory at UCSD.

Finally, our results contribute to the growing field of green materials engineering and sustainable design. As battery manufacturers consider safer chemistries for next-generation energy storage (e.g., solid-state lithium, sodium-ion, or aqueous zinc batteries), studies like this can help benchmark environmental performance from a system-thinking perspective. By integrating biological toxicity data into life-cycle assessments and material selection, we can ensure that the push for electrification and energy storage doesn't come at the cost of long-term ecosystem damage.

In conclusion, this study highlights the urgent need for science-based policy on battery recycling and disposal. We show that metals commonly found in batteries vary dramatically in their impact on plants and seeds, with lithium and nickel posing acute threats, lead causing chronic suppression, and zinc being relatively safe. Efforts to educate the public, reform recycling logistics, and improve soil screening should all incorporate these findings to reduce the ecological footprint of battery use and disposal.

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