International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 6, 2025
https://theaspd.com/index.php

The Function of *Camponotus compressus* in Enhancing Physiological Efficiency in Coriander Plants: Ants as Natural Soil Engineers

David Debjit Ambett[1], Majesh Tomson[2]
[1]PhD Scholar, Department of Life Sciences, School of Sciences, Christ University, Bengaluru, Karnataka, INDIA
[2]Assistant Professor, Department of Life Sciences, School of Sciences, Christ University, Bengaluru, Karnataka, INDIA

Abstract- *This study examines how the physiological and biochemical characteristics of coriander (Coriandrum sativum) plants are affected by ant nest soil, specifically from Camponotus compressus. In 17 field sites, coriander plants were cultivated in soils with and without ant nests. The growth parameters, pigment concentrations, and photosynthetic characteristics of the plants were examined. Results revealed that plants grown in ant nest soil exhibited significantly enhanced green biomass, root length, leaf diameter, and leaf number. Biochemical assessments indicated increased chlorophyll-a, chlorophyll-b, and total chlorophyll content in the experimental group, signifying improved light absorption and pigment biosynthesis. In addition, plants grown in ant nest soil exhibited decreased proline content, increased water potential, stomatal conductance, transpiration rate, and net photosynthetic rate—all of which point to decreased abiotic stress and improved physiological efficiency. These plant's enhanced ability to use light was reflected in their higher photosynthetically active radiation (PAR). These results were corroborated by an analysis of soil samples from nest and non-nest areas, which showed that nest-associated soils had higher concentrations of vital cations and nutrients. According to these findings, Camponotus compressus plays an important ecological role as a natural soil enhancer and has the ability to support agroecosystem productivity and sustainable plant growth.*
Keywords- *Camponotus compressus, Ant nest soil, Coriandrum sativum, Photosynthetic efficiency, Soil–plant interaction.*

1. INTRODUCTION

A micro-scale change in the soil can alter the structure and composition. Changes in the soil can produce an adverse effect on the vegetation, modifying the soil composition and creating an abundance and richness in plants. There are animals such as agoutis, rabbits, wild pigs, armadillos, termites and ants can bring a modification in the soil that have effect on ecology through perturbations of soil [1]. Ants are considered as one of the important sources of modifiers of soil throughout the world due to their wide diversity and abundance, wide geographical distribution and social behaviour [2]. Around 20,000 species have been observed across all continents [3]. It has been observed that ants remove the soil surface of vegetation and bring up the large amount of underground soil into superficial layers to build their nests. They also accumulate organic matter and excrete large amount of organic waste in particular chambers or on top of the soil surface. This is the reason why ant nest soil results in a change in physical and chemical properties thereby creating an effect on the surrounding vegetation [4]. Hence ants nest are considered one of the main influences when it comes to minor-scale disturbances in the soil [5]. Majority of the studies showed that there is an increase in organic matter and soil nutrients in ant nest sites [6]. It has been observed that there are striking evidence of plants that grow near the ant nest or near the ant nest have high level of their performance or abundance [7]and the effects of ant nests on plant diversity [8]. To understand the effect of ant nests on soil and plants we have selected *Camponotus compressus* species of ants for our study. Here for the first time we have analysed the nest soil chemistry of *Camponotus compressus* through GCMS and also for the first time we did a mainstream work on the nest soil nutrient of *Camponotus compressus*. All these we have quantitatively assessed to determine whether ant nests have an effect on soil fertility and overall performances of coriander plants.

The modification brought by ant nest on soil and plants could be due to the substrate sampled, feeding type of the ant, the exact geographical location of the nest, the plant variable and the type of data. All ants excrete organic waste. These wastes are deposited in the underground chamber or in outside refuse

piles depending on the species [9]. Results showing that there is some proves that refuse material and nest soil might be different in their mineral composition [5], the varieties of substrate found could also explain the types of soil observed in soil fertility around ant nests. Ants consume various items such as green plants, materials, seeds and dead or live arthropods [10]. Provided that different food sources differ in their content of nutrient [11] their deposits in the nest and the debris may affect the ant nest on soil chemistry [12], [13]. There are various abiotic and biotic characteristics that change with latitude and among biomes which affects the ability of ants to enhance the soil fertility. For instance, temperate regions and habitats that are dry show extreme temperature that might limit the ant foraging period [14] decreasing their ability as soil modifiers. Moreover, food items such as plants and arthropods differ in nutrient content, number and identity along geographical and environmental gradients [15].
The present study aims at the physico-chemical characteristics of ant nest crater rim debris soil of a common and abundant plant-visiting carpenter ant *Camponotus compressus* (Fabricius, 1787). Carpenter ants belong to the hyper dispersed genus *Camponotus* which contains polydomous species [16]. There are two types of nests constructed by carpenter ant colonies: the primary nests and the associated satellite nests. *Camponotus compressus* are found mostly in South and Southeast Asia which includes India [17] [18]. The nests of *Camponotus compressus* are observed to be found in various ecosystems including annual and perennial agroecosystems [19]. A recent study shows that *Camponotus compressus* alters the soil pH and the nutrients [19]. These ants go and visits extra floral nectar bearing plants [20] and consumes honeydew from homopterans.
A question usually raised all the time [2] that do ants change the soil? Therefore, in the present study we have selected 17 sites in Chikkaballapur forest to study the nest excaration and activities maintained by *Camponotus compressus* colonies influencing the soil in different areas. The following questions were researched on (i) What is the nutrient content of the soil from the 17 sites (ii) What is the chemical compounds released by ants present in the soil by GCMS (iii) Whether there is any change in the plant grown on the soil near to ant nest.

2. MATERIALS AND METHODS

We had examined reference sections of recently published articles on our topic and searched keywords in Biological abstracts, Google Scholar and searched words like ant nest and soil fertility and soil nutrients and nest effects on plants. We have included our research records such as (i) Comparing fertility of the soil and plant traits between ant nest sites and adjacent sites without ant nest (control); (ii) The means, their sample sizes and standard errors for the experimental soil and the control soil. We had performed different meta-analysis to examine the effect of *Camponotus compressus* on 17 soil sites in Chikkaballapur district of Karnataka, India with their nest and adjacent sites without nest and three coriander plant performances were studied which were grown on ant nest soil and soil without ant nest. For examining the soil fertility we had studied the effect of *Camponotus compressus* on the nutrients such as (N, P, K and C) and cations such as (Al, Ca, Mg and Fe) and pH of the soil was also examined [21].
The Coriander plant performances we had analysed separately by examining the plant growth (eg- stem diameter, lesf and root biomass and plant height). In order to know whether the plants were under stress when grown in ant nest soil we had performed Prolene test and to study whether there was any change in the protein we had performed protein test by Lowry's method. To estimate the prolene content in leaf tissues of coriander plant, about 20.5 mg of leaf sample was homogenized in 1 mL of an ethanol-water mixture, that is, 400 µL ethanol and 600 µL distilled water, prepared in the ratio of 40:60 (v/v). As the mixture was kept at room temperature overnight, extraction was eased. Prior to being centrifuged at 14,000 rpm for 5 minutes, the samples underwent incubation. Afterward, researchers collected for further analysis the clear supernatant.
To prepare the reaction mixture, glacial acetic acid (6 mL), ethanol (2 mL), and distilled water (2 mL) were well mixed. To this, 0.1 g of ninhydrin was added so it dissolved completely, within which formed the acid ninhydrin reagent. Next, we pipetted 100 µL of that reagent mixture right into each well of some 96-well plate for some reaction tube. Next, we put in 50 µL of proline standard or the plant extract. Prepared standards had concentrations measuring 20, 40, 60, 80, and 100 µg/mL. Water that was distilled did replace that extract for preparation of a blank. After that, the tubes were wrapped in aluminum foil

and incubated for 20 minutes at 98°C in a water bath. Following incubation, cold water was used to bring the tubes to room temperature. Any remaining particle matter was then settled with a quick centrifugation (10–20 seconds). For the absorbance measurement, 100 µL of each reaction mixture was carefully moved to sterile tubes. A UV spectrophotometer was used to determine the optical density (OD) of the resultant colored complexes at 520 nm.
To estimate the protein content first, plant extracts were made by homogenizing the leaf material in an appropriate extraction buffer in order to assess the total protein content in leaf tissues. Following centrifugation, the supernatant was used for protein analysis and kept in a cool environment. Bovine serum albumin (BSA) at various concentrations (10 µg, 20 µg, 30 µg, 40 µg, and 50 µg) was used to create a standard curve for the estimation. Working standards were obtained by dissolving 50 mg of BSA in 500 mL of distilled water to create a stock solution of BSA at 100 µg/mL. Six milliliters of glacial acetic acid, two milliliters of ethanol, and two milliliters of distilled water were mixed to create the reagent mixture. 0.1 g of Coomassie Brilliant Blue G-250 (or another suitable dye reagent based on the Bradford protocol adaption) was added to this solution and left to dissolve fully. The Bradford reagent was this mixture.

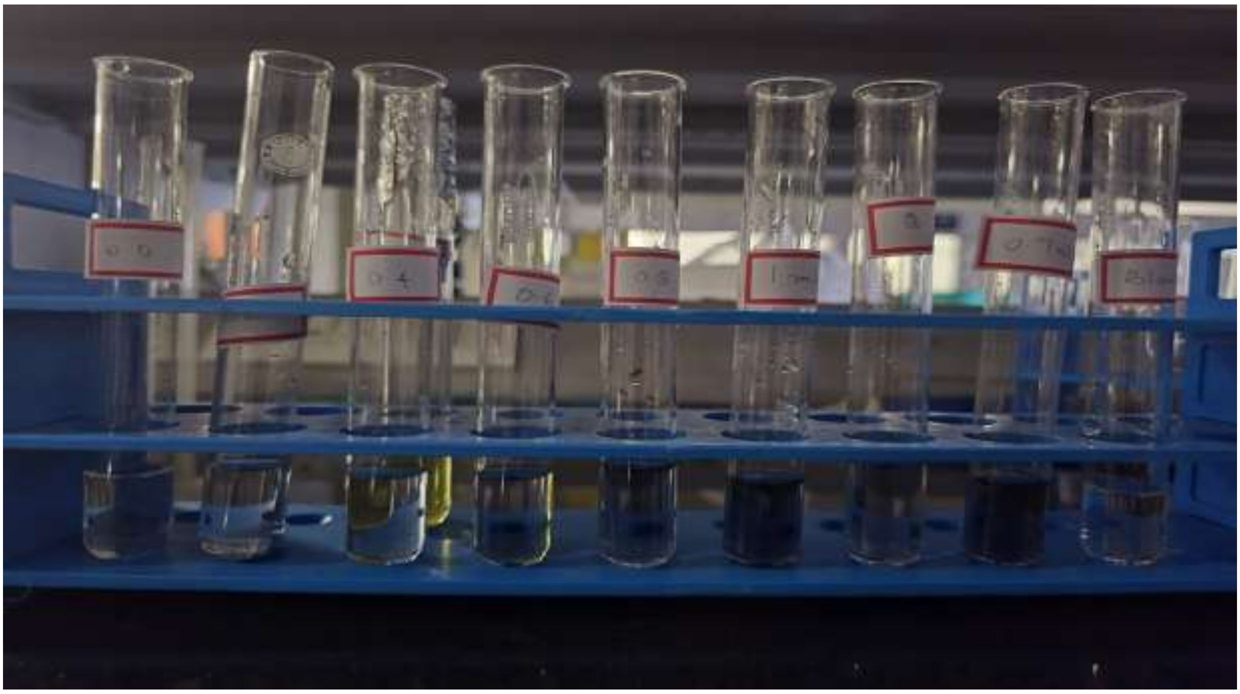
In a standard experiment, 50 µL of the protein extract or BSA standard was added after 100 µL of the reagent had been pipetted into sterile reaction tubes or wells. Instead of employing the protein extract, distilled water was used to create a blank. The tubes were mixed and then allowed to develop color at room temperature.
To get rid of any precipitates, the tubes were spun for ten to twenty seconds after the blue-coloured complex had formed. A UV spectrophotometer was then used to measure the absorbance (optical density) at 520 nm after 100 µL of each reaction mixture had been carefully transferred to clean tubes. The standard curve obtained from the known BSA concentrations was used to calculate the protein concentration in the samples.
Protein concentration in plant samples can be accurately and sensitively ascertained using this method, which is especially useful for examining physiological reactions to experimental or environmental treatments.
We had used two instruments to check the other parameters in coriander plants: (i) First we had used CI-710s Leaf Spectrometer which was used to analyse the quantity of chlorophyll a, b and t present in the coriander plants grown on ant nest soil and soil without ant nest (ii) Second instrument which we had used was CI 340 Hand held Photosynthesis system which had analysed the photosynthetic Active Radiation (PAR), Water Potential, Net Photosynthetic Rate (NPR), Transpiration rate (E) and Leaf Stomatal Conductance (C) in coriander plants grown on ant nest soil and soil without ant nest.
For statistical analysis we had performed ONE WAY ANOVA for each parameter with the help of the SPSS software [21].

3. RESULTS AND DISCUSSION

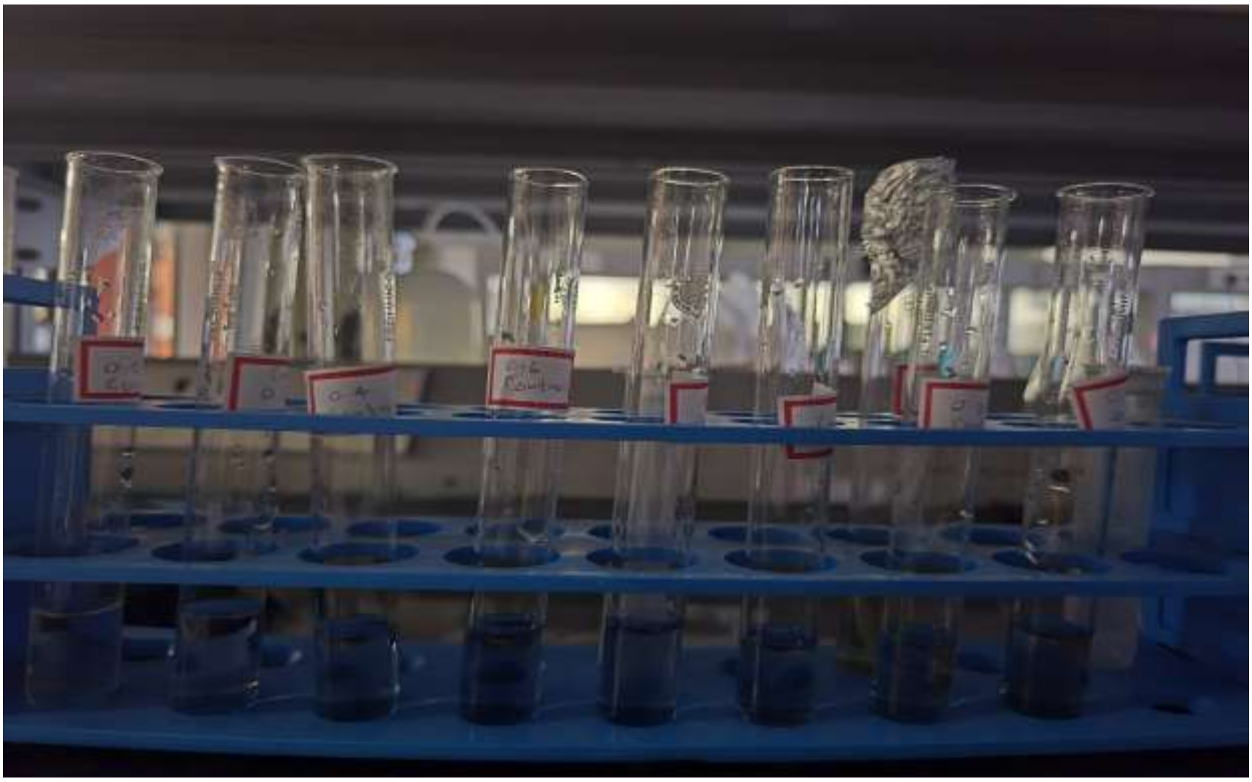
3.1. Assessment of proline content in Experimental and control coriander plants

Proline was first observed in wilting perennial ryegrass [22] and then after further analysis they were found to show physiological responses if they are under environmental stresses [23] [24]. Uusally if they are exposed to some high level of salinity [25], [26], drought, [27], water stress[28], heavy metals [29], [30]. Proline has been known to help as osmolyte and osmoprotective compound and thereby acting as molecular chaperone in osmotic adjustment and shielding of cellular structures, proteins and membranes against osmotic stress. Proline also helps in acting as a scavenger of reactive oxygen species to decrease the adverse effects done by oxidative stress triggered by high level salinity, drought, heavy metals, etc.[31], [32], [33], [34]. In many plants such as potato proline plays an important role in osmotic adjustment [35]. Various studies shows the benefits of proline when they are under environmental stress mostly salt and water [36]. It has been observed that Proline acts as an elicitor of various defense responses such as osmotic adjustment, membrane and protein stabilisation, free radical scavenging, cell signalling events and gene expression modulation [37]. The metabolic pathway of proline in bacteria has been best described by [5] where he stated that proline is usually synthesised from glutamate in three steps (1) γ-glutamyl kinase phosphorylates glutamate using ATP, which produces glutamyl- γ-phosphate, which is broken down to

SA by glutamic- γ- semialdehyde dehydrogenase; (2) GSA is rpidly converted to P5C; and (3) P5C is broken down to proline by P5CR with consumption of NADPH [21]. A bifunctional enzyme called P5CS which is present in plants and animals rapidly catalyzes the first two steps of proline biosynthesis using ATP and NADPH. IN addition plants they do have an alternative proline synthesis pathway in mitochondria which OAT enzyme converts ornithine and α-ketoglutarate to P5C by transamination [21]. P5CS route is the important pathway of biosynthesis of proline in plants. The biosynthetic pathway's spatially distinct process of proline catabolism takes place in mitochondria [38]. ProDH activity limits the breakdown of proline by encouraging its oxidation to P5C, which P5CDH then transforms into glutamate. The mitochondrial enzymes PDH and P5CDH use FAD and NAD+ as electron acceptors to produce FADH2 and NADH, respectively, and supply electrons for the electron transport chain in the mitochondria. In some plant species, including barley [39], rice, sainfoin [40], maize, and tomato, exogenous proline application has become a viable substitute to lessen the harmful effects of salinity.
In this investigation, we discovered that experimental coriander plants cultivated in *Camponotus compressus* nest soil had a substantially lower proline content than those cultivated in nearby non-nest control soil. The generally favorable plant growth responses observed in situations where ant nest debris improves soil fertility are in contrast to this observation. The physical and chemical characteristics of the nest soil are influenced by C. compressus nests, according to prior research. These nests' debris soils usually show: (i) higher percentages of large soil particles; (ii) higher levels of moisture, total N, P, and NO_3 N; (iii) lower levels of total C and NH_4 N; (iv) increased soil porosity and a shift toward neutral pH [41]. It is known that these changes produce nutrient-rich "islands" that could encourage plant growth in a variety of systems [42], [43], [21]. Plants cultivated in ant nest soils frequently exhibit higher root and shoot biomass than those in control soils, according to meta-analytical evidence from several ant taxa.[21]. However, it is uncommon to measure particular effects on osmoprotectants like proline, which are frequently elevated under abiotic stress (such as salinity or drought). According to our data, plants cultivated on *C. compressus* nest soils accumulate less proline. This implies that even though there are more nutrients available, these soil conditions may result in less stress, which would lower proline biosynthesis and osmotic adjustment. Alternatively, stress-responsive pathways may be down-regulated by the constant signals of moisture and nutrients. nutrient-rich, low-stress setting, Nest soil with higher levels of nitrate, phosphorus, and moisture may meet plant metabolic needs and lessen the need for osmoprotectants like proline [41]. By stabilizing conditions (pH, moisture), regular nest maintenance and debris deposition can effectively protect plants from physiological stressors usually linked to proline synthesis. As far as we are aware, no previous research has specifically measured proline levels in plants—especially *C. compressus*—grown on ant nest soils. As a result, our research provides a fresh perspective on the physiological effects of soils modified by ants as shown in fig (1) (2) (3).



(1) **Fig 1:** Lighter coloring, which indicates a decreased proline concentration, is seen in both control and experimental samples cultivated on *Camponotus compressus* nest soil.



(2)
Fig 2: increased proline concentration is shown in the increased hue of the experimental and control samples cultivated in soil devoid of ant nests.
.

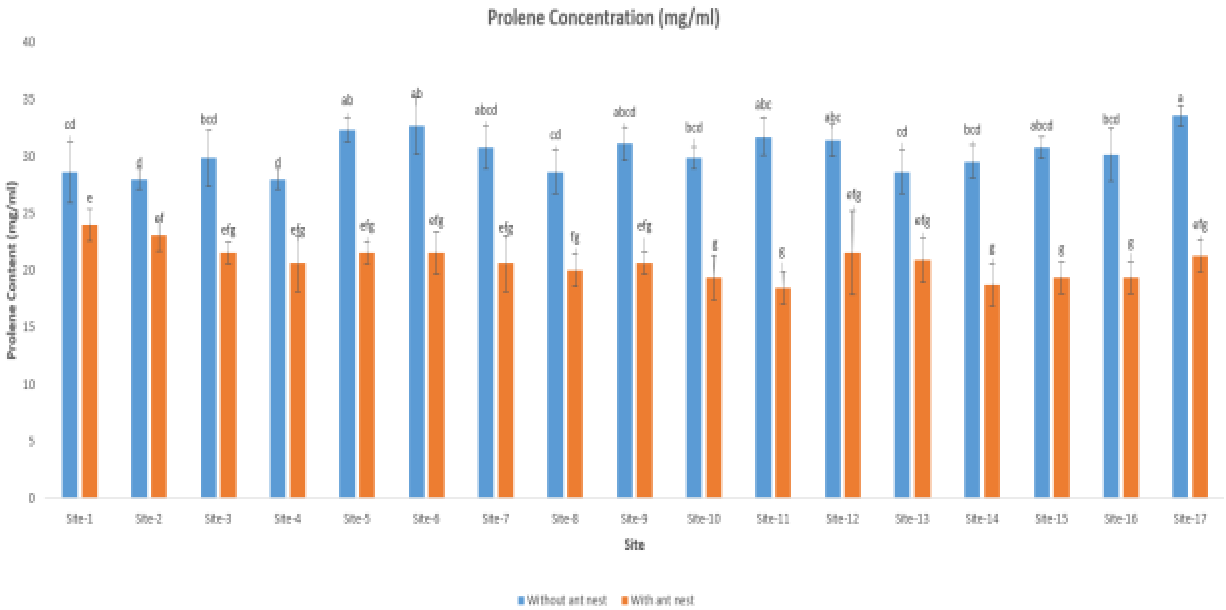


Fig 3: The higher hue of the control samples than the experimental sample grown in soil free of ant nests indicates a higher proline concentration.

3.2. Assessment of protein content in Experimental (with ant nest) and control coriander plants (without ant nest).

Along with lipids and carbohydrates, protein is a key macronutrient that aids in the development and upkeep of the human body and provides energy, [14]. In essence, a protein's function is determined by its structure, which is acquired following the ribosomal synthesis of its amino acid chain. Moreover, the physical and chemical conditions of a protein's surroundings largely dictate its conformation. These conditions are impacted by high temperatures, reactive substances, heavy metal (HM) ions, and other stresses that not only prevent newly synthesized proteins from folding correctly but also cause pre-existing proteins to misfold [5].

In this study, coriander (*Coriandrum sativum*) plants grown in *Camponotus compressus* nest soils (experimental group) had a significantly higher total protein content than plants grown in nearby non-nest soils (control group). The Duncan's Multiple Range Test (DMRT) confirmed the statistical significance of this pattern, which was consistently seen across 17 independent sites. Because of ant bioturbation, soils affected by *C. compressus* nests are known to be richer in vital nutrients like nitrate (NO_3^-), phosphorus (P), and potassium (K). They also show better aeration and moisture retention [19]. The growth and metabolism of plants may be greatly impacted by these modifications. Increased nitrogen bioavailability, which directly supports amino acid biosynthesis, protein assembly, and improved cellular function, may be the cause of the higher protein content in coriander cultivated on these enriched soils. Plants cultivated in nutrient-poor control soils, on the other hand, might have restricted nitrogen uptake, which would result in relatively less protein synthesis. Both the experimental and control groups' mean protein concentrations (measured in milligrams per gram of fresh weight) were plotted, with standard error bars added to show variation. This trend was not caused by random variation across sites, as the Duncan's post-hoc test showed that the difference in protein content between the two groups was statistically significant ($p < 0.05$). These results are consistent with earlier studies showing that ant nest soils act as [21]. The higher protein content in coriander, a plant with culinary and therapeutic uses, might be the result of better soil nitrogen cycling and plant nitrogen uptake efficiency. Additionally, the ant colony's soil conditioning effect improves the biochemical quality of plants even though *Camponotus compressus* is not directly myrmecophilous with coriander as shown in fig-4, 5 and 6.

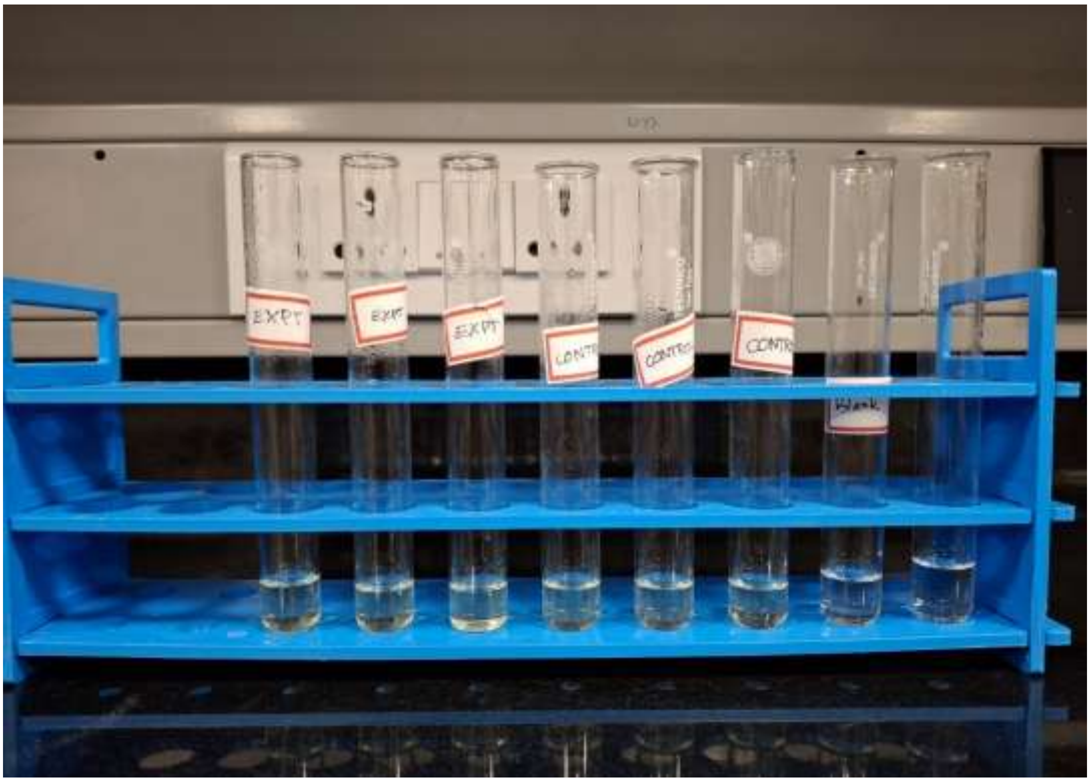


Fig 4: Test tubes demonstrating the Lowry method of protein quantification from coriander plants cultivated in ant without nest and ant with nest soil types.

EXPT: Plants grown in *Camponotus compressus* nest soil, showing higher intensity green colour**,** indicating higher protein concentration.
CONTROL: Plants grown in non-nest (control) soil, showing lighter colour, suggesting lower protein levels.

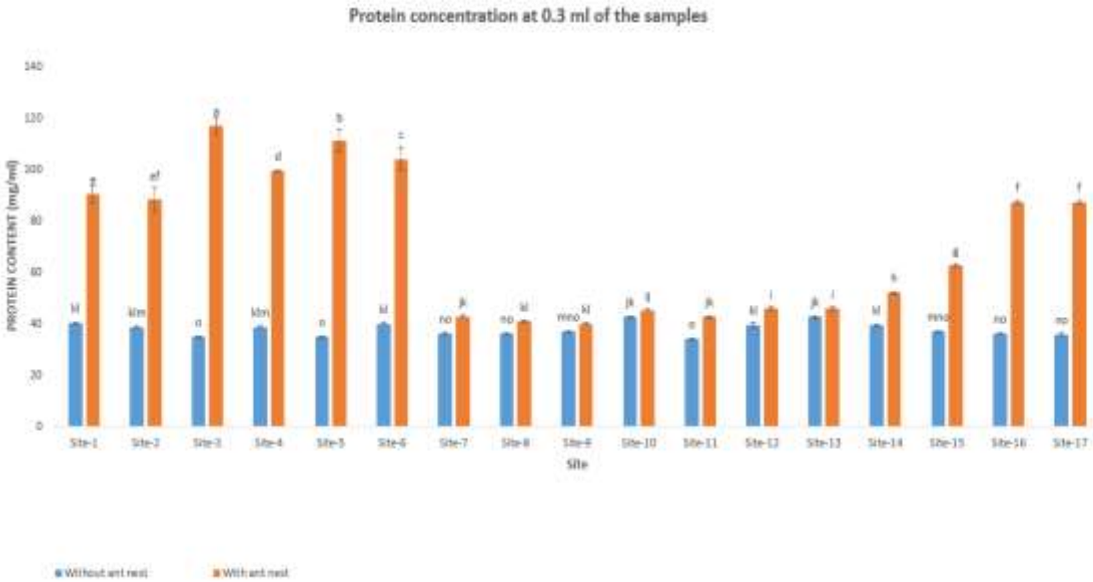


Fig 5: This bar graph compares the mean protein content (± SE) of coriander plants grown in ant nest soil at a concentration of 0.3 ml to control soil at 17 different sites. The Duncan's test is used to determine statistical significance.

Fig 6: This bar graph compares the mean protein content (± SE) of coriander plants grown at 17 different sites at a concentration of 0.7 ml from ant nest soil to control soil. The Duncan's test is used to determine statistical significance.

3.3. Meta-analyses of soil fertility and plant performance affected by ant nest soil

There is multiple work that shows that ants have an effect on soil properties, vegetation patterns, but there still is some conflicting evidence on whether these have an effect which ca increase or decrease the nutrient content of soils and let to influence the plant growth. Although most studies show that there is an increase in organic matter and soil nutrients in ant nest sites [43]. It has been observed that the effect of ant nests on soil and plants could be affected by the substrate sampled, the ant feeding type, the geographical location of nests, the plant variable measured. All ants generate organic waste. This waste gets deposited in the underground specific chambers or in outside refuse piles based on the ant species [45]. There are some studies that there are differences in the mineral content of refuse material and nest soils [5], the type of substrate sampled could partially explain the variation observed in soil fertility around the ant nest. Secondly ants intake green plant material, seeds and dead or live arthropods [46]. As a result various food sources differ in their nutrient composition [11] their presence inside the nest and the associated debris may have an effect of ant nest on soil chemistry [47]. Third, ants' capacity to increase soil fertility is impacted by a number of biotic and abiotic traits that vary with biome and with latitude. For instance, ants' capacity to modify soil is diminished in temperate regions and arid ecosystems due to the high temperatures that may restrict their foraging season. Additionally, within geographic and environmental gradients, food items like plants and arthropods differ in terms of their nutrient content, quantity, and identity [48]. Given that the quality of food stored and detritus created by ants is closely linked to their effects on soil fertility [49], ant nest size may be impacted by variations in food availability along environmental and latitudinal gradients as soil disturbances. Lastly, as soil fertility frequently affects plant performance and abundance, all of the above mentioned elements may have an impact on vegetation patterns; however, the effects may vary depending on the type of data and the degree of organization examined. By favoring the dominance of a small number of species at the community level, enhanced nutrient patches may reduce plant diversity while simultaneously improving plant performance at the individual and population levels [50]. Furthermore, because greenhouse plants are frequently kept in controlled environments, whereas field plants may be subject to resource constraints, environmental changes, and natural enemy attacks, the findings of measurements taken in greenhouses and the field may differ. All things considered, these variables could affect the magnitude and direction of the effect of ant nests on soil fertility and plant performance, which would account for the disparate findings of various investigations.

We assessed the effects of ant nests on many aspects of plant performance and soil fertility. Ant nests' effects on soil nutrient content (C, N, P, and K), soil cation content (Al, Ca, Mg, Na, S, Cu, Zn, Fe), soil

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 6, 2025
https://theaspd.com/index.php

pH, EC (Electrical conductivity), plant green development (plant height, and plant root growth, leaf size, number of leaves, diameter of leaves, Photosynthetic Active Radiation, water potential, Net Photosynthetic Rate, Transpiration Rate, Leaf Stomatal Conductance, Chlorophyl-T, Chlorophyl-a, Chlorophy-b were assessed using different meta-analyses.

In comparison to nearby control soils devoid of ant activity, soils associated with *Camponotus compressus* nests had noticeably greater amounts of the macronutrients organic carbon (C), total nitrogen (N), accessible phosphorus (P), and potassium (K), according to soil nutrient analysis. Ants' ecological function as natural soil engineers and biofertilizers is supported by this trend, which is consistent across all 17 study locations.

Nest soils were found to have much larger quantities of organic carbon (C). Ant activity aggressively incorporates organic waste, including decomposing plant matter, insect prey leftovers, ant dung, and nest debris, into the soil matrix, which is why there has been an increase in this area [2]; [53] as shown in fig-7.

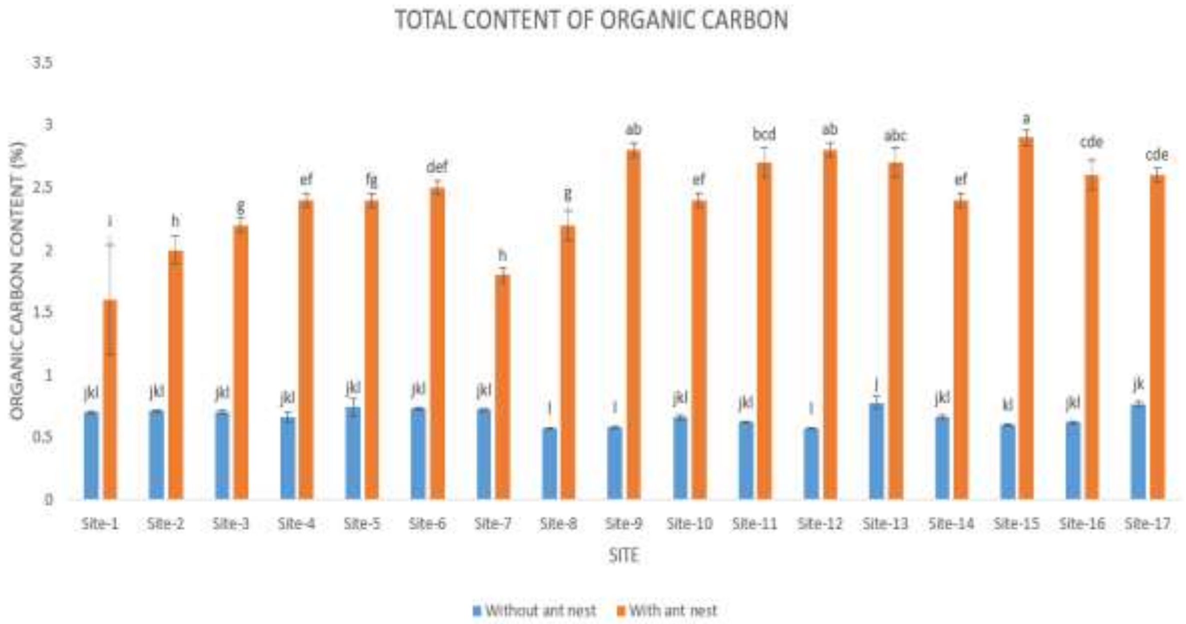


Fig 7: The difference in organic carbon content between soils from *Camponotus compressus* nests and control soils is depicted in the graph. Significantly increased quantities of organic carbon were found in ant nest soils, indicating improved organic matter accumulation. Duncan's Multiple Range Test was used to evaluate statistical significance ($p < 0.05$), and the data are displayed as mean ± standard error (SE).

Nest soils also shown a notable enrichment in total nitrogen (N) concentration. Through the deposition of nitrogen-rich waste and the breakdown of dead ants and food remnants inside the nest, ants help to enhance nitrogen. Furthermore, increasing aeration and organic inputs frequently boost microbial activity in nests, which aids in nitrogen cycling even more [51] [52] as shown in fig-8.

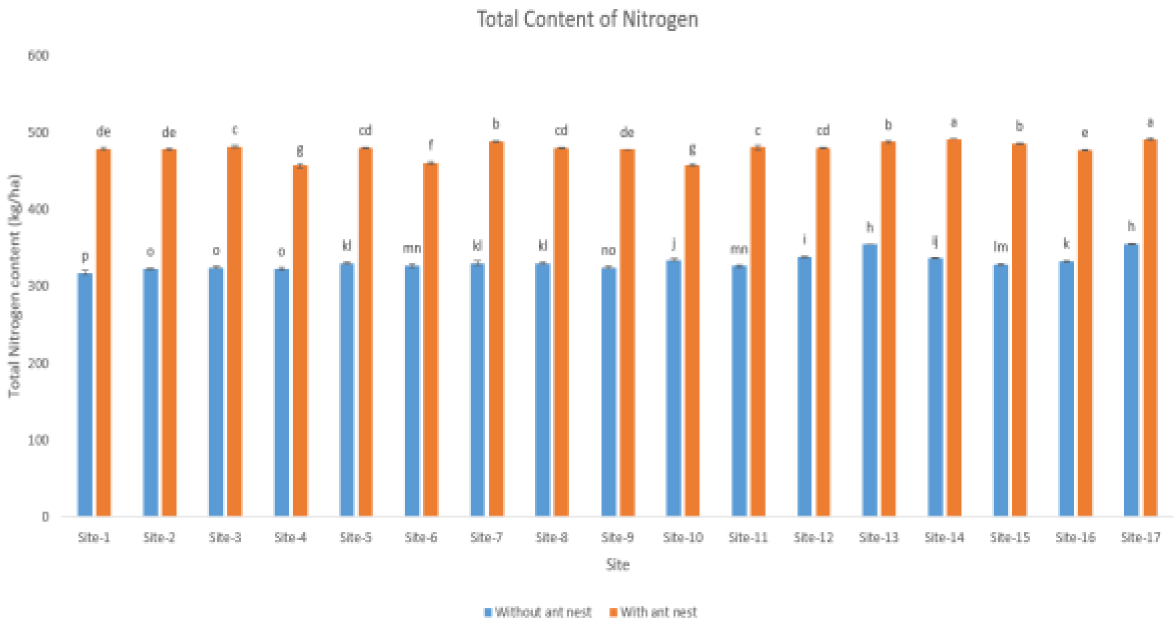


Fig 8: The graph shows how the nitrogen content of control soils and soils from *Camponotus compressus* nests varies. Ant nest soils had noticeably higher nitrogen levels, a sign of better nutrient enrichment. Duncan's Multiple Range Test was used to evaluate statistical significance ($p < 0.05$), and the data are displayed as mean ± standard error (SE).

The amount of available phosphorus (P) in nest soils was noticeably higher. Ant secretions, particularly formic acid and other exocrine chemicals that mobilize phosphorus from mineral particles, may be the cause of this, as may the concentration of organic phosphorus sources and chemical weathering [53] [54] as shown in fig-9.

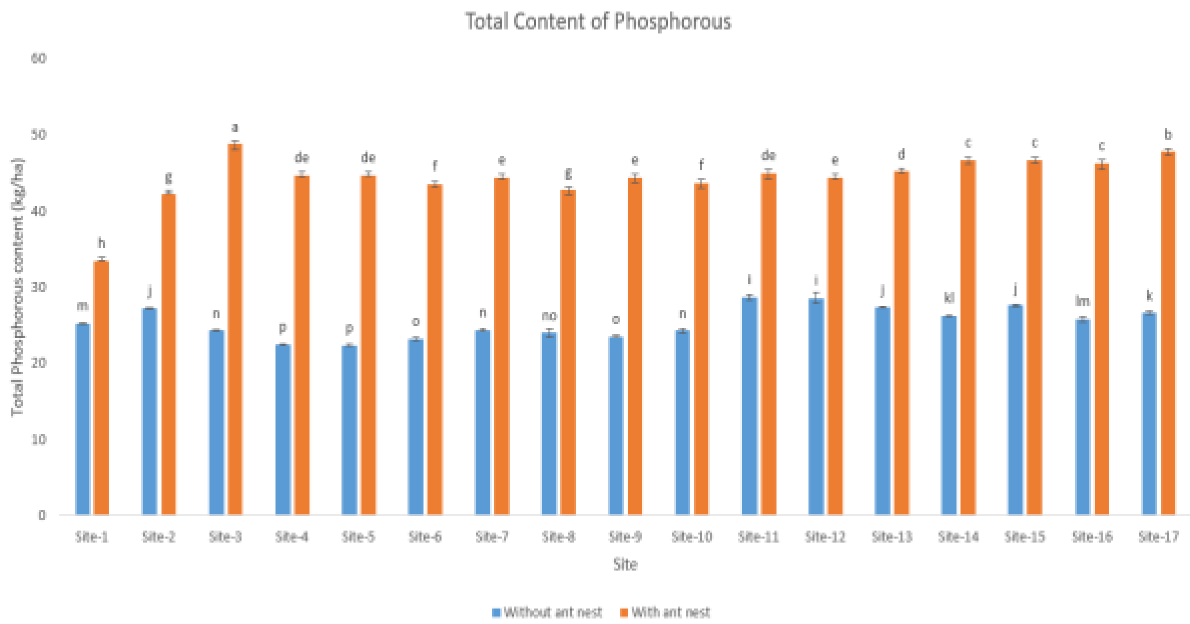


Fig 9: The difference in phosphorus content between control soil and *Camponotus compressus* nest soil is depicted in the graph. Phosphorus contents were much greater in ant nest soils, indicating improved nutritional availability. Duncan's Multiple Range Test was used to evaluate statistical significance ($p < 0.05$), and the data are displayed as mean ± standard error (SE).

Ant nest soils also had higher potassium (K) values. This is probably caused by bioturbation, greater root penetration in the loose soil structure of nests, and ant feeding and tunnelling activities that redistribute potassium-rich mineral particles [4] [55]as shown in fig-10.

.

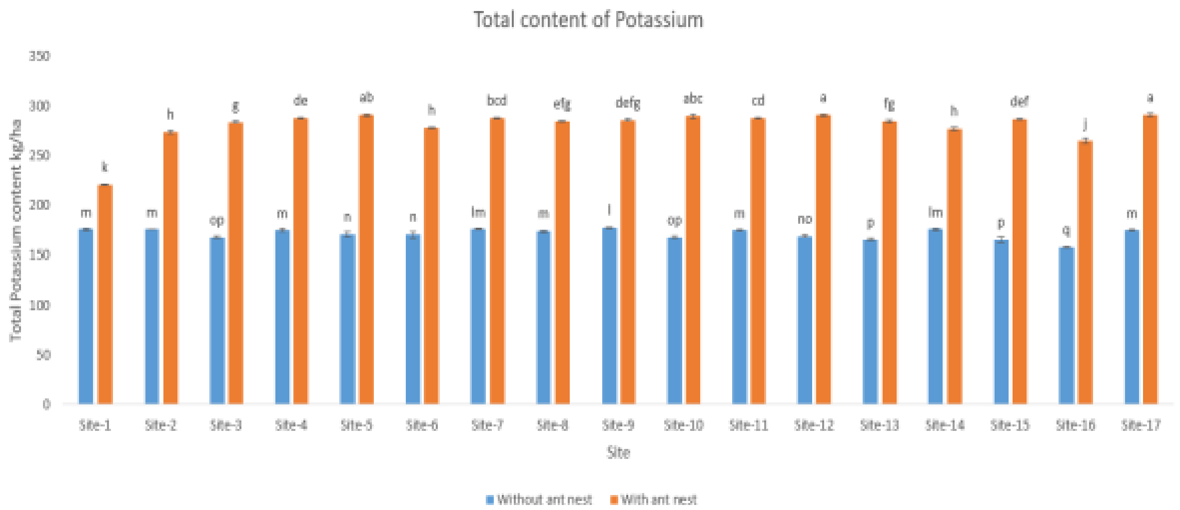


Fig 10: The difference in potassium content between control and *Camponotus compressus* nesting soils is depicted in the graph. Significantly higher potassium levels were found in soils connected to ant nests, indicating better cation accumulation. Duncan's Multiple Range Test was used to evaluate statistical significance ($p < 0.05$), and the data are displayed as mean ± standard error (SE).

The elemental analysis of soil samples revealed significantly higher concentrations of several essential macro- and micronutrient cations—including aluminum (Al), calcium (Ca), magnesium (Mg), sodium (Na), sulfur (S), copper (Cu), zinc (Zn), and iron (Fe)—in soils from *Camponotus compressus* nests as compared to adjacent control soils without ant activity. These findings, statistically validated using Duncan's Multiple Range Test (DMRT) across all 17 sites, suggest the role of ants as key agents in soil geochemical redistribution and enrichment

Nest soils had a notable concentration of calcium (Ca). When building a nest, ants frequently move and gather calcareous particles. Ant tunneling improves porosity and aeration, which increases calcium availability, which is essential for plant cell wall stability [56] as shown in fig-11.

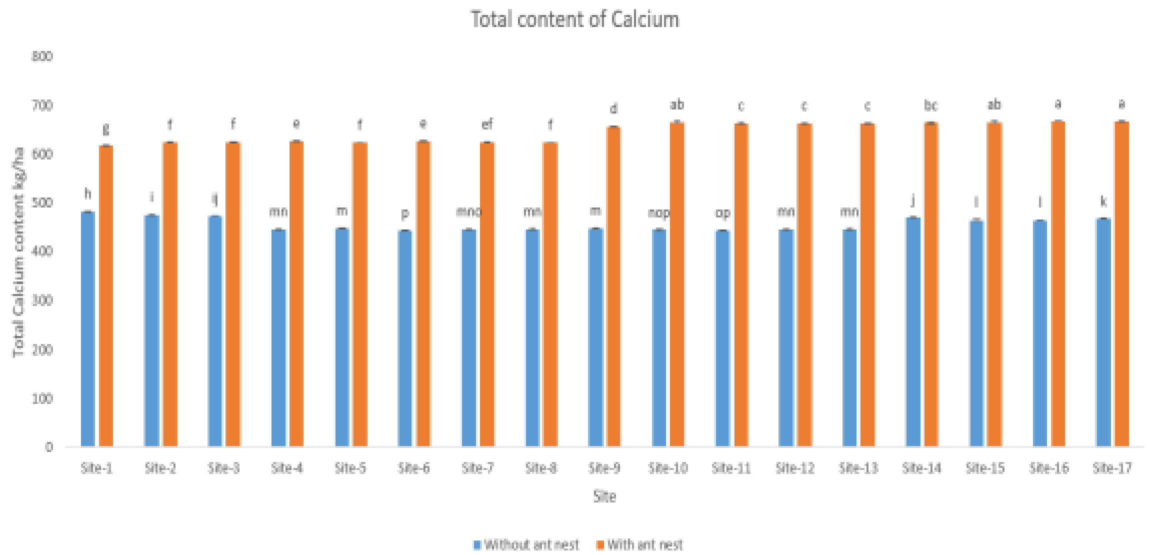


Fig 11: The difference in calcium concentration between control and nest soils for Camponotus compressus is depicted in the graph. Significantly increased calcium levels were found in ant nest soils, suggesting improved mineral enrichment. Duncan's Multiple Range Test was used to evaluate statistical significance ($p < 0.05$), and the data are displayed as mean ± standard error (SE).

There was also a notable increase in magnesium (Mg), a crucial element of chlorophyll, in nest soils. Ants carry soil higher and sort particles during nest building, which can bring magnesium closer to the top [54] [55] as shown in fig-12.

.

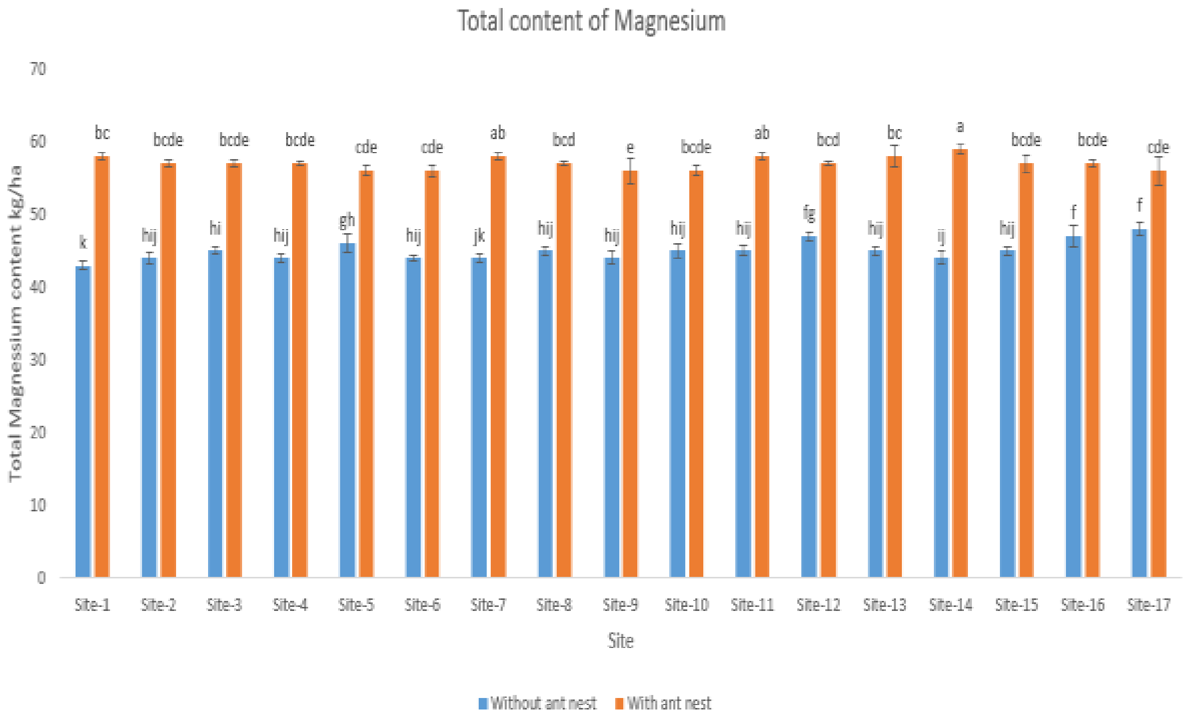


Fig 12: The graph shows how the magnesium content of control soils and soils from *Camponotus compressus* nests varies. Ant nest soils showed a notable rise in magnesium, indicating increased soil fertility. Duncan's Multiple Range Test was used to evaluate statistical significance ($p < 0.05$), and the data are displayed as mean ± standard error (SE).

Nest soils had higher levels of sulfur (S), a necessary component of enzymes and amino acids. By enhancing microbial populations and encouraging the decomposition of organic debris, ants indirectly improve sulfur cycling and increase the availability of sulfate [59] as shown in fig-13.

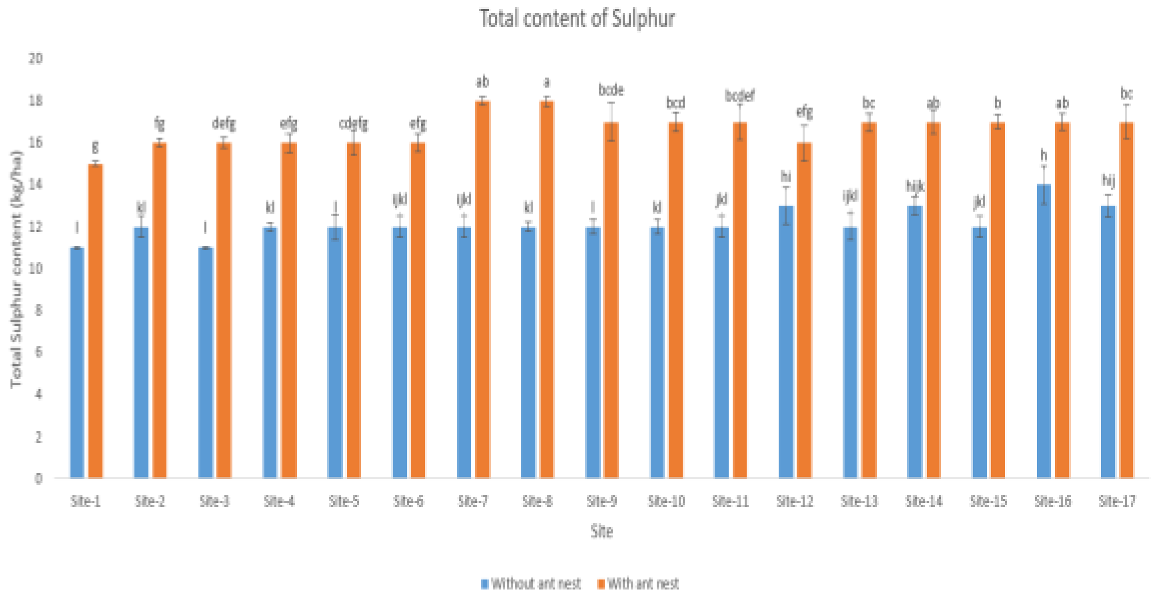


Fig 13: The difference in sulfur concentration between control soil and *Camponotus compressus* nest soil is depicted in the graph. Due to increased microbial activity, ant nest soils had noticeably greater sulfur levels. Duncan's Multiple Range Test was used to evaluate statistical significance ($p < 0.05$), and the data are displayed as mean ± standard error (SE).

Due to the presence of organic matter and microbe-rich habitats that store trace metals, copper (Cu) concentrations were noticeably higher in nest soils. According to [52], copper is essential for respiratory and photosynthetic enzymes as shown in fig-14.

.

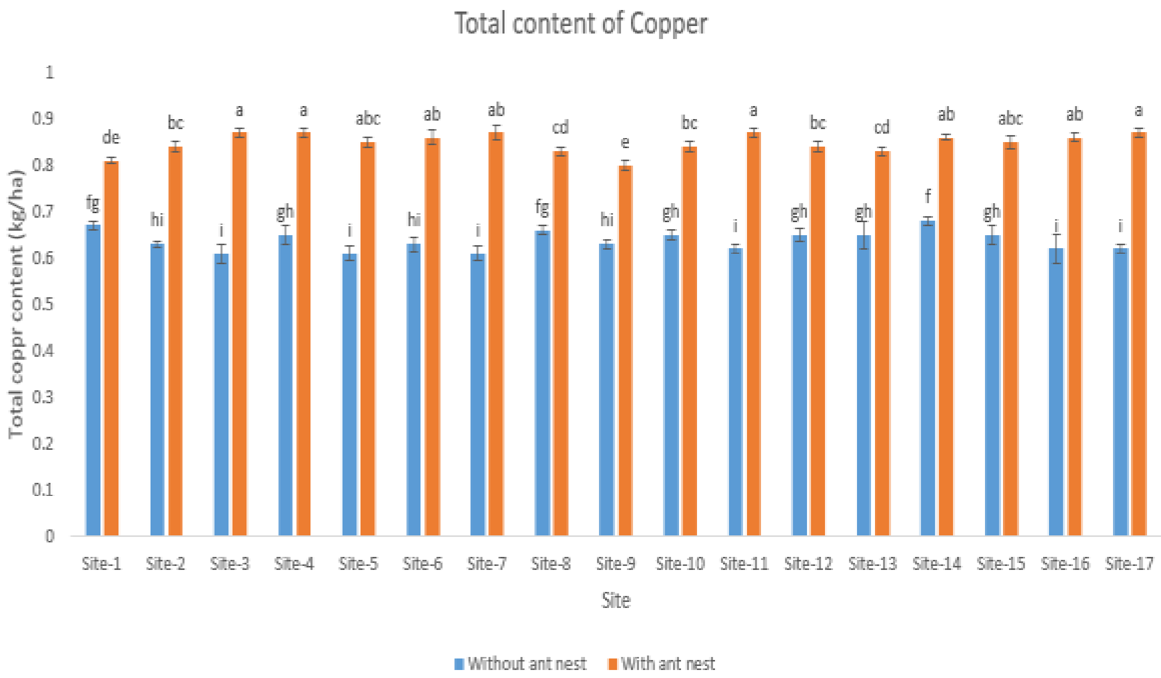


Fig 14: The difference in copper concentration between soils from *Camponotus compressus* nests and control soils is depicted in the graph. Copper levels were much higher in ant nest soils, indicating better micronutrient dynamics. Duncan's Multiple Range Test was used to evaluate statistical significance ($p < 0.05$), and the data are displayed as mean ± standard error (SE).

In comparison to control soils, manganese (Mn) levels were likewise noticeably higher in soils connected to Camponotus compressus nests. As a cofactor in enzymatic activities, manganese is an essential micronutrient that plays a role in photosynthesis, nitrogen metabolism, and plant defense systems. Enhanced microbial activity, increased organic matter deposition, and soil aeration are all ant-mediated processes that can affect Mn solubility and mobility in the rhizosphere, which is why nest soils have higher Mn availability [52].
Furthermore, deeper mineral particles rich in trace elements like manganese are transported upward by ants' constant excavation and soil turnover. The bioavailability of Mn can be improved by this biological redistribution mechanism, particularly in acidic or moderately worn soils [2] [4] respiratory and photosynthetic enzymes as shown in fig-15.

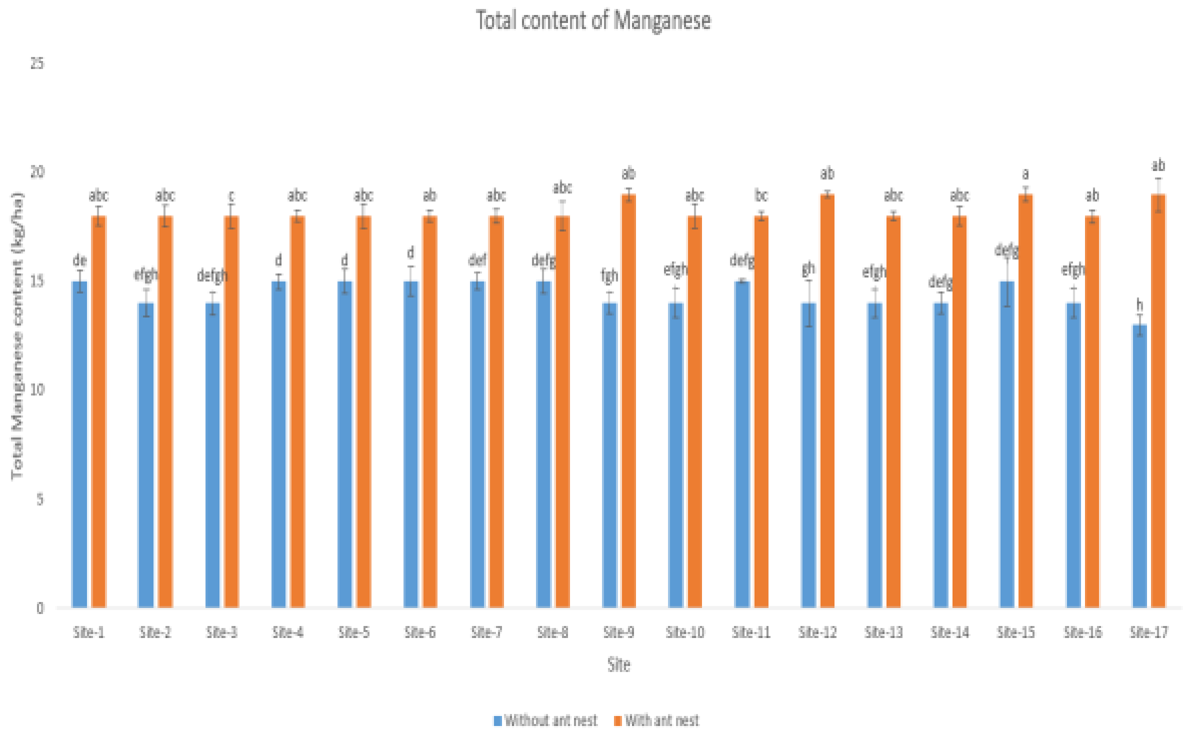


Fig 15: The difference in manganese content between control and nest soils for *Camponotus compressus* is depicted in the graph. Ant nest soils had a noticeably higher manganese content, suggesting that the micronutrient availability was beneficial. Duncan's Multiple Range Test was used to evaluate statistical significance ($p < 0.05$), and the data are displayed as mean ± standard error (SE).

Nest soils have substantially higher levels of zinc (Zn), a crucial mineral involved in hormone production and plant gene expression. Zn retention and bioavailability are probably facilitated by the biologically active and organic-rich nest environment [51] as shown in fig-16.

.

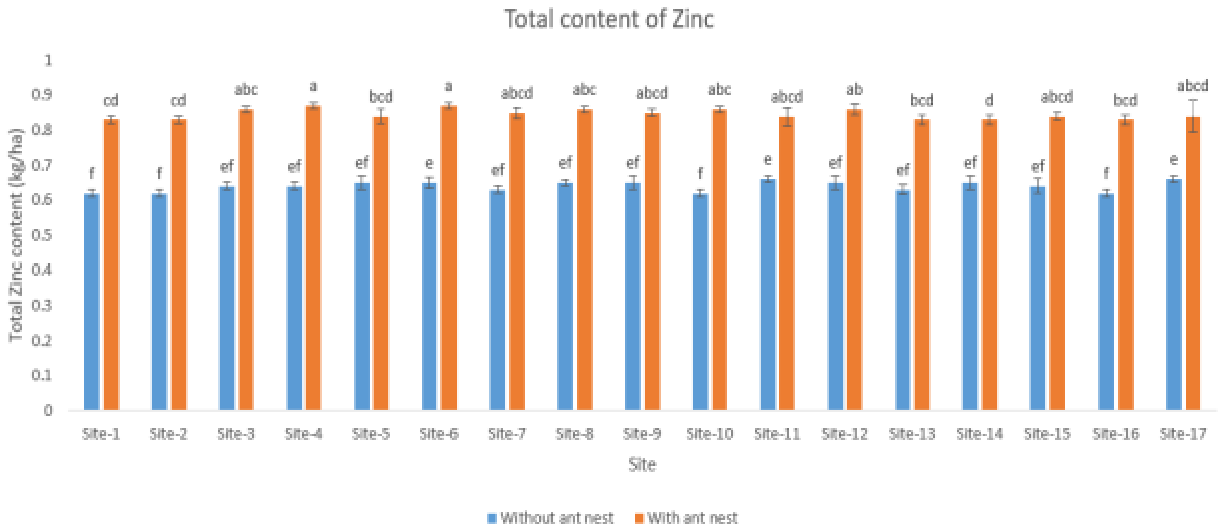


Fig 16: The difference in zinc level between control and *Camponotus compressus* nesting soils is depicted in the graph. Significantly higher zinc levels were found in ant nest soils, indicating improved trace element enrichment. Duncan's Multiple Range Test was used to evaluate statistical significance ($p < 0.05$), and the data are displayed as mean ± standard error (SE).

Nest soils also have higher levels of iron (Fe). Chlorophyll production and respiration depend on iron. Ant nests increase the mobility and availability of iron via improving aeration and redox potential in soil microenvironments (Jouquet, Mathieu, et al., 1994.)[61] as shown in fig-17.

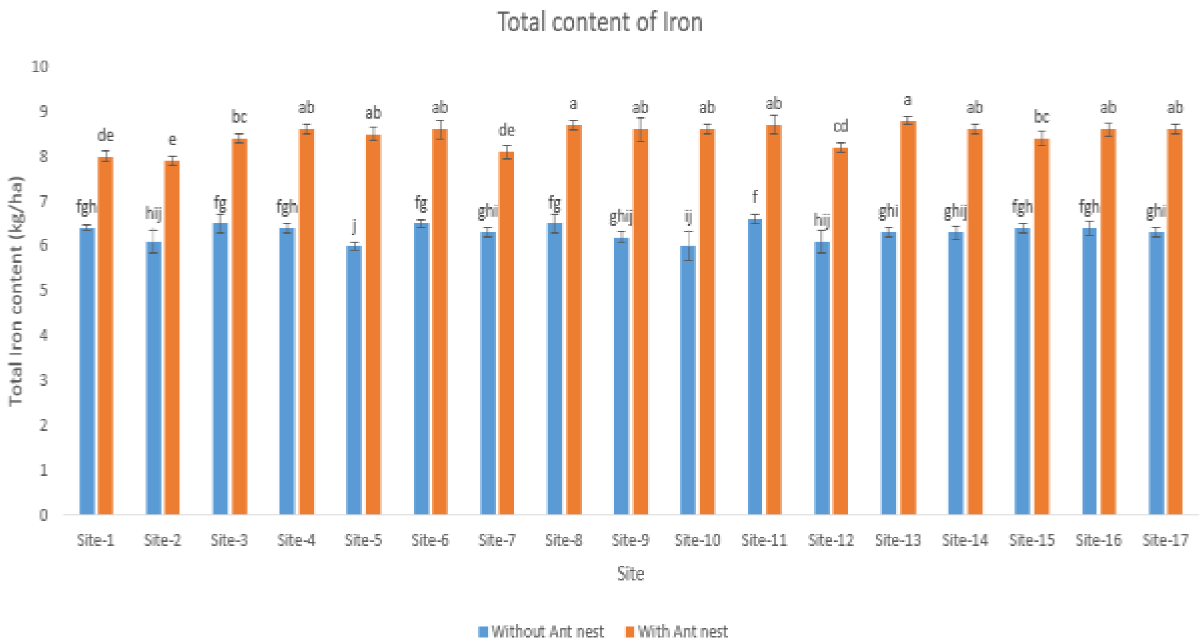


Fig 17: The graph shows how the iron content of the control soil and the nest soil of *Camponotus compressus* differs. Iron levels in ant nest soils were noticeably higher, suggesting better micronutrient content. Duncan's Multiple Range Test was used to evaluate statistical significance ($p < 0.05$), and the data are displayed as mean ± standard error (SE).

3.4. Performance of Coriander plants grown in ant nest soil and soil without ant nest

It was observed that green growth of coriander plants was higher when they were grown on ant nest soil than in soil without ant nest as show in (Fig-18 and 19) (table-1 and 2). Root growth was also higher in plants, number of leaves and diameter of leaves were comparatively more than the non-nest soil. There was a noticeable increase in biomass, denser foliage, and taller shoots in the plants cultivated on ant nest soil. These plants also showed noticeably more vigorous root growth, with longer roots and more branching patterns, which suggests better nutrient absorption capacities. Ant nest soil was positively correlated with overall vegetative development, as evidenced by the experimental group's significantly higher number of leaves per plant and individual leaf diameter. These outcomes are consistent with research by [6], which found that ant-modified soils improve soil porosity, organic matter, and mineral content, all of which increase plant nutrient uptake. By leaving organic waste, dead insects, and feces in their nests, ants are also known to aid in the cycling of nutrients. These materials break down and enrich the nearby soil with vital macro- and micronutrients [62] [63]. The observed growth improvements were probably caused by the increased availability of elements like calcium, magnesium, phosphorus, and nitrogen in ant nest soils table-1 and table-2. According to these results, ant nests serve as organic bioturbators and biofertilizers, forming microhabitats that support stronger and healthier plant growth shown in fig-18 and 19.

Fig 18: Coriander plants grown in experimental soil (with *Camponotus compressus* ant nest) The image demonstrates enhanced vegetative growth, with taller shoots, larger and more numerous leaves, and more developed root systems due to the nutrient-enriched ant nest soil.

Fig 19: Coriander plants grown in control soil (without *Camponotus compressus* ant nest). The image shows reduced green growth, fewer and smaller leaves, and shorter root length in plants cultivated in soil without ant nest activity.

Table 1: Morphological parameters of coriander plants grown in experimental soil (with *Camponotus compressus* ant nest) representing data on plant height, root length, number of leaves and leaf diameter in coriander plants cultivated in nest soil

SL NO.	PLANT SIZE (cm)	ROOT SIZE (cm)	NO. OF LEAVES (cm)	DIAMETER OF LEAF (cm)
1	16	4.5	10	0.8
2	14	3.8	12	0.8
3	11	4	8	0.7
4	13.8	4.1	9	0.8
5	20	6.5	17	0.8

Table 2: Morphological parameters of coriander plants grown in control soil (without *Camponotus compressus* ant nest) representing data on plant height, root length, number of leaves and leaf diameter in coriander plants cultivated in non-nest soil

SL NO.	PLANT SIZE (cm)	ROOT SIZE (cm)	NO. OF LEAVES (cm)	DIAMETER OF LEAF (cm)
1	8	2	4	0.3
2	6	2	3	0.2
3	8.5	1.7	3	0.3
4	7	2.3	4	0.4
5	9	2.8	3	0.4

3.5. Assessment of Photosynthetic Active Radiation in coriander plants grown in ant nest soil and soil without ant nest

The 400–700 nm spectral range of solar radiation that plants use to power the light-dependent processes of photosynthesis is known as photosynthetically active radiation, or PAR. A plant's photosynthetic rate, biomass accumulation, and overall productivity are all influenced by how well it absorbs and uses PAR. The coriander plants (*Coriandrum sativum*) cultivated in the soil of *Camponotus compressus* ant nests and those cultivated in non-nest (control) soil showed notable variations in PAR absorption in the current study. Plants from the experimental group (ant nest soil) demonstrated markedly higher PAR values, indicating a more efficient photosynthetic performance. The combination of enhanced morphological characteristics and physiological efficiency in the plants cultivated in ant nest soil is responsible for this higher PAR absorption. The buildup of organic debris and ant nutrient cycling probably resulted in an enriched soil environment with higher concentrations of essential nutrients like iron, magnesium, and nitrogen—all of which are necessary for the synthesis and operation of chlorophyll [64] [65]. A higher concentration of chlorophyll improves photosynthetic photon flux density (PPFD) absorption by increasing the leaves' ability to absorb light in the PAR range. Additionally, plants cultivated in ant nest soil showed increased leaf thickness and area, which are positively connected with PAR absorption and light interception [66]. This is in line with recent research that demonstrates how soil fertility and microbial interactions drive leaf structural adaptations that improve agricultural species' ability to absorb light and absorb carbon [52]. The higher PAR uptake further suggests increased stomatal conductance and improved internal CO_2 diffusion, both of which are integral to efficient photosynthetic output [68]. The higher PAR values in plants grown in ant nest soil support the idea that soil biodiversity, especially ant-mediated modifications, shapes plant physiological responses. By changing the structure of the soil, improving aeration, and redistributing mineral nutrients, ant nests act as natural biofertilizers that eventually improve photosynthetic efficiency and plant vigour [62] [67]as shown in fig-20.

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 6, 2025
https://theaspd.com/index.php

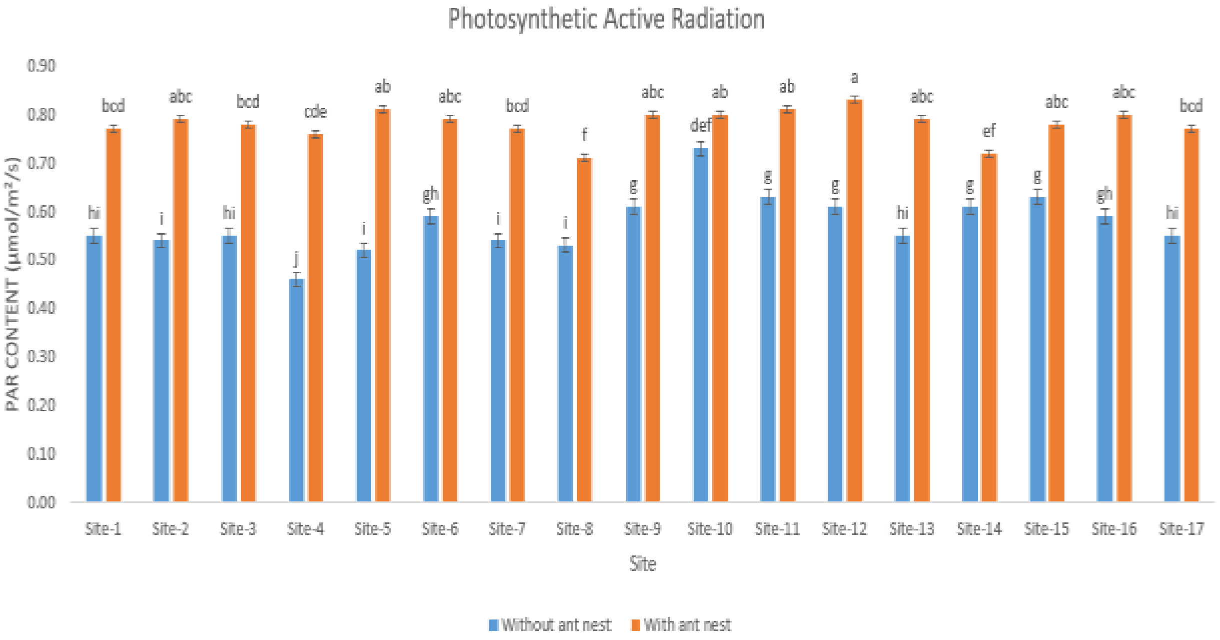


Fig 20: Photosynthetically Active Radiation (PAR) levels in coriander plants grown on ant nest soil and non-nest soil. The graph compares the PAR absorption (measured in µmol/m²/s) by coriander plants grown in soil with *Camponotus compressus* nests (experimental) and in soil without ant nests (control), indicating improved light capture efficiency in the ant nest soil group.

3.6. Assessment of Water Potential in coriander plants grown in ant nest soil and soil without ant nest

One important physiological factor that controls the flow of water within plant tissues and between the plant and its surroundings is water potential (Ψw). It is a vital sign of a plant's level of hydration, turgor pressure, and capacity to absorb water from the soil. It shows the potential energy of water per unit volume in comparison to pure water. When compared to plants grown in non-nest (control) soil, coriander plants (*Coriandrum sativum*) cultivated in soil containing *Camponotus compressus* ants showed a significantly higher (i.e., less negative) water potential, suggesting better water availability and retention in the rhizosphere. Numerous ant-mediated improvements in soil composition and structure are probably the cause of this increased water potential. Through their tunneling and foraging activities, ants are known to aerate the soil and mix organic matter, increasing soil porosity and water-holding capacity [62] (M. Cammaerts et al., 2023). Ant nest soils' higher organic content and finer soil particles function as organic sponges, retaining more water and delaying evaporation. These circumstances make it easier for plant roots to consistently absorb water, preserving the ideal turgor pressure necessary for stomatal control, cell expansion, and general growth [64]. Furthermore, the experimental plants' increased water potential might support improved physiological processes like effective protein synthesis, photosynthesis, and nutrient transport. According to recent research, ant-promoted soils with increased microbial activity and structure promote better root-soil contact and increase root hydraulic conductivity, both of which help plants have a favourable water potential [70]. Plants cultivated in non-nest soils, on the other hand, showed lower (more negative) water potential values because they were more compacted and had less organic matter. This indicates a state of stress in which there is less water available, which may result in restricted gas exchange, partial stomatal closure, and decreased metabolic activity. As evidenced by the control group's decreased shoot height, leaf count, and root growth, such circumstances have a detrimental effect on plant growth.

These results demonstrate how *Camponotus compressus* ants alter soil hydrodynamics and improve plant water relations in a subtle but significant way. Ant nest soils improve water potential, which makes the microenvironment more conducive to long-term plant growth, particularly in semi-arid or seasonally dry conditions as shown in fig-21.

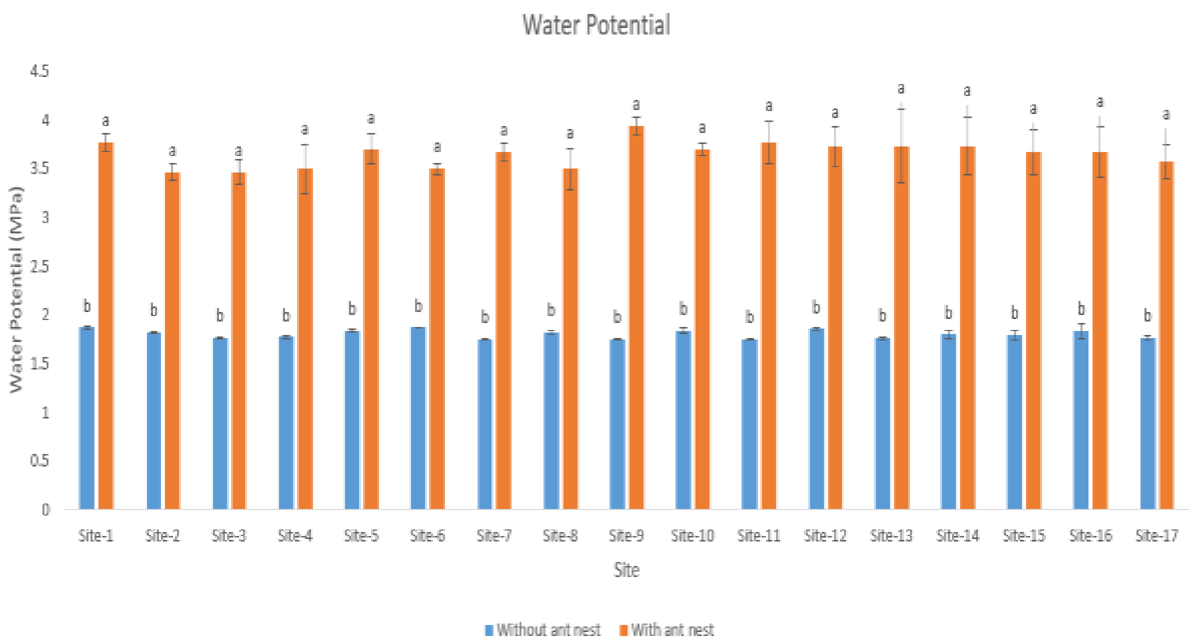


Fig 21: The graph illustrates the variation in water potential (measured in MPa) between coriander plants cultivated in *Camponotus compressus* nest soil and those in control soil. Plants grown in ant nest soil exhibited significantly higher (less negative) water potential values, indicating better water retention and hydration. Data are presented as mean ± standard error (SE), and statistical significance was determined using Duncan's Multiple Range Test (**p** < 0.05).

3.7. Assessment of Net Photosynthetic Rate (Pn) in coriander plants grown in ant nest soil and soil without ant nest

A key physiological metric that represents the equilibrium between the uptake of carbon dioxide (CO_2) during photosynthesis and its exhalation during respiration is the net photosynthetic rate (Pn). As a direct measure of the plant's carbon gain, biomass production potential, and overall photosynthetic efficiency, it is commonly expressed in units of μmol CO_2 m^{-2} s^{-1}. Coriander plants (*Coriandrum sativum*) cultivated in ant nest soil (experimental group) demonstrated noticeably greater net photosynthetic rates than those cultivated in non-nest (control) soil in the current study. This discrepancy suggests that plants linked to *Camponotus compressus* nest environments have more favourable physiological conditions for carbon fixation. There are several interconnected reasons for the increased Pn seen in the experimental group. First off, the biosynthesis of chlorophyll and the proper operation of the photosynthetic apparatus depend on organic matter, nitrogen, magnesium, and iron, all of which are commonly found in ant nest soils [64]. The experimental plants' higher chlorophyll content probably improved light absorption, which in turn improved electron transport and accelerated the rate of carbon assimilation. Furthermore, ant activity may have produced better soil aeration, structure, and water-holding capacity, which may have produced ideal circumstances for gas exchange and root respiration [62] [71]. As previously noted in this study, the experimental plants' higher water potential and turgor pressure would have also helped the stomata open, allowing for a greater uptake of CO2. Water availability and Pn are strongly correlated, with drought or reduced water potential dramatically lowering photosynthetic activity because of stomatal closure and metabolic limitations [21]. In order to support sustained photosynthetic performance, coriander plants' superior water status in ant nest soils probably maintained higher stomatal conductance (gs) and internal CO_2 concentration (Ci). Additionally, the presence of ants may indirectly influence the microbial community in the soil, which may contribute to the promotion of plant hormone synthesis and nutrient mobilization, thus augmenting photosynthetic traits [65]. This is in line with the increasing amount of research that highlights how crucial soil-plant interactions and belowground biodiversity are in controlling plant physiological processes, particularly photosynthesis [72] [73]. In general, the higher net photosynthetic rate in coriander plants cultivated on soil from *Camponotus compressus* nests highlights how advantageous ant-engineered microhabitats are for boosting plant physiological capacity and yield. According to these results, ant nests may serve as organic soil enrichers, enhancing essential metabolic functions like photosynthesis as well as plant morphology and nutrient status as shown in fig-22.

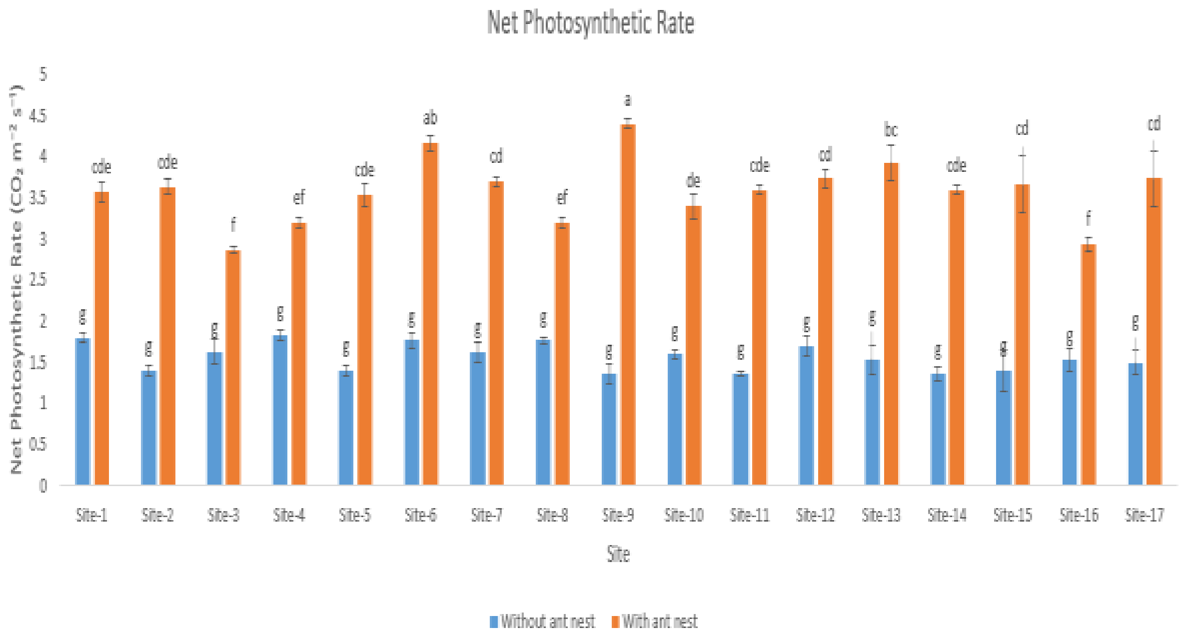


Fig 22: The graph illustrates the comparison of net photosynthetic rate (µmol CO_2 m^{-2} s^{-1}) between coriander plants grown in *Camponotus compressus* nest soil (experimental) and those in control soil (without ant nest). A significantly higher Pn value was recorded in plants from the ant nest soil group, reflecting improved photosynthetic efficiency. Values are expressed as mean ± SE, and statistical significance was assessed using Duncan's Multiple Range Test (**p** < 0.05)

3.8. Assessment of Transpiration rate (E) in coriander plants grown in ant nest soil and soil without ant nest

One important physiological indicator that shows how quickly water vapor is released from plant leaves into the atmosphere is the transpiration rate (E), which is commonly expressed in mmol H_2O m^{-2} s^{-1}. It is mostly controlled by stomatal conductance and environmental factors like soil moisture, temperature, and humidity. In the current study, coriander plants (*Coriandrum sativum*) cultivated in the soil of *Camponotus compressus* ant nests showed a noticeably higher rate of transpiration than those cultivated in non-nest (control) soil, indicating improved stomatal activity and physiological functioning. The improved soil moisture availability and nutrient enrichment in ant nest soil are probably the causes of the experimental plants' increased transpiration rate. By improving the soil's porosity, organic matter, and nutrient levels, ant nests improve root access to water and enable constant transpiration flow [62] [67]. In addition to promoting water uptake, these enhancements aid in preserving the ideal leaf turgor pressure, which keeps stomata open for gas exchange. In this study, plants grown in ant nests also had higher levels of stomatal conductance (gs) and net photosynthetic rate (Pn), which are frequently positively connected with higher transpiration rates. Better cooling of the leaf surfaces and the movement of nutrients from the roots to the aerial portions of the plant are made possible by increased transpiration, which is essential for biomass accumulation and metabolic activity [21]. According to studies, in non-stressful environmental conditions, well-hydrated soils with high microbial and faunal activity—such as those influenced by ants—create favorable conditions for sustaining transpiration flow [64]. Furthermore, the physiological adaptation of coriander plants to a more hospitable microclimate produced by ant nest structures may also be reflected in the increased transpiration that has been observed. By buffering extremes in soil temperature and moisture, these nests can indirectly lessen abiotic stress and maintain transpiration without causing undue water loss [64].

Plants cultivated in non-nest soil, which is distinguished by its compacted texture, lower porosity, and decreased moisture content, on the other hand, displayed significantly less transpiration. These plants' lower water potential might have caused partial stomatal closure, which would have limited transpiration and possibly reduced nutrient flow and carbon assimilation. These results emphasize even more how ants are ecosystem engineers that have a beneficial impact on the dynamics of gas exchange and plant water relations. The increased transpiration rate in coriander plants cultivated in ant nest soil, which is bolstered by better soil structure, hydration, and stomatal regulation, indicates a more active and efficient physiological state overall. This underscores the ecological significance of ants in augmenting plant function as shown in fig-23.

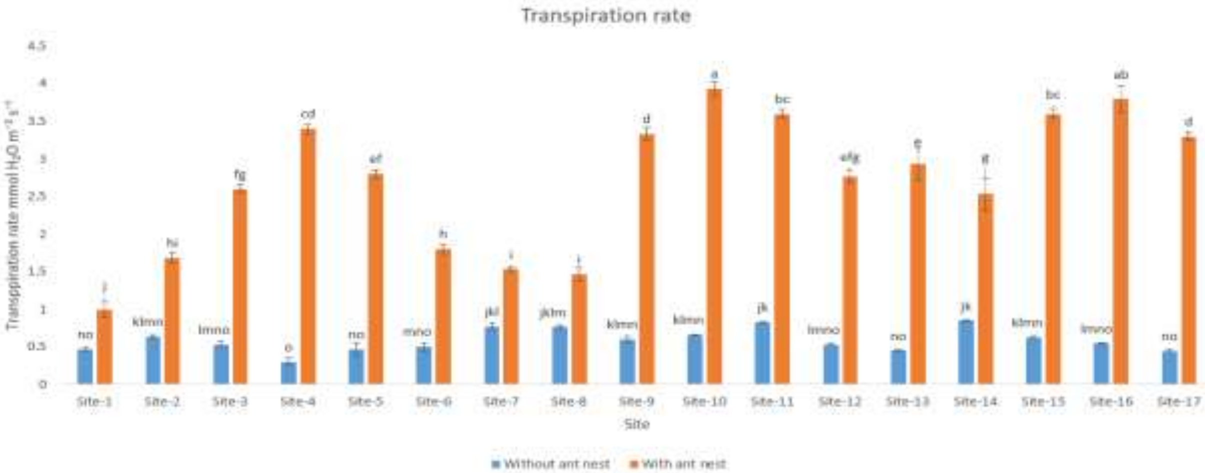
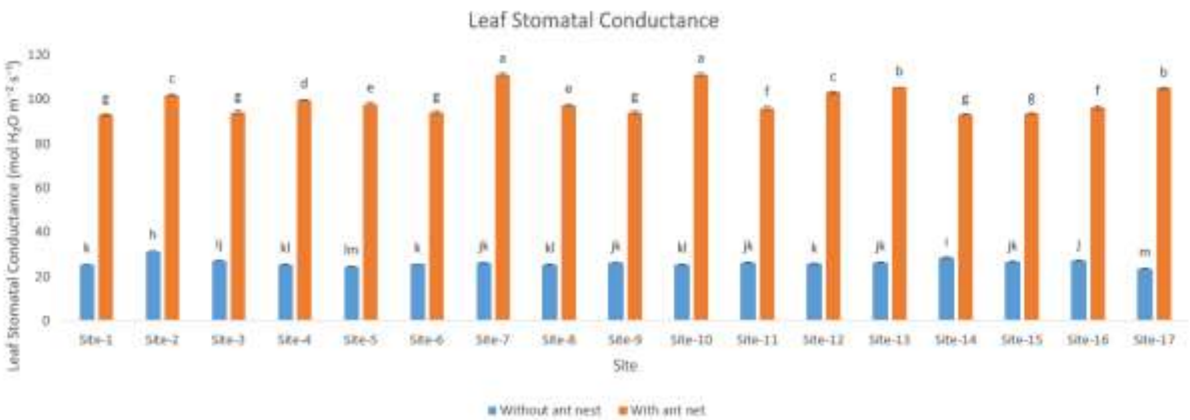


Fig 23: The graph compares the transpiration rate (mmol H_2O m^{-2} s^{-1}) between coriander plants cultivated in *Camponotus compressus* ant nest soil and control soil. Plants in ant nest soil exhibited a significantly higher transpiration rate, indicating improved stomatal function and water transport efficiency. Data are presented as mean ± standard error (SE), with significance tested using Duncan's Multiple Range Test (**p** < 0.05).

3.9. Assessment of Leaf Stomatal Conductance in coriander plants grown in ant nest soil and soil without ant nest

A crucial physiological metric, stomatal conductance (gs) measures how quickly CO_2 enters and water vapor leaves a leaf's stomata. It represents the dynamic balance between transpiration-driven water loss and photosynthetic carbon uptake and is commonly expressed in mol H_2O m^{-2} s^{-1}. The current study found that coriander plants (*Coriandrum sativum*) cultivated in the soil of *Camponotus compressus* ant nests



had a significantly higher stomatal conductance than those cultivated in non-nest (control) soil. This suggests that the experimental group's physiological performance and gas exchange efficiency were improved. The improved soil conditions brought about by ant activity are probably linked to this increase in stomatal conductance. Through bioturbation, the buildup of organic debris, and enhanced microbial interactions, ant nests enhance soil aeration, porosity, and nutrient content [69][62]. Better root development and water uptake result from these enhancements, raising the water potential and turgor pressure of the leaves—two factors that are critical for preserving open stomata. Therefore, under ideal hydration conditions, coriander plants cultivated in ant nest soil may be able to maintain higher rates of gas exchange. Higher net photosynthetic rate (Pn) and transpiration rate (E), which are all connected, are also correlated with elevated stomatal conductance in these plants. More access to water and vital nutrients helps plants keep their stomata open more regularly, which permits the best possible CO_2 influx for photosynthesis without sacrificing water efficiency [74]. Furthermore, it is known that the osmotic regulation of the stomatal aperture and guard cell functioning are influenced by magnesium, potassium, and nitrogen, which are frequently found in ant nest soils [64]. Enhanced stomatal conductance in nutrient-rich, biologically active soils promotes photosynthesis and increases plant resistance to abiotic stress, particularly in the presence of fluctuating light or water conditions, according to recent studies [75]. A strong stomatal regulatory mechanism that allows coriander plants to maximize carbon gain and water use efficiency (WUE) is suggested by the higher gs values seen in plants grown in ant nest soil. As a defense against dehydration, plants in control (non-nest) soil, on the other hand, probably had less water available and less root-soil contact, which caused them to partially close their stomata. This reaction results in decreased photosynthetic efficiency and growth, despite being advantageous for water conservation. In conclusion, the observed enhancement of stomatal conductance in coriander plants grown on *Camponotus compressus* nest soil underscores the role of ants as ecosystem engineers. By modifying the physical and chemical properties of soil, ants indirectly influence key physiological traits like stomatal behavior, thereby improving the plant's ability to regulate gas exchange and maintain metabolic activity under natural conditions as shown in fig-24.

Fig 24: The graph illustrates stomatal conductance (gs) measured in mol H_2O m^{-2} s^{-1} in coriander plants cultivated on *Camponotus compressus* nest soil and control soil. Plants grown on ant nest soil showed significantly higher stomatal conductance, indicating enhanced gas exchange and better physiological adaptation. Values are expressed as mean ± standard error (SE), and statistical differences were assessed using Duncan's Multiple Range Test (**p** < 0.05).

4.0. Assessment of Chlorophyll-T in coriander plants grown in ant nest soil and soil without ant nest

Green plants' main pigment for photosynthetic processes, chlorophyll, is essential for absorbing light and converting energy during photosynthesis. An essential physiological indicator of plant health, productivity, and nitrogen status is total chlorophyll content (Chlorophyll-T), which is the sum of chlorophyll a and b. The chlorophyll-T content of coriander plants (*Coriandrum sativum*) cultivated in *Camponotus compressus* ant nest soil was considerably higher than that of plants grown in control (non-nest) soil in the current study.

Ant nest soil offers a number of ecological and biochemical benefits that are responsible for the observed rise in total chlorophyll content. As ecosystem engineers, ants improve the nutrient status of soil by accumulating organic matter, increasing microbial biomass, and improving moisture retention and aeration [62] [67]. The biosynthesis of chlorophyll molecules depends on essential nutrients like iron, magnesium, and nitrogen, which are better absorbed as a result of these modifications. A key component of the chlorophyll structure is nitrogen, whose availability has a direct impact on the amount of chlorophyll and photosynthetic efficiency [75]. Increased stomatal conductance, net photosynthetic rate, and plant growth metrics like leaf area and biomass accumulation are all positively connected with higher chlorophyll-T content [74]. In order to maximize carbon fixation and light harvesting, plants in nutrient-rich soils—such as those modified by ant activity—tend to retain higher levels of chlorophyll. Furthermore, a sufficient supply of magnesium, which is the central atom in the chlorophyll porphyrin ring and is frequently found in ant nest soils, improves the stability and formation of pigments [64]. Additionally, recent research highlights how biologically active soils help retain chlorophyll and slow down leaf senescence. By regulating oxidative stress and enzyme activity, favorable soil conditions not only increase pigment content but also prolong the functional lifespan of leaves [67]. This phenomenon was demonstrated in the current study, where coriander plants grown in ant nest soils showed improved morphological characteristics like more leaflets, larger leaf diameters, and greener leaves in addition to higher chlorophyll-T levels. On the other hand, plants in control soil might have experienced nutrient limitations, particularly a lack of nitrogen and magnesium, which resulted in decreased chlorophyll synthesis, as they did not have the improved soil dynamics of ant nests. Additionally, these plants displayed decreased vegetative growth and paler foliage, which suggested a direct physiological reaction to unfavorable edaphic conditions. In summary, the high level of total chlorophyll found in coriander plants cultivated in soil from *Camponotus compressus* ant nests highlights the important role that ant-mediated soil enrichment plays in plant physiology. Ants' role in influencing above-ground plant function through below-ground ecological engineering is highlighted by these increases in pigment concentration, which directly support improved light utilization, photosynthetic efficiency, and overall plant vigour as shown in fig-25.

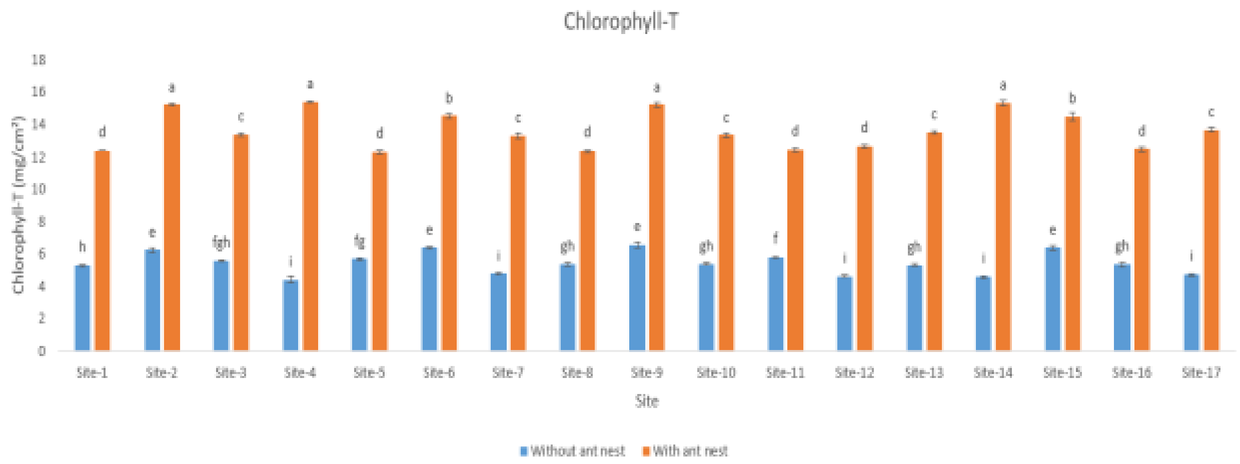


Fig 25: The graph represents the total chlorophyll content (mg/g fresh weight) in coriander plants cultivated in *Camponotus compressus* ant nest soil and in control soil without ant nests. Plants in ant nest soil exhibited significantly higher Chl-T levels, indicating improved chlorophyll biosynthesis and greater photosynthetic pigment accumulation. Values are shown as mean ± standard error (SE), and statistical differences were determined using Duncan's Multiple Range Test (**p** < 0.05).

4.1. Assessment of Chlorophyll-a in coriander plants grown in ant nest soil and soil without ant nest

The main pigment in higher plants that absorbs light energy during photosynthesis is chlorophyll-a. By mainly promoting the photochemical reactions in both Photosystem I and Photosystem II, it plays a crucial part in transforming solar energy into chemical energy. Therefore, a plant's ability to photosynthesize and its physiological state can be directly determined by its chlorophyll-a content [70]. In the current study, the concentration of chlorophyll-a was significantly higher in coriander plants (*Coriandrum sativum*) grown in soil from *Camponotus compressus* ant nests than in control (non-nest) soil. Improved soil fertility, aeration, and microbial activity in the ant nest environment are probably the causes of this increase. Ants are known to increase the availability of nutrients in the soil, especially iron, magnesium, and nitrogen, which are essential for the biosynthesis of chlorophyll [62], [67]. The amount of chlorophyll-a synthesized in plant tissues is largely determined by nitrogen, an essential part of the chlorophyll molecule [75]. Another essential component is magnesium, which is found at the center of the chlorophyll porphyrin ring. Ant nest soil's increased magnesium availability promotes the formation of chlorophyll-a [64]. Increased light absorption efficiency is linked to higher levels of chlorophyll-a, which raises the rates of transpiration, stomatal conductance, and net photosynthesis. Increased chlorophyll-a content increases light use efficiency (LUE), especially in ideal soil conditions, according to a number of recent studies [76] [77]. In the current analysis, coriander plants in ant nest soil showed superior physiological performance as evidenced by accompanying measurements of PAR absorption, water potential, and photosynthetic rate, in addition to having deeper green foliage, which is a sign of high pigment density. Conversely, control plants showed reduced levels of chlorophyll-a, indicating less than ideal soil nutrient conditions. Reduced photosynthetic efficiency and stunted morphological characteristics, like smaller leaves, fewer leaflets, and pale colouring, were probably caused by this. Chlorophyll-a is therefore an early indicator of soil quality and plant health in addition to being a biochemical marker of photosynthetic potential. The findings of this study highlight how crucial ant-mediated soil modification is for boosting pigment biosynthesis and, in turn, increasing plant vigor and productivity in general as shown in fig-26.

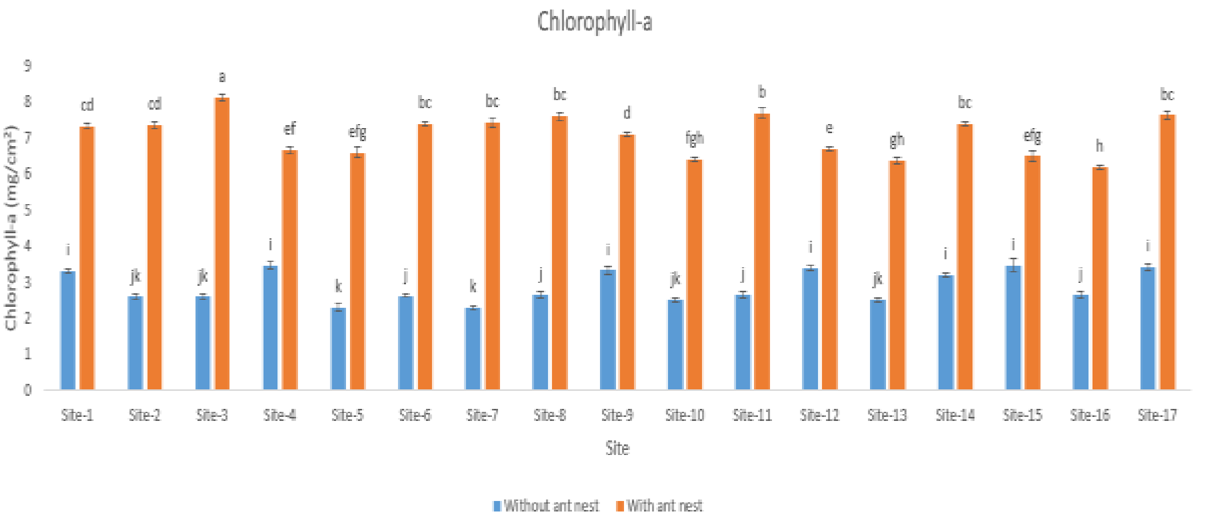


Fig 26: This graph illustrates chlorophyll-a concentration (mg/g fresh weight) in coriander plants grown in *Camponotus compressus* ant nest soil and in control soil. A significant increase in Chl-a content was recorded in plants grown in nest soil, suggesting enhanced photosynthetic potential due to better nutrient availability. Data are expressed as mean ± standard error (SE), with significance tested using Duncan's Multiple Range Test (**p** < 0.05).

4.2. Assessment of Chlorophyll-b in coriander plants grown in ant nest soil and soil without ant nest

An essential component in broadening the spectrum of light wavelengths absorbed during photosynthesis is the accessory light-harvesting pigment chlorophyll-b. As the main pigment in the reaction centers of Photosystems I and II, chlorophyll-a (Chl-a) is complemented by chlorophyll-b, which absorbs light in the red-orange and blue (approximately 455 nm) regions and transfers the energy to chlorophyll-a molecules for effective photochemical activity [77]. The chlorophyll-b content of coriander plants (*Coriandrum sativum*) cultivated in soil from *Camponotus compressus* ant nests was considerably higher than that of plants grown in non-nest (control) soil in this investigation. Ant nest soil's enriched nutrient composition, which includes greater amounts of magnesium, nitrogen, and trace metals like iron and manganese—all essential for chlorophyll biosynthesis—is probably the cause of this increase [75]. The development of light-harvesting complex (LHC) proteins, particularly LHCII, which serve as antennae around Photosystem II, is also intimately associated with chlorophyll-b [77]. Therefore, higher Chl-b content in experimental plants might indicate better structural arrangement of these complexes, improving the overall efficiency of energy transfer and light absorption. Additionally, plants grown in ant nest soil have higher levels of chlorophyll-b, which may indicate a more active synthesis of photosynthetic proteins and an adaptive response to maximize light utilization in nutrient-rich microenvironments [64]. Furthermore, a stronger and healthier physiological state is supported by higher chlorophyll-b, which is frequently correlated with larger leaf area and thickness, both of which were seen in the experimental coriander plants. However, the levels of chlorophyll-b were lower in control plants that were grown in regular soil that wasn't used for ant nests. This implies that inadequate nutrient availability might restrict pigment biosynthesis, which would therefore limit photosynthetic performance and growth by decreasing the plant's capacity to maximise light capture. When combined, the data support the notion that chlorophyll-b is a sensitive measure of soil quality and the effectiveness of light harvesting. The beneficial role of ant-mediated soil modification in enhancing photosynthetic pigment profiles and overall plant productivity is demonstrated by the influence of *Camponotus compressus* nest soil on increasing chlorophyll-b content as shown in fig-27.

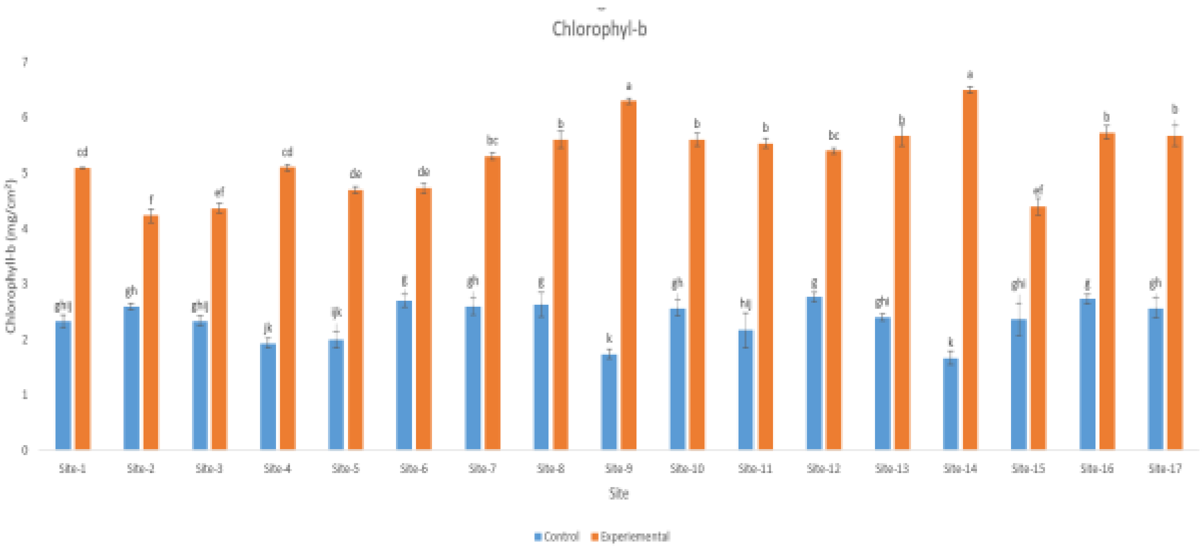


Fig 27: This graph shows the concentration of chlorophyll-b (mg/g fresh weight) in coriander plants cultivated in *Camponotus compressus* ant nest soil versus standard control soil. Plants grown in ant nest soil exhibited significantly higher Chl-b levels, indicating improved accessory pigment synthesis and enhanced light-harvesting efficiency. Data are presented as mean ± standard error (SE), with statistical significance assessed using Duncan's Multiple Range Test (**p** < 0.05).

5. CONCLUSION

The current study unequivocally shows that soils impacted by *Camponotus compressus* ant nests greatly improve *Coriandrum sativum* plant growth and physiological performance. Plants grown in ant nest soil consistently performed better than those grown in non-nest (control) soil across all measured parameters, including morphological, biochemical, and physiological. Superior vegetative growth was demonstrated by the experimental plants' improved root and shoot development, larger and more numerous leaves, and noticeably greener foliage. Significantly greater amounts of chlorophyll-a, chlorophyll-b, and total chlorophyll were found in the plants grown in ant nests by biochemical analysis, indicating enhanced pigment biosynthesis and light-harvesting ability. These plants showed increased stomatal conductance, water potential, transpiration rates, and net photosynthetic rates, all of which are physiological markers of improved hydration and metabolic efficiency. The idea that plants in nest soils face less environmental stress is further supported by a concurrent drop in proline content. Because of the bioturbation, organic debris accumulation, and microbial activity linked to ant behavior, soil analysis verified that ant nest soils are enriched with essential macronutrients and micronutrients. Together, these results demonstrate how *Camponotus compressus* functions as a natural ecosystem engineer, enhancing soil fertility and fostering plant health. Strong evidence from this study suggests that using ant-modified soils as a low-cost, sustainable way to raise crop productivity and soil quality in agroecosystems is possible. The wider applicability of these findings to other crop species and ant genera may be investigated in future research.

REFERENCE

[1] Fox-Dobbs, K., Doak, D. F., Brody, A. K., and Palmer, T. M., 2010, "Termites Create Spatial Structure and Govern Ecosystem Function by Affecting N2 Fixation in an East African Savanna," Ecology, **91**(5), pp. 1296–1307. https://doi.org/10.1890/09-0653.1.

[2] Frouz, J., News, V. J.-M., and 2008, undefined, "The Effect of Ants on Soil Properties and Processes (Hymenoptera: Formicidae)," Acad. Frouz, V JilkováMyrmecological News, 2008•academia.edu. [Online]. Available: https://www.academia.edu/download/84940301/index.pdf. [Accessed: 27-Jul-2025].

[3] Ward, P. S., 2014, "UC Davis UC Davis Previously Published Works Title The Phylogeny and Evolution of Ants Publication Date," annualreviews.org, **45**, pp. 23–43. https://doi.org/10.1146/annurev-ecolsys-120213-091824.

[4] Folgarait, P. J., 1998, "Ant Biodiversity and Its Relationship to Ecosystem Functioning: A Review," Biodivers. Conserv., **7**(9), pp. 1221–1244. https://doi.org/10.1023/A:1008891901953.

[5] Farji-Brener, A. G., and Werenkraut, V., 2015, "A Meta-Analysis of Leaf-Cutting Ant Nest Effects on Soil Fertility and Plant Performance," Ecol. Entomol., **40**(2), pp. 150–158. https://doi.org/10.1111/een.12169.

[6] Wagner, D., and Nicklen, E. F., 2010, "Ant Nest Location, Soil Nutrients and Nutrient Uptake by Ant-Associated Plants: Does Extrafloral Nectar Attract Ant Nests and Thereby Enhance Plant Nutrition?," Wiley Online Libr. Wagner, E Fleur NicklenJournal Ecol. 2010•Wiley Online Libr., **98**(3), pp. 614–624. https://doi.org/10.1111/j.1365-2745.2010.01640.x.

[7] Saha, A., Carvalho, K., ... L. da S. S.-J. of T., and 2012, undefined, "Effect of Leaf-Cutting Ant Nests on Plant Growth in an Oligotrophic Amazon Rain Forest," cambridge.orgAK Saha, KS Carvalho, L da SL Sternberg, P MoutinhoJournal Trop. Ecol. 2012•cambridge.org. [Online]. Available: https://www.cambridge.org/core/journals/journal-of-tropical-ecology/article/effect-of-leafcutting-ant-nests-on-plant-growth-in-an-oligotrophic-amazon-rain-forest/82B0F23976659E474128A0064F12DF74. [Accessed: 27-Jul-2025].

[8] Farji-Brener, A. G., and Ghermandi, L., 2000, "Influence of Nests of Leaf-cutting Ants on Plant Species Diversity in Road Verges of Northern Patagonia," J. Veg. Sci., **11**(3), pp. 453–460. https://doi.org/10.2307/3236638.

[9] Hölldobler, B., and Wilson, E., 1990, *The Ants*. [Online]. Available: https://books.google.com/books?hl=en&lr=&id=R-7TaridBX0C&oi=fnd&pg=PA1&dq=Wilson+(1990)+on+ants&ots=sM3RmdEN5d&sig=YpUhdgWkpwTKep4WwoplCRAqsx4. [Accessed: 24-May-2023].

[10] Hölldobler, B., and Wilson, E., 1990, *The Ants*. [Online]. Available: https://books.google.com/books?hl=en&lr=&id=R-7TaridBX0C&oi=fnd&pg=PA4&dq=Holldobler,+B.,+%26+Wilson,+E.O.+1990+on+ants&ots=sNZSgbyT7h&sig=1tsEkhAfUhbikmcRc1Oyb4IjTKk. [Accessed: 02-Sep-2024].

[11] Gannes, L. Z., O'Brien, D. M., and Del Rio, C. M., 1997, "Stable Isotopes in Animal Ecology: Assumptions, Caveats, and a Call for More Laboratory Experiments," Ecology, **78**(4), pp. 1271–1276. https://doi.org/10.1890/0012-9658(1997)078[1271:SIIAEA]2.0.CO;2.

[12] Singh, H., Rastogi, N., Agarwal, V. M., Shukla, R. K., Singh, H., Rastogi, N., and Agarwal, V. M., 2013, "Impact of Abundant Pheidole Ant Species on Soil Nutrients in Relation to the Food Biology of the Species," Appl. Soil Ecol., **71**, pp. 15–23. https://doi.org/10.1016/j.apsoil.2013.05.002.

[13] Wu, H., Batzer, D., Yan, X., Lu, X., Ecology, D. W.-A. S., and 2013, undefined, "Contributions of Ant Mounds to Soil Carbon and Nitrogen Pools in a Marsh Wetland of Northeastern China," Elsevier. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S092913931300098X. [Accessed: 27-Jul-2025].

[14] LIGHTON, J. R. B., QUINLAN, M. C., and JR, D. H. F., 1994, "Is Bigger Better? Water Balance in the Polymorphic Desert Harvester Ant Messor Pergandei," Physiol. Entomol., **19**(4), pp. 325–334. https://doi.org/10.1111/j.1365-3032.1994.tb01059.x.

[15] Kaspari, M., Welti, E. A. R., and de Beurs, K. M., 2020, "The Nutritional Geography of Ants: Gradients of Sodium and Sugar Limitation across North American Grasslands," J. Anim. Ecol., **89**(2), pp. 276–284. https://doi.org/10.1111/1365-2656.13120.

[16] Buczkowski, G., 2011, "Suburban Sprawl: Environmental Features Affect Colony Social and Spatial Structure in the Black Carpenter Ant, Camponotus Pennsylvanicus," Ecol. Entomol., **36**(1), pp. 62–71. https://doi.org/10.1111/j.1365-

2311.2010.01245.x.
[17] Bharti, H., Guénard, B., Bharti, M., ZooKeys, E. E.-, and 2016, undefined, "An Updated Checklist of the Ants of India with Their Specific Distributions in Indian States (Hymenoptera, Formicidae)," ncbi.nlm.nih.govH Bharti, B Guénard, M Bharti, EP Econ. 2016•ncbi.nlm.nih.gov. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4741291/. [Accessed: 11-Jan-2024].
[18] Nettimi, R., Science, P. I.-C., and 2015, undefined, "Patch Fidelity in Camponotus Compressus Ants Foraging on Honeydew Secreted by Treehoppers," JSTORRP Nettimi, P IyerCurrent Sci. 2015•JSTOR. [Online]. Available: https://www.jstor.org/stable/24905864?casa_token=BBI8N-MchFkAAAAA:noNdK-_39YCUDBYOSDPOspNwTiw64ky3VO7xEVeYwKB5-ak1AnCr-LkV4oMTbDRLVOutCQMgcJGPneuuv2jnNlN_nBgxCUNvBNwN1aLK4C-EWI4ZsOcb. [Accessed: 27-Jul-2025].
[19] Kumari, S. S., and Singh, H. H., 2016, "Influence of the Sugar-Loving Ant, Camponotus Compressus (Fabricius, 1787) on Soil Physico-Chemical Characteristics." [Online]. Available: https://www.cabidigitallibrary.org/doi/full/10.5555/20173206376. [Accessed: 27-Jul-2025].
[20] Agarwal, V. M., and Rastogi, N., 2008, "Deterrent Effect of a Guild of Extrafloral Nectary-Visiting Ant Species on Raphidopalpa Foveicollis, a Major Insect Pest of Sponge Gourd, Luffa Cylindrica," Entomol. Exp. Appl., **128**(2), pp. 303–311. https://doi.org/10.1111/j.1570-7458.2008.00727.x.
[21] Farji-Brener, A. G., and Werenkraut, V., 2017, "The Effects of Ant Nests on Soil Fertility and Plant Performance: A Meta-Analysis," J. Anim. Ecol., **86**(4), pp. 866–877. https://doi.org/10.1111/1365-2656.12672.
[22] Kemble, A., Journal, H. M.-B., and 1954, undefined, "Liberation of Amino Acids in Perennial Rye Grass during Wilting," pmc.ncbi.nlm.nih.govAR Kemble, HT MacphersonBiochemical Journal, 1954•pmc.ncbi.nlm.nih.gov. [Online]. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC1269838/. [Accessed: 27-Jul-2025].
[23] Rhodes, D., Handa, S., physiology, R. B.-P., and 1986, undefined, "Metabolic Changes Associated with Adaptation of Plant Cells to Water Stress," Acad. Rhodes, S Handa, RA BressanPlant Physiol. 1986•academic.oup.com. [Online]. Available: https://academic.oup.com/plphys/article-abstract/82/4/890/6082046. [Accessed: 27-Jul-2025].
[24] Ae, N. V., and Hermans, C., 2008, "Proline Accumulation in Plants: A Review," SpringerN Verbruggen, C HermansAmino acids, 2008•Springer, **35**(4), pp. 753–759. https://doi.org/10.1007/s00726-008-0061-6.
[25] Ahmad, I., Wright, S. J. W., Stewart, G. R., and Wainwrightt, S. J., 1981, "THE SOLUTE AND WATER RELATIONS OF AGROSTIS STOLONIFERA ECOTYPES DIFFERING IN THEIR SALT TOLERANCE," New Phytol, **87**(3), pp. 615–629. https://doi.org/10.1111/j.1469-8137.1981.tb03232.x.
[26] Armengaud, P., Thiery, L., Buhot, N., March, G. G. De, and Savouré, A., 2004, "Transcriptional Regulation of Proline Biosynthesis in Medicago Truncatula Reveals Developmental and Environmental Specific Features," Physiol. Plant., **120**(3), pp. 442–450. https://doi.org/10.1111/j.0031-9317.2004.00251.x.
[27] Yamada, M., Morishita, H., Urano, K., Shiozaki, N., Yamaguchi-Shinozaki, K., Shinozaki, K., and Yoshiba, Y., "Effects of Free Proline Accumulation in Petunias under Drought Stress," Acad. Yamada, H Morishita, K Urano, N Shiozaki, K Yamaguchi-Shinozaki, K ShinozakiJournal Exp. Bot. 2005•academic.oup.com. https://doi.org/10.1093/jxb/eri195.
[28] Huang, A., Physiology, A. C.-P., and 1979, undefined, "Proline Oxidase and Water Stress-Induced Proline Accumulation in Spinach Leaves," Acad. Huang, AJ CavalieriPlant Physiol. 1979•academic.oup.com. [Online]. Available: https://academic.oup.com/plphys/article-abstract/63/3/531/6076433. [Accessed: 27-Jul-2025].
[29] Mehta, S. K., and Gaur, J. P., 1999, "Heavy Metal-Induced Proline Accumulation and Its Role in Ameliorating Metal Toxicity in Chlorella Vulgaris," New Phytol., **143**(2), pp. 253–259. https://doi.org/10.1046/j.1469-8137.1999.00447.x.
[30] Chen, C. T., Chen, L.-M., Lin, C., and Kao, C. H., 2001, *Regulation of Proline Accumulation in Detached Rice Leaves Exposed to Excess Copper*. [Online]. Available: www.elsevier.com/locate/plantsci. [Accessed: 27-Jul-2025].
[31] Saradhi, P., AliaArora, S., research, K. P.-B. and biophysical, and 1995, undefined, "Proline Accumulates in Plants Exposed to UV Radiation and Protects Them against UV-Induced Peroxidation," ElsevierPP Saradhi, S AliaArora, K PrasadBiochemical Biophys. Res. Commun. 1995•Elsevier. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0006291X85714611. [Accessed: 27-Jul-2025].
[32] Smirnoff, N., Phytochemistry, Q. C.-, and 1989, undefined, "Hydroxyl Radical Scavenging Activity of Compatible Solutes," Elsevier. [Online]. Available: https://www.sciencedirect.com/science/article/pii/0031942289801827. [Accessed: 27-Jul-2025].
[33] Hong, Z., Lakkineni, K., Zhang, Z., physiology, D. V.-P., and 2000, undefined, "Removal of Feedback Inhibition of Δ1-Pyrroline-5-Carboxylate Synthetase Results in Increased Proline Accumulation and Protection of Plants from Osmotic Stress," academic.oup.com. [Online]. Available: https://academic.oup.com/plphys/article-abstract/122/4/1129/6098815. [Accessed: 27-Jul-2025].
[34] Alia, Mohanty, P., and Matysik, J., 2001, "Effect of Proline on the Production of Singlet Oxygen," Amino Acids, **21**(2), pp. 195–200. https://doi.org/10.1007/s007260170026.
[35] Büssis, D., Botany, D. H.-J. of E., and 1998, undefined, "Acclimation of Potato Plants to Polyethylene Glycol-Induced Water Deficit II. Contents and Subcellular Distribution of Organic Solutes," Acad. Büssis, D HeinekeJournal Exp. Bot. 1998•academic.oup.com. [Online]. Available: https://academic.oup.com/jxb/article-abstract/49/325/1361/506280. [Accessed: 28-Jul-2025].
[36] Carvalho, H., Helio Costa, J., De, R., Miranda, S., and Saraiva, K., 2019, "Salt Acclimation in Sorghum Plants by Exogenous Proline: Physiological and Biochemical Changes and Regulation of Proline Metabolism," SpringerPAF Freitas, HH Carvalho, JH Costa, RS Miranda, KDC Saraiva, FDB OliveiraPlant cell reports, 2019•Springer, **38**(3), pp. 403–416. https://doi.org/10.1007/s00299-019-02382-5.
[37] De Almeida, T., Mesléard, F., Santonja, M., Gros, R., Dutoit, T., and Blight, O., 2020, "Above-and below-Ground

Effects of an Ecosystem Engineer Ant in Mediterranean Dry Grasslands," royalsocietypublishing.org, **287**(1935). https://doi.org/10.1098/rspb.2020.1840.
[38] Kavi Kishor, P. B., and Sreenivasulu, N., 2013, "Is Proline Accumulation per Se Correlated with Stress Tolerance or Is Proline Homeostasis a More Critical Issue?," Wiley Online Libr. Kavi Kishor, N SreenivasuluPlant, cell Environ. 2014•Wiley Online Libr., **37**(2), pp. 300–311. https://doi.org/10.1111/pce.12157.
[39] Agami, R. A., 2014, "Applications of Ascorbic Acid or Proline Increase Resistance to Salt Stress in Barley Seedlings," SpringerRA AgamiBiologia plantarum, 2014•Springer, **58**(2), pp. 341–347. https://doi.org/10.1007/s10535-014-0392-y.
[40] Cerdà, A., and Doerr, S. H., 2010, "The Effect of Ant Mounds on Overland Flow and Soil Erodibility Following a Wildfire in Eastern Spain," Ecohydrology, **3**(4), pp. 392–401. https://doi.org/10.1002/eco.147.
[41] Banik, S., Biswas, S., Karmakar, R., and Brahmachary, R., 2010, "Necrophoresis in Two Indian Ant Species, Camponotus Compressus (Fabricius) and Diacamma Vagans (Smith) (Insecta: Hymenoptera: Formicidae)," Proc. Zool. Soc., **63**(2), pp. 87–91. https://doi.org/10.1007/s12595-010-0012-6.
[42] Shukla, R. K., Rastogi, N., and Singh, H., 2018, "Contribution of the Nutrient-Enriched Ant Nest Debris Soil to Growth and Yield of Kalmegh (Andrographis Paniculata) under Natural and Experimental Field Conditions," Biol. Agric. Hortic., **34**(3), pp. 173–185. https://doi.org/10.1080/01448765.2017.1408492.
[43] Wagner, D., and Nicklen, E. F., 2010, "Ant Nest Location, Soil Nutrients and Nutrient Uptake by Ant-Associated Plants: Does Extrafloral Nectar Attract Ant Nests and Thereby Enhance Plant Nutrition?," Wiley Online Libr. Wagner, E Fleur NicklenJournal Ecol. 2010•Wiley Online Libr., **98**(3), pp. 614–624. https://doi.org/10.1111/j.1365-2745.2010.01640.x.
[44] (Sweden), V. Y.-S. J. of N., and 1992, undefined, "Protein and Amino Acid Requirements in Humans: Metabolic Basis and Current Recommendations," agris.fao.org. [Online]. Available: https://agris.fao.org/search/en/providers/122495/records/647756fcf2e6fe92b3657258. [Accessed: 28-Jul-2025].
[45] Hölldobler, B., and Wilson, E., 1990, *The Ants*. [Online]. Available: https://books.google.com/books?hl=en&lr=&id=R-7TaridBX0C&oi=fnd&pg=PA1&dq=Holldobler+and+Wilson+1990+&ots=sM1WlcBN5h&sig=l4hGPGnykqk0ECiaC3HPOdLx26c. [Accessed: 30-Nov-2022].
[46] Hölldobler, B., and Wilson, E., 1990, *The Ants*. [Online]. Available: https://books.google.com/books?hl=en&lr=&id=R-7TaridBX0C&oi=fnd&pg=PA1&dq=Holldobler+and+Wilson,+1990+on+ants&ots=sNXSdaDM-i&sig=X3oELf99ZbuV0DSd88F20OCGgiM. [Accessed: 11-Jan-2024].
[47] Singh, H., Rastogi, N., Agarwal, V. M., Shukla, R. K., Singh, H., Rastogi, N., and Agarwal, V. M., 2013, "Impact of Abundant Pheidole Ant Species on Soil Nutrients in Relation to the Food Biology of the Species," Appl. Soil Ecol., **71**, pp. 15–23. https://doi.org/10.1016/j.apsoil.2013.05.002.
[48] Lessard, J. P., Sackett, T. E., Reynolds, W. N., Fowler, D. A., and Sanders, N. J., 2011, "Determinants of the Detrital Arthropod Community Structure: The Effects of Temperature and Resources along an Environmental Gradient," Oikos, **120**(3), pp. 333–343. https://doi.org/10.1111/j.1600-0706.2010.18772.x.
[49] Tadey, M., and Farji-Brener, A. G., 2007, "Indirect Effects of Exotic Grazers: Livestock Decreases the Nutrient Content of Refuse Dumps of Leaf-Cutting Ants through Vegetation Impoverishment," J. Appl. Ecol., **44**(6), pp. 1209–1218. https://doi.org/10.1111/j.1365-2664.2007.01338.x.
[50] Garrettson, M., Stetzel, J., ... B. H.-J. of T., and 1998, undefined, "Diversity and Abundance of Understorey Plants on Active and Abandoned Nests of Leaf-Cutting Ants (Atta Cephalotes) in a Costa Rican Rain Forest," cambridge.orgM Garrettson, JF Stetzel, BS Halpern, DJ Hear. BT Lucey, MJ McKONEJournal Trop. Ecol. 1998•cambridge.org. [Online]. Available: https://www.cambridge.org/core/journals/journal-of-tropical-ecology/article/diversity-and-abundance-of-understorey-plants-on-active-and-abandoned-nests-of-leafcutting-ants-atta-cephalotes-in-a-costa-rican-rain-forest/85652949D30749CB15C3146B70FFFA5B. [Accessed: 28-Jul-2025].
[51] Lenoir, L., Persson, T., and Bengtsson, J., 2001, "Wood Ant Nests as Potential Hot Spots for Carbon and Nitrogen Mineralisation," Biol. Fertil. Soils, **34**(4), pp. 235–240. https://doi.org/10.1007/s003740100405.
[52] Cammeraat, E. L. H., and Risch, A. C., 2008, "The Impact of Ants on Mineral Soil Properties and Processes at Different Spatial Scales," *Journal of Applied Entomology*, pp. 285–294. https://doi.org/10.1111/j.1439-0418.2008.01281.x.
[53] Jouquet, P., Mathieu, J., ... C. C.-... H. N. S., and 2007, undefined, "Soil Engineers as Ecosystem Heterogeneity Drivers," Acad. Jouquet, J Mathieu, C Choosaï, S BarotEcology Res. Progress. Hauppauge Nov. Sci. Publ. 2007•academia.edu. [Online]. Available: https://www.academia.edu/download/99441852/39840858.pdf#page=201. [Accessed: 28-Jul-2025].
[54] Killham, K., 1994, *Soil Ecology*. [Online]. Available: https://books.google.com/books?hl=en&lr=&id=zDIaumF3MCYC&oi=fnd&pg=PR15&dq=Soil+Ecology&ots=7JqO_w_J0k&sig=3JZjCIb1CWtcxCrJpfrua8iFpc4. [Accessed: 28-Jul-2025].
[55] Brener, A., Biotropica, J. S.-, and 1995, undefined, "Leaf-Cutting Ant Nests and Soil Fertility in a Well-Drained Savanna in Western Venezuela," JSTORAGF Brener, JF SilvaBiotropica, 1995•JSTOR. [Online]. Available: https://www.jstor.org/stable/2389001?casa_token=kJWzrdXwE-AAAAAA:_MFfognoqloV4OuTvACHYwawuYWfgJhdmJaNq4btuEgoPOGZ2yAxIjo6Hzh-Inx4j_BQMU7FHrtmqM7rkWoeDkaPOvjNINw6d1dgfoGdJ0_P5uVSRl2i. [Accessed: 28-Jul-2025].
[56] Dean, W. R. J., Milton, S. J., and Klotz, S., 1997, "The Role of Ant Nest-Mounds in Maintaining Small-Scale Patchiness in Dry Grasslands in Central Germany," Biodivers. Conserv., **6**(9), pp. 1293–1307. https://doi.org/10.1023/A:1018313025896.
[57] Frouz, J., News, V. J.-M., and 2008, undefined, "The Effect of Ants on Soil Properties and Processes (Hymenoptera: Formicidae)," Acad. Frouz, V JilkováMyrmecological News, 2008•academia.edu. [Online]. Available: https://www.academia.edu/download/84940301/index.pdf. [Accessed: 28-Jul-2025].

[58] Brener, A., Biotropica, J. S.-, and 1995, undefined, "Leaf-Cutting Ant Nests and Soil Fertility in a Well-Drained Savanna in Western Venezuela," JSTORAGF Brener, JF SilvaBiotropica, 1995•JSTOR. [Online]. Available: https://www.jstor.org/stable/2389001?casa_token=jX1Zf6ABbT8AAAAA:ho75roW_x99W17FhxrpA_g9mZf_MAYr8znSNk_K93DzDAMadI8-WgHslKZv1HnYkalZGl-Z5R_h014QpyxuCIwwxANuZuZuWltdXRiNTpFCVneNsyhOe. [Accessed: 28-Jul-2025].
[59] Dauber, J., Schroeter, D., Biology, V. W.-E. J. of S., and 2001, undefined, "Species Specific Effects of Ants on Microbial Activity and N-Availability in the Soil of an Old-Field," Elsevier. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1164556301010949. [Accessed: 28-Jul-2025].
[60] Jouquet, P., Dauber, J., Lagerlöf, J., ecology, P. L.-A. soil, and 2006, undefined, "Soil Invertebrates as Ecosystem Engineers: Intended and Accidental Effects on Soil and Feedback Loops," Elsevier. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0929139305001265. [Accessed: 28-Jul-2025].
[61] Llanos, C., Sanabria, C., Lavelle, P., and Fonte, S. J., 2014, "Ants as Indicators of Soil-Based Ecosystem Services in Agroecosystems of the Ants as Indicators of Soil-Based Ecosystem Services in Agroecosystems of the Colombian Llanos," Elsevier. https://doi.org/10.1016/j.apsoil.2014.07.001.
[62] Toro, I. Del, Ribbons, R. R., and Ellison, A. M., 2015, "Ant-Mediated Ecosystem Functions on a Warmer Planet: Effects on Soil Movement, Decomposition and Nutrient Cycling," Wiley Online Libr., **84**(5), pp. 1233–1241. https://doi.org/10.1111/1365-2656.12367.
[63] Dauber, J., and Wolters, V., 2000, "Microbial Activity and Functional Diversity in the Mounds of Three Different Ant Species Microbial Activity and Functional Diversity in the Mounds of Three Di□erent Ant Species," Artic. Soil Biol. Biochem. https://doi.org/10.1016/S0038-0717(99)00135-2.
[64] Zhong, Z., Li, X., Sanders, D., Liu, Y., Wang, L., Ortega, Y. K., Pearson, D. E., and Wang, D., 2021, "Soil Engineering by Ants Facilitates Plant Compensation for Large Herbivore Removal of Aboveground Biomass," Ecology, **102**(5). https://doi.org/10.1002/ecy.3312.
[65] Ouattara, K., Yeo, K., Kouakou, L. M. M., and Dekoninck, W., 2023, "Ant Nests Effect on Organic Matter, Carbon, and Nitrogen Flux in the Soil under Grasses Tufts in Lamto Savannah (Côte d'Ivoire)," Agrosystems, Geosci. Environ., **6**(2). https://doi.org/10.1002/agg2.20374.
[66] Sankovitz, M., and Purcell, · J, 2022, "Ant Nests Differentially Affect Soil Chemistry across Elevational Gradients," Insectes Soc., **69**(2–3), pp. 293–298. https://doi.org/10.1007/s00040-022-00869-1.
[67] Wu, D., Du, E., Eisenhauer, N., Mathieu, J., Nature, C. C.-, and 2025, undefined, "Global Engineering Effects of Soil Invertebrates on Ecosystem Functions," nature.comD Wu, E Du, N Eisenhauer, J Mathieu, C ChuNature, 2025•nature.com. [Online]. Available: https://www.nature.com/articles/s41586-025-08594-y. [Accessed: 28-Jul-2025].
[68] Wagner, D., Brown, M. J. F., and Gordon, D. M., 1997, "Harvester Ant Nests, Soil Biota and Soil Chemistry," Oecologia, **112**(2), pp. 232–236. https://doi.org/10.1007/s004420050305.
[69] Cammaerts, M., Evershed, R., physiology, E. M.-J. of insect, and 1983, undefined, "The Volatile Components of the Mandibular Gland Secretion of Workers of the Ants Myrmica Lobicornis and Myrmica Sulcinodis," Elsevier. [Online]. Available: https://www.sciencedirect.com/science/article/pii/0022191083900197. [Accessed: 03-Sep-2024].
[70] Wang, R., Yang, J., Liu, H., Sardans, J., Zhang, Y., Wang, X., Wei, C., Xiaotao, L., Dijkstra, F. A., Jiang, Y., Han, X., and Peñuelas, J., 2022, "Nitrogen Enrichment Buffers Phosphorus Limitation by Mobilizing Mineral-Bound Soil Phosphorus in Grasslands," Ecology, **103**(3). https://doi.org/10.1002/ecy.3616.
[71] Cammaerts, M. C., and Cammaerts, R., 2023, "Ants' Capability of Associating Odors with Time Periods of the Day," J. Ethol., **41**(1), pp. 79–89. https://doi.org/10.1007/s10164-022-00770-1.
[72] Sankovitz, M., and Purcell, · J, 2022, "Ant Nests Differentially Affect Soil Chemistry across Elevational Gradients," SpringerM Sankovitz, J PurcellInsectes Sociaux, 2022•Springer, **69**(2–3), pp. 293–298. https://doi.org/10.1007/s00040-022-00869-/ldr.2681.
[75] Luo, B., Huang, M., Wang, W., Niu, J., Shrestha, M., Zeng, H., Ma, L., Degen, A. A., Liao, J., Zhang, T., Bai, Y., Zhao, J., Fraser, L. H., and Shang, Z., 2023, "Ant Nests Increase Litter Decomposition to Mitigate the Negative Effect of Warming in an Alpine Grassland Ecosystem," R. Luo, M Huang, W Wang, J Niu, M Shrestha, H Zeng, L Ma, AA Degen, J Liao, T ZhangProceedings R. Soc. B, 2023•royalsocietypublishing.org, **290**(2001). https://doi.org/10.1098/rspb.2023.0613.
[76] Zhang, X., Zhang, Z., The, H. W.-Y. Y. S. tai xue bao=, and 2020, undefined, "Effects of Ant Disturbance on Soil Organic Carbon Cycle: A Review.," Eur. Zhang, ZS Zhang, HT WuYing Yong Sheng tai xue bao= J. Appl. Ecol. 2020•europepmc.org. [Online]. Available: https://europepmc.org/article/med/33393270. [Accessed: 28-Jul-2025].
[77] Chen, M., Wang, S., Chen, W., ... R. C.-Y. Y. S. tai, and 2019, undefined, "Effects of Ant Nesting on Soil Microbial Biomass Carbon and Quotient in Tropical Forest of Xishuangbanna.," Eur. Chen, SJ Wang, WQ Chen, R Cao, QB Cao, P Wang, QQ Zuo, Z Zhang, SH LiYing Yong Sheng tai xue bao= J. Appl. Ecol. 2019•europepmc.org. [Online]. Available: https://europepmc.org/article/med/31529872. [Accessed: 28-Jul-2025].