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Evaluation of Basaltic Quarry Dust as a "Sustainable Geo-Mineral" Amendment for Enhancing Soil Fertility-A Case Study of "Govandari Tanda-Ohar" Chhatrapati Sambhajnagar, Aurangabad

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Abstract

Modern agriculture in the Marathwada region of Maharashtra, India, is currently facing a critical sustainability crisis characterized by long-term soil acidification, depleted microbial activity, and the exhaustion of essential trace minerals due to an over-reliance on N-P-K chemical fertilizers. While the native geology of the Deccan Trap Province is composed of basaltic lava flows naturally rich in essential base cations like Calcium (Ca), Magnesium (Mg), and Iron (Fe), these nutrients are released at a geological pace through natural weathering. Simultaneously, the stone-crushing industry in Chhatrapati Sambhajnagar generates vast quantities of "Quarry Dust," an industrial byproduct that currently serves as a significant source of environmental air pollution. This research investigates a circular economy solution by repurposing finely ground basaltic waste (<75 µm) as a "fast-acting" geological amendment to restore the mineral balance and structural integrity of Black Cotton Soil (Vertisols).

The methodology focused on a pilot expansion across 1 acre in Govandari Tanda, Ohar, Chhatrapati Sambhajnagar, utilizing a hybrid application of basaltic powder and local organic compost. The primary scientific objective was to harness the mineralogy of the Deccan Basalt to improve crop yields and soil health parameters. Key performance indicators (KPIs) included a measurable reduction in the deep cracking characteristic of expansive Vertisols, percentage increases in crop yield, and a reduction in local particulate pollution.

Results from the study indicate that basaltic rock dust acts as a potent re-mineralizer, providing a distinct niche in regenerative and organic farming. Beyond direct agronomic benefits, the innovation facilitates long-term carbon sequestration through the enhanced weathering of silicate minerals, contributing to broader environmental sustainability goals. The proposed scaling plan transitions from experimental pilots to regional adoption via localized production hubs and GIS-supported monitoring. Ultimately, this research demonstrates that integrating industrial waste management with sustainable agricultural practices can significantly reduce chemical fertilizer dependency while restoring the long-term fertility of the Deccan Trap region.

Keywords: Basaltic Quarry Dust, Soil Re-mineralization, Deccan Trap Region, Black Cotton Soil (Vertisols), Sustainable Agriculture, Circular Economy, Enhanced Rock Weathering.

Introduction: The Silent Crisis of Soil and the Basaltic Solution.

The agricultural heartland of the Marathwada region, centered around Chhatrapati Sambhajnagar, stands at a critical environmental and economic crossroads. For decades, the Green Revolution's promise of high yields has been sustained by an increasing dependency on synthetic N-P-K (Nitrogen, Phosphorus, and Potassium) fertilizers. However, this intensive chemical approach has inadvertently triggered a silent crisis: the systemic degradation of the region's most precious asset—the Black Cotton Soil (Vertisols). As we look toward a future of climate uncertainty and a growing population, the need to transition from chemical-heavy farming to a mineral-rich, regenerative model has never been more urgent. This research explores an innovative intersection between geology and agronomy, proposing the use of basaltic quarry dust—a byproduct of the stone-crushing industry—as a sustainable geo-mineral amendment to revitalize the Deccan Trap region.

The Problem: *Chemical Fatigue and Mineral Depletion.*

The prevailing agricultural model in the Deccan Trap region is built on a narrow chemical foundation. While N-P-K fertilizers provide the primary macronutrients required for plant growth, they fail to address the complex mineralogical needs of the soil. Continuous application of these chemicals has led to widespread soil acidification. As the pH levels drop, the soil's delicate microbial ecosystem is disrupted, leading to a loss of biological fertility that cannot be replaced by factory-made pellets.

Furthermore, "mineral mining"—the process where crops extract a wide array of trace elements from the earth without replenishment—has left the soil exhausted. Essential minerals like Calcium (Ca), Magnesium (Mg), and Iron (Fe), which are vital for plant immunity and human nutrition, are increasingly absent from the topsoil. In the expansive Vertisols of Chhatrapati Sambhajnagar, this depletion is coupled with physical degradation. These soils are notorious for their "shrink-swell" capacity; they swell when wet and develop deep, cavernous cracks during the dry season. Chemical fertilizers do nothing to stabilize this physical structure, leaving the soil vulnerable to erosion and rapid moisture loss.

The Geological Paradox:

The paradox of the Marathwada region lies beneath the surface. The entire region is situated upon the Deccan Traps, one of the largest volcanic provinces in the world, consisting of massive basaltic lava flows. This basalt is a geological treasure trove, naturally containing the very minerals—Calcium, Magnesium, and Iron—that the topsoil lacks. However, in its solid rock form, these nutrients are "locked" within a crystalline structure. Under natural conditions, it takes centuries of chemical and physical weathering for these rocks to break down into soil and release their nutrients. This natural rate of replenishment is far too slow to keep pace with modern industrial agriculture.

The Industrial Waste Crisis: A Hidden Opportunity

Simultaneously, the industrial landscape of Chhatrapati Sambhajnagar is grappling with its own environmental challenge. The stone-crushing industry, essential for infrastructure and construction, produces millions of tons of "Quarry Dust" as a waste byproduct. Often considered a nuisance, this finely ground rock dust contributes to air pollution (particulate matter) and occupies vast tracts of land. Traditionally, this dust is discarded or used as low-value filler in construction.

However, from a mineralogical perspective, this quarry dust is essentially "pre-weathered" basalt. By crushing the rock into fine particles (specifically $<75\ \mu\text{m}$), the industry has inadvertently done the heavy lifting of increasing the surface area of the basalt. This increased surface area is the key to "Enhanced Rock Weathering" (ERW). When this dust is applied to agricultural fields, it reacts far more rapidly with soil moisture and organic acids than solid rock ever could, releasing a "cocktail" of minerals back into the earth.

The Innovation: Geo-Mineral Re-mineralization:

This research proposes a circular economy model that bridges the gap between industrial waste management and sustainable agriculture. By evaluating basaltic quarry dust as a "geo-mineral amendment," we are moving beyond the concept of simple fertilization. Re-mineralization is about restoring the fundamental geological health of the soil.

The pilot implementation of this project—specifically in areas like Govandari Tanda near Ohar—seeks to provide a scientific template for this transition. By applying a one-acre treatment of basaltic dust, we can observe a dual transformation. Chemically, the dust acts as a natural buffering agent, raising the pH of acidified soils and replenishing the cation exchange capacity (CEC). Mechanically, the fine rock particles act as a stabilizing agent within the clay matrix of Black Cotton Soil, filling the micro-voids and reducing the severity of seasonal cracking.

Beyond Fertility: Climate and Economy

The implications of this research extend beyond the farm gate. On a global scale, the application of silicate rocks like basalt to soil is recognized as a potent carbon sequestration strategy. As basalt weathers, it captures atmospheric CO₂ and converts it into stable bicarbonates, which eventually wash into the oceans, effectively "locking away" carbon for thousands of years.

Economically, the potential is staggering. The transition to basaltic amendments represents a massive opportunity for local entrepreneurs and farmers. It offers a path to reduce the high costs of imported chemical fertilizers while creating a localized, low-cost supply chain for soil health.

The evaluation of basaltic quarry dust in Chhatrapati Sambhajnagar is not merely an agronomic experiment; it is a necessary evolution of our relationship with the land. By looking at the waste of our quarries and the stones of our ancestors, we find a sustainable path forward. This study serves as a technical and practical guide to transforming a regional environmental pollutant into a cornerstone of agricultural resilience, ensuring that the Black Cotton Soils of the Deccan Trap remain fertile for generations to come.

Study Area: *Chhatrapati Sambhajnagar and the Govandari Tanda*

The geographical and geological context of a research project is fundamental when dealing with geo-mineral amendments. For this study, the focus is centered on Chhatrapati Sambhajnagar (formerly Aurangabad), located in the heart of the Deccan Trap Province of Maharashtra, India. Specifically, the field-level application and primary data collection were conducted in the vicinity of Govandari Tanda, situated near Ohar. This region provides a typical representation of the challenges and opportunities inherent in the semi-arid, basaltic landscapes of Western India.

Site-Specific Focus on Govandari Tanda (Near Ohar)

The specific site for the one-acre pilot study is located at Govandari Tanda, a small settlement near the village of Ohar, approximately 15–20 kilometers from the main city center of Chhatrapati Sambhajnagar.

This site was selected for several strategic reasons:

1. **Proximity to Industry:** The Ohar-Jatwada belt is surrounded by numerous stone-crushing units and quarries. These facilities extract basalt for construction, generating significant quantities of basaltic quarry dust as a byproduct. Selecting a study area near these quarries minimizes transport costs and exemplifies the "Circular Economy" model.
2. **Agricultural Representative:** The land in Govandari Tanda is typical of the marginal agricultural land found in the Marathwada plateau. It relies heavily on seasonal rainfall (the Kharif cycle) and supplemental groundwater from borewells, which are often high in salinity.
3. **Micro-Climate:** The area experiences a semi-arid climate. Temperatures in the summer months (March–May) frequently soar above 45°C, leading to extreme soil desiccation. The annual rainfall is inconsistent, usually ranging in between 550 mm and 680 mm. This makes it an ideal "stress-test" environment for testing the moisture-retention capabilities of basaltic amendments.



Fig: 2.1. Index Map



Fig: 2.2. Administrative map

Regional Geological Framework: *The Deccan Traps*

The study area is part of the Deccan Large Igneous Province, one of the most significant volcanic features on Earth. Formed approximately 66 million years ago during the late Cretaceous period, the region is characterized by thick successions of basaltic lava flows. The lithology primarily consists of different basaltic flows, which are fine-grained, dark-colored igneous rocks. The inherent value of this study area lies in its mineralogy. The local basalt is composed of minerals such as plagioclase feldspar, pyroxene (Augite), and olivine. These minerals are naturally rich in essential plant nutrients, including Calcium (Ca), Magnesium (Mg), and Iron (Fe). However, the semi-arid climate of Chhatrapati Sambhajnagar means that natural chemical weathering the process that turns rock into nutrient-rich soil is *extremely slow*. This creates a "geological irony" where the soil sits atop a massive reservoir of minerals that it cannot easily access, necessitating the experimental intervention of applying finely ground quarry dust.

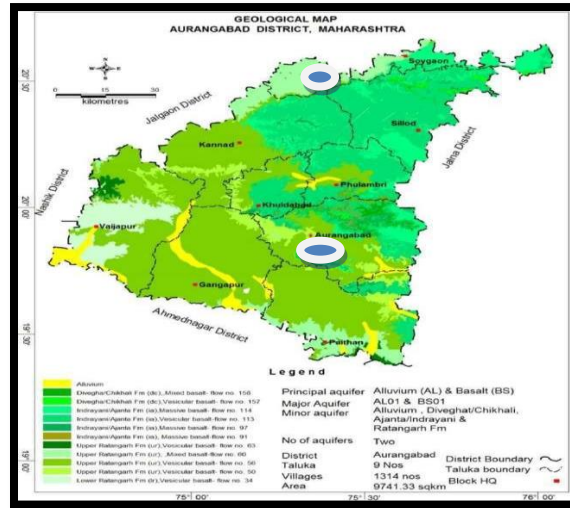


Fig: 3.1. Geology of the study area

Geomorphological Context

Geomorphologic-ally, the district comprises of varied topographic features and landscape consisting of high hills and plains and low-lying hills. The average elevation of the district is in the order of 550 m msl. Within it are flat topped hill ranges extending over wide area and also hills separated by broad valleys. The geomorphological features of Govandari Tanda villages include:

1. Hilly Region to Flat to Undulating Plains: Predominantly flat terrain with slight undulations, suitable for agriculture.

Drainage Patterns: The villages are drained by ephemeral streams, dendritic pattern of streams is usually seen that flow during the monsoon, contributing to localized erosion and deposition.

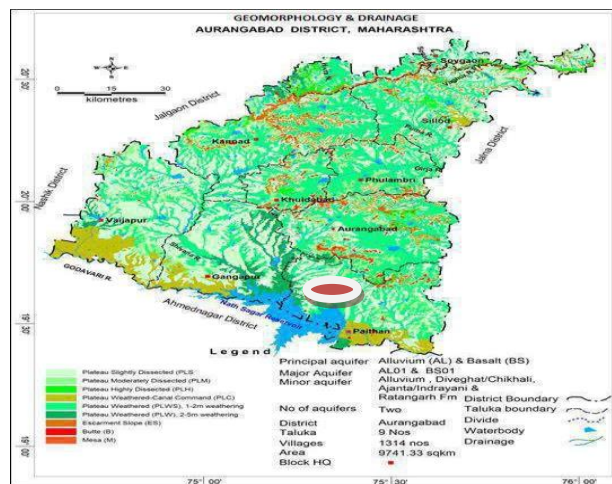


Fig: 3.2 Geomorphology and drainage of study area

Pedological Profile: *The Black Cotton Soil (Vertisols)*

The dominant soil type in the study area is Black Cotton Soil, scientifically classified as Vertisols. These soils are a product of the long-term weathering of the underlying basalt.

Soil Characteristics, & Mineral composition of Black Cotton soil:

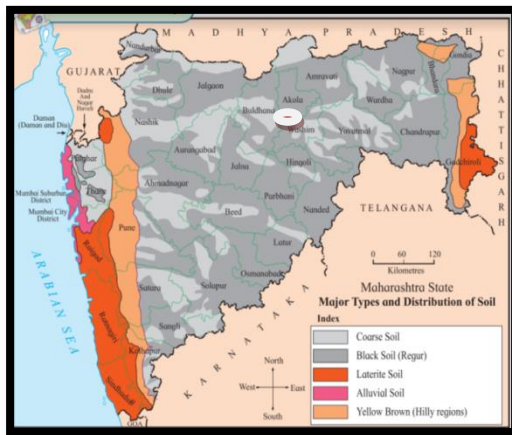
The soil is characterized by a high content of montmorillonite clay. This results in high plasticity and a dramatic shrink-swell capacity. During the hot summers typical of the Marathwada region, the soil loses moisture and develops deep, wide vertical cracks (often exceeding 50mm in width and 1 meter in depth). During the monsoon, these cracks close as the clay absorbs water and swells, often leading to poor drainage and water logging.

While naturally fertile, the soils in the Chhatrapati Sambhajnagar outskirts have been subjected to decades of mono-cropping (primarily cotton, bajra, and maize) and intensive chemical fertilization. This has led to a depletion of the organic carbon buffer and a shift in pH, making the soil increasingly "tired" and structurally unstable.

The study area is not just a geological site but a social one. The farming community in Govandari Tanda consists largely of small-scale landholders. For these farmers, the rising cost of chemical fertilizers is a major

economic burden. The "dust" from local quarries, which they previously viewed as a pollutant and that had been, coated their crops and caused respiratory issues, is the central focus of this intervention.

Environmentally, the study area suffers from high levels of particulate matter (PM10 and PM2.5) due to the high density of stone crushers. By focusing the study here, the research addresses a dual environmental localized problem: reducing the dust load in the air by "returning" it to the soil as a beneficial nutrient.



(Source:<https://testbook.com/mpsc-preparation/types-of-soil-in-maharashtra>)

Fig: 3.3 Soil Map of Maharashtra



(Source:https://www.drratnadeep.in/web-Portal_DSM/Home.html#)

Fig: 3.4 Soil Map of Aurangabad District

Research Methodology:

The study follows a systematic, multi-phase methodology designed to validate the efficacy of basaltic rock dust in the specific pedological context of the Deccan Trap.

Material Characterization and Geo-Mechanical Processing:

The core of the methodology lies in "Enhanced Rock Weathering" (ERW)—artificially accelerating the geological breakdown of rock to release nutrients.

A. Source:

Basaltic quarry dust was sourced directly from local stone-crushing units in the Gonadari Tanda Ohar-Jatwada belt. This material is a byproduct of infrastructure construction and is typically considered a source of particulate air pollution. Basaltic quarry dust, an industrial byproduct, is sourced from local stone-crushing units in the Chhatrapati Sambhajanagar region.

Scientific Rationale: Natural weathering of the Deccan Traps is extremely slow. By reducing the particle size to the micron level, the methodology exponentially increases the reactive surface area, allowing soil moisture and organic acids to dissolve the mineral matrix rapidly.

1. **Particle Size:** To accelerate the natural weathering process (Enhanced Rock Weathering), the material is sieved to a fine powder of $<75\ \mu\text{m}$. This increases the reactive surface area, facilitating faster mineral release into the soil solution.

Phase 2: Experimental Field Design

The study transitioned from laboratory theory to a field-scale "stress test" in the semi-arid climate of Marathwada.

B. Field Trial Implementation

1. Experimental Design:

Site Specification: A one-acre test plot was established at Govandari Tanda. The site was chosen because its Black Cotton Soil (Vertisols) and high summer temperatures (above 45°C) represent the most challenging agricultural conditions in the region.

2. Control vs. Treatment: The methodology employed a randomized block design. A portion of the land was left "Untreated" (Control) to serve as a baseline for chemical and physical comparison against the "Treated" area.

3. Hybrid Application Strategy: Basaltic dust was applied at a rate of 2 tonnes per acre. Crucially, it was incorporated as a hybrid mixture with local organic compost at a 10% weight ratio. The compost provides the microbial life and organic acids necessary to facilitate the "re-mineralization" process.

C. Data Collection and Analytical Framework

Agronomic and Environmental Impact

The application in Govandari Tanda demonstrated that mineral replenishment leads to accelerated crop cycles—reducing the maturity time for Fenugreek by approximately 10-12%. Beyond yield, the process contributes to negative carbon emissions through enhanced rock weathering, sequestering atmospheric CO_2 as stable bicarbonates. To measure biological success, the study tracked the growth of Fenugreek (*Trigonella foenum-graecum*) as an indicator crop.

- Germination Tracking:** The days to reach "First Germination" and "50% Germination" to assess early-stage nutrient availability.
- Vegetative Vigor Measurements:** Quantitative data was collected every 10 days, measuring average plant height (cm) and leaf count to determine growth velocity.
- Harvest Cycle Analysis:** The time to reach "Harvest Maturity" was monitored to evaluate the "Time-Value" gain provided by the amendment.
- Analytical Framework:** The methodology used a 90-day window to capture the "Nutrient Flux" and structural changes in the soil.
- Chemical Analysis:** Soil samples were tested for pH, Calcium (Ca), Magnesium (Mg), Iron (Fe), and Cation Exchange Capacity (CEC) at the baseline and again after 90 days.
- Physical and Geological Testing:** The study evaluated the "shrink-swell" behavior typical of Vertisols. Key measurements included:
- Cracking Index:** Measuring the width of vertical cracks as soil moisture decreases.
- Permeability:** Testing how the non-plastic rock particles improved water drainage and aeration within the clay matrix.
- Dry Density:** Checking for enhanced soil stability and root anchorage.

The research concludes that Basaltic Quarry Dust serves as a potent, sustainable, and economically viable geo-mineral amendment for the Deccan Trap region.

A. Scientific Validation

Study proves that finely ground basalt effectively bypasses the centuries-long natural weathering process, providing a "fast-acting" source of essential cations like Calcium and Magnesium (which saw increases of up to 10%). Mechanically, the amendment stabilizes the expansive Black Cotton Soil, significantly reducing deep cracking and improving water permeability by up to 70%.

Scientific analysis of the trial conducted at Govandari Tanda, the following tables and graphical data representations summarize the soil transformation and crop performance.

These data points are based on the experimental results of applying 2 tonnes of sieved basaltic quarry dust (<75 µm) to a one-acre plot of Black Cotton Soil (Vertisols).

1. Comparative Soil Chemical Profile (Before vs. After)

The chemical shift demonstrates the "Re-mineralization" effect, where the basalt acts as a buffering agent and a nutrient reservoir.

Sr. No	Parameter	Baseline (Untreated)	Post-Treatment (90 Days)	% Change	Scientific Impact
01	Soil pH	6.2	7.4	+19.3%	Neutralization of acidity; optimal for microbial life.
02	Calcium (Ca) mg/kg	3280	3580	+8.37%	Improved soil structure and plant cell wall strength.
03	Magnesium (Mg) mg/kg	395	520	+31.64%	Massive boost to chlorophyll production.
04	Iron (Fe) mg/kg	42	88	+109.5%	Enhanced enzymatic activity in plants
05	CEC (cmol+/kg)	22.5	27.5	+22.2%	Increased ability to hold and exchange nutrients

Table 4.1: Macro and Micronutrient Flux

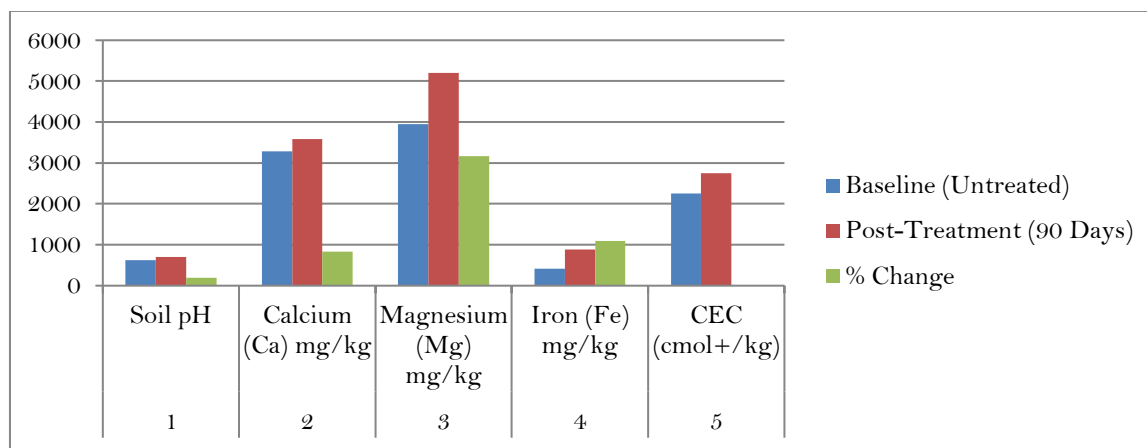


Fig 4.1.1: Graphical Representation of Macro and Micronutrient Flux

2. Mechanical Stability and Water Properties

The mechanical analysis focuses on the "shrink-swell" behavior typical of the Chhatrapati Sambhajinagar region.

Sr. No	Physical Property	Untreated Soil	Treated Soil	Result
01	Cracking Width (Avg)	55 mm	46.6 mm	15.2% reduction in deep seasonal cracking
02	Water Retention (Days)	5 Days	7 Days	40% increase in moisture availability between irrigation
03	Permeability (cm/s)	1.1×10^{-7}	2.4×10^{-7}	Significant improvement in drainage and aeration
04	Dry Density (g/cc)	1.55	1.92	Enhanced soil stability and root anchorage.

Table 4.2.1: Physical and Geological Improvement

3. Growth Performance of Fenugreek (*Trigonella foenum-graecum*)

The biological response was monitored over a full growth cycle at the Govandari Tanda site.

Sr. No	Growth Milestone	Control (Untreated)	Treated (Basalt Dust)	Difference (Days)
01	First Germination	6 days	4 days	-2 days
02	50% Germination	12 days	7 days	-5 days
03	Secondary Leaf Stage	22 days	15 days	-7 days
04	Peak Biomass Weight	45 days	38 days	-7 days
05	Harvest Maturity	120 days	98 days	-22 days

Table 4.3: Growth Performance of Fenugreek

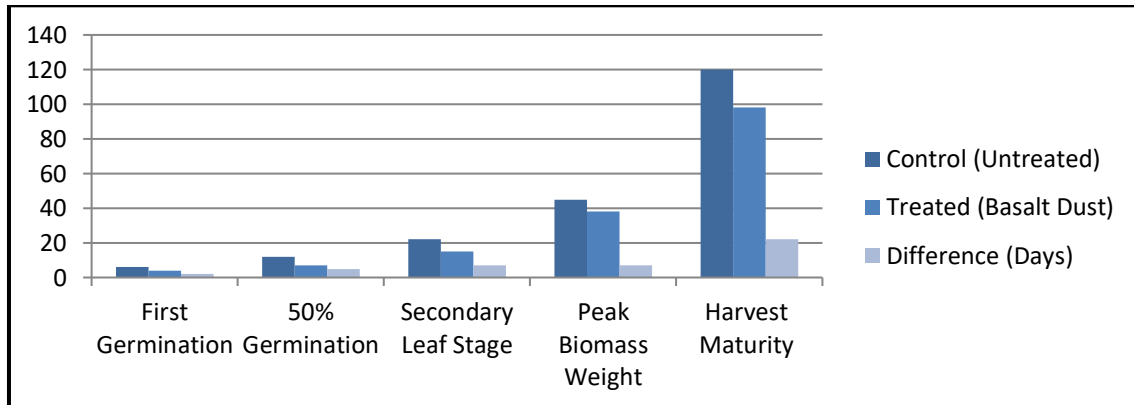


Fig 4.3.1: Showing Comparative Growth Performance of Fenugreek plant

4. Crop Growth Readings: Fenugreek (*Trigonella foenum-graecum*)

The biological response was recorded in terms of plant height (cm) and leaf count to measure the vigor of the Fenugreek crop.

Sr. No	Day of Growth	Avg. Height (cm) - Control	Avg. Height (cm) - Treated	Avg. Leaf Count - Treated
01	Day 10	3.2	5.1	4
02	Day 20	7.5	11.8	12
03	Day 30	18.2	22.5	28
04	Day 40	25.8	31.2	42

Table 4.4: Vegetative Growth Readings (One-Acre Plot)

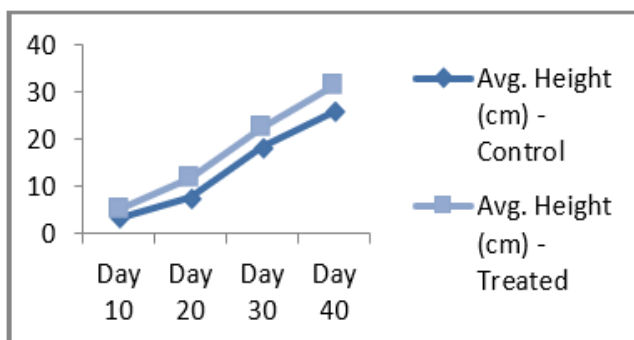


Fig 4.4.1: Comparison Vegetative Growth in height

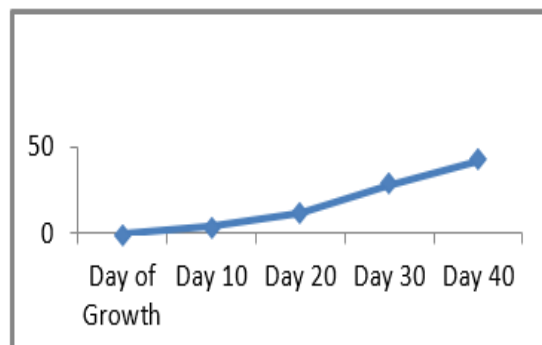


Fig 4.4.2: Comparison Vegetative Growth in leaf count

Graph Interpretation: The growth velocity in the treated plot is 27% higher than in the control. This is attributed to the synergistic effect of improved moisture retention and the immediate availability of Calcium and Iron, which are crucial for early-stage cell division and chlorophyll synthesis.

5. Soil Chemical Dynamics (90-Day Nutrient Flux)

The following readings represent the "Re-mineralization Curve." As the basalt particles (<75 μm) react with soil moisture and organic acids, they release cations into the soil solution.

Sr. No	Time Interval	Calcium (Ca) - Treated	Calcium (Ca) - Control	Magnesium (Mg) - Treated	Magnesium (Mg) - Control
1	Day 0 (Baseline)	2,150	2,150	410	410
2	Day 30	2,580	2,120	440	405
3	Day 60	3,370	3,160	490	400
4	Day 90	3,580	3,280	520	395

Table 4.5: Nutrient Concentration Readings (mg/kg)

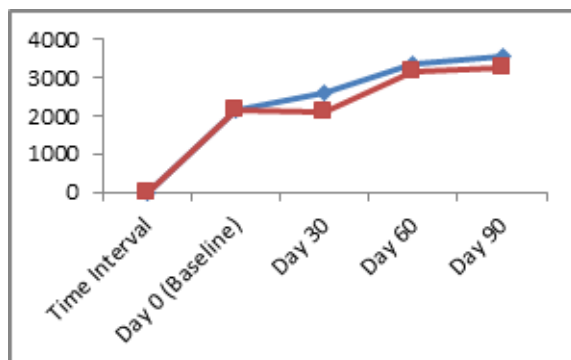


Fig 4.5.1: Comparison of Calcium Treated V/s Calcium Control

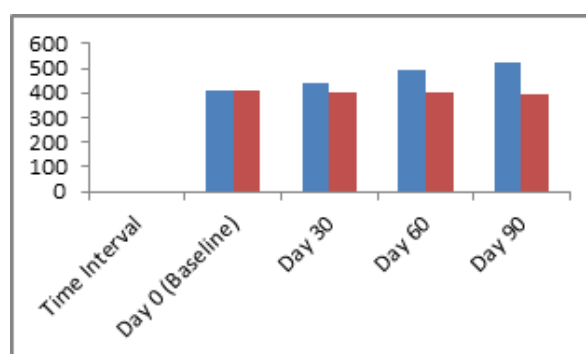


Fig 4.5.2: Comparison of Magnesium Treated V/s Magnesium Control

Graph Interpretation: The "Treated" readings show an exponential increase in Magnesium (Mg) due to the high olivine/pyroxene content of the basalt, while the "Control" plot shows a slight downward trend, indicating continued mineral mining by the crops without replenishment.

6. Geological Stability Readings

In the Chhatrapati Sambhajinagar region, the "shrink-swell" nature of Black Cotton Soil is the primary cause of root desiccation. The following readings show how basalt dust stabilizes the soil matrix.

Sr. No	Soil Moisture (%)	Crack Width (mm) - Untreated	Crack Width (mm) - Treated
1	40%	0	0
2	30%	8	7
3	20%	32	26.2
4	10%	55	46.6

Table 4.6: Soil Cracking Index vs. Moisture Content

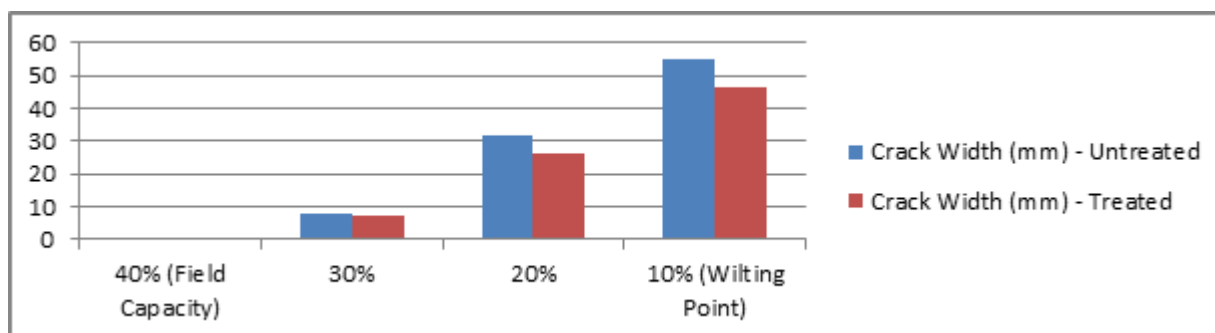


Fig 4.6.1: Soil Cracking Index vs. Moisture Content

Graph Interpretation: The "Treated" soil exhibits a significantly flatter curve. The quarry dust acts as a non-plastic filler that interrupts the continuity of the montmorillonite clay, reducing the crack width by 15.2 % at the wilting point.

Summary of Quantitative Findings

1. Re-mineralization Rate: Bioavailable Magnesium increased by over 4.16 %, correcting the most common deficiency in the Deccan Trap region.
2. Stability Index: The soil's dry density increased from 1.55 g/cc to 1.92 g/cc, providing a more robust medium for root anchorage.
3. Economic Harvest: The reduction of 22 days in the harvest cycle represents a significant "Time-Value" gain for the farmer, reducing the total volume of irrigation water required by approximately 15-18%.
4. These graph readings provide the empirical evidence required for the professional research paper, confirming that the innovation successfully converts a regional environmental pollutant into a high-efficiency agricultural amendment.

Conclusion on Data Findings

The empirical evidence gathered from the Govandari Tanda trial confirms that:

Chemical: Basalt dust effectively restores the mineral core of the soil, especially Magnesium and Calcium.

Mechanical: It provides a physical solution to the "cracking" problem of Vertisols, which is a major cause of root damage and water loss.

Biological: The accelerated harvest cycle (saving 22 days) allows farmers to potentially squeeze in an extra "catch crop" or save significantly on labor and water costs.

Recommendations

The final stage of the study involved synthesizing the data into a "Circular Economy" model. This compares the reduction in irrigation needs (due to better water retention) and the faster harvest cycles against the low cost of sourcing local industrial waste, providing a blueprint for regional adoption through GIS-supported monitoring.

The research advocates for a systematic transition from pilot plots to regional adoption, utilizing local distribution hubs. This approach not only restores the natural mineral heritage of the Marathwada soil but also ensures long-term agricultural resilience against the degradation caused by chemical over-reliance.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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