From Earth to Textile: Exploring the Soil-to-Silk Continuum

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Article Info

P-ISSN: 3051-3448
E-ISSN: 3051-3456
Volume: 07
Issue: 02
Received: 08-07-2026
Accepted: 06-08-2026
Published: 04-09-2026
Page No: 61-64

Abstract

The silk production is one of the most complex biological process, which is governed by the interaction of silkworm genetics, host plant quality, environmental conditions, and nutritional availability. The biological foundation of this process upstream into the soil nutrition availability in the 'Soil to Silk' continuum. This present review examines this continuum emphasising how soil fertility and nutrient availability influence host plant nutritional and biochemical quality, which subsequently affects larval growth, silk-gland development, cocoon characteristics and silk productivity. Evidences from domesticated *Bombyx mori* and semi-domesticated and wild silk-producing species, including *Antheraea mylitta*, *A. assamensis*, *A. pernyi* and *A. yamamai*, is synthesized in this review across major sericultural regions. Studies on *B. mori* demonstrate that soil fertility, balanced NPK nutrition and micronutrient availability influence mulberry productivity and leaf quality, while leaf nitrogen and aminoacid composition are associated with silkworm growth and silk production in the species. In tropical Tasar and Muga systems, although this continuum is strongly influenced by forest ecology, host plant identity, climate and local soil conditions. Notably, evidence from *A. mylitta* demonstrates that nutrient availability does not necessarily translate into higher silk productivity as proven through Mn continuum. Thus the silk productivity is not simply governed by nutrient abundance, but by nutrient balance and ecological compatibility. This review identifies a critical research gap in soil to plant and plant to silkworm interactions which are generally investigated separately, whereas the integrated soil-plant-silkworm-silk pathway remains insufficiently characterized.

DOI: https://doi.org/10.54660/JSFR.2026.7.2.61-64

Keywords: Tasar silk, Soil, Parent Material Minerology, Nutrition, Soil-Silk Continuum

1. Introduction

Silk as a biologically derived natural fibre, whose production represents the culmination of a complex interaction among insect genetics, host-plant quality, environmental conditions and nutritional availability altogether. Although, the conventional silk production in silkworm pathway follows from silkworm to cocoon to silk, biologically however the silk production starts much earlier than that, i.e., through host plant and soil nutrient availability of the ecozones of the silkworm. The availability of the nutrients in the soil reaches the silk through host plant root nutrient acquisition, to the host leaf and through the silkworm, to silk gland development, which in turn determines the quality of the Sericin and Fibroin production that regulates the commercial characteristics of the silk. Hence, the soil in which the host plant develops can be regarded as an upstream component of the silk production system (Hasansab A. Nadaf *et al*. 2022) [3]. Host plants with advantageous mineral and biochemical profiles can influence larval food consumption, nutrient utilization, silk-gland protein content and the final composition of silk. This pathway does not imply that the soil nutrients are transferred unchanged into silk, rather the soil nutrients influence plant physiological processes and subsequently converts mineral resources into proteins, amino acids, carbohydrates and other compounds that are consumed by the silkworm, it impacts the quality of silk produced. Although this relationship is particularly evident in domesticated mulberry sericulture based on *Bombyx mori*, where *Morus* is cultivated specifically to provide foliage for larval feeding, however it becomes ecologically more complex in semi domesticated and wild silk varieties, including Tropical Tasar silkworm (*Antheraea mylitta* Drury), Chinese Oak silkworm (*A. pernyi* Guérin-Méneville), Japanese Oak silkworm (*A. yamamai Guérin-Méneville*), Muga (*A. assamensis* Helfer) and Eri (*Samia ricini* Jones). The importance of the plant nutrition composition extends beyond the host plant quality, nutrition, biomass and into mineral and biochemical composition of the leaf as well. Host plants with better nutritional profile influence the larval food consumption, nutrient assimilation, silk gland protein content and eventually the composition of the silk produced by the silkworm (Nath *et al*. 2025) [10]. An important evidence of this concept comes from China, Hubei where the fertilisation practices with macronutrients such as Nitrogen, Phosphorous, Potassium and micronutrient revealed higher silk production in Mulberry silkworm (Chen *et al* 2009) [2]. Even difference in nutritional value of mulberry leaves differed among strains led to different silk ratio, and was found to be correlated with leaf nitrogen and particular amino acids, including methionine, histidine and threonine (Machii & Katagiri, 1991) [9]. Hence the Soil to Silk concept not only establishes the connection between soil nutrient but also integrates two different aspects of traditionally different fields; soil fertility management and silk production.

In this paper we will be discussing evidence based proof on how soil to silk continuum impacts the silk production across the silk producing Lepidopteran, including both domesticated and semi domesticated varieties across the globe.

2. The Biological Bridge Between Nutrients in Soil to Silk:

2.1. *Bombyx Mori* As A Global Model

As a complete domesticated variety *B. mori* serves as an excellent model to observe the soil to silk relation because the host plant of this species *Morus alba* or Mulberry plant can be grown in controlled environments specifically for feeding. Soil fertility in this case becomes a manageable variant while cultivating the host plants in the field, especially in East-Asian, Tropical, and Sub tropical countries from where most of the Mulberry silk are harvested from. Evidences from China, the top producer of mulberry silk suggest that, poor soil fertility along with nutrient imbalance can constrain both mulberry productivity and leaf quality, with balanced N, P and K fertilization, supplemented by other nutrients such as Mg, S and B where required, recommended according to prevailing soil conditions in the host plant growing farms (Chen *et al*., 2009) [2]. Their result also extended beyond the plant productivity to the relationship of the larval growth stages to the leaf nutrient produced under different fertilization regimes in Hubei Province, establishing soil management role in different larval stage. But the soil mediated effect on the silk production might not be a direct correlation between soil to silk gland relation since the nutrition from soil travels through host plant. The intermediate pathway from soil to the host plant was well reviewed by Machii and Katagiri (1991) [9] in Japan. Variance in the nutritive value of mulberry leaves and their consequences for silkworm production efficiency revealed that Silk ratio is strongly associated with leaf Nitrogen and with specific amino acids, including methionine, histidine and threonine, which implies that intermediary nutritional value of the host plant strongly influence the larval growth and hence silk production. Further the experiment also revealed that soil fertility alone cannot explain silk productivity, as mulberry genotype also influenced nutritional quality and production efficiency under comparable growing conditions. Another Korean Mulberry silk cultivation system also gave similar evidence as that of Japan, suggesting geographical variation in soil properties also influence leaf nutritional composition greatly (Ju *et al*., 2022). Variations in soil organic matter, and available Phosphorous were linked to available Potassium in the soil, even in close proximity areas, which suggest that even in localised production system, soil conditions can generate appreciable differences in their property. These cumulative findings from East Asian countries suggest that the soil to silk relationship should be viewed as a multistep interaction involving soil nutrient availability, plant nutrient acquisition, host plant genotype, leaf biochemical composition and larval utilisation efficiency, rather than a simple linear transfer of nutrients from soil to the silk.

Similar findings have also been achieved from the tropical and the subtropical countries like India and Brazil etc particularly under environmentally constrained mulberry production systems in northeastern India. Two different mulberry growing regions from Mizoram, Rangvamual and Durtlang showed differences in soil C and N, C/N ratio, available P, pH, moisture and microbial biomass carbon. Comparatively more fertile Durtlang soils, found to be associated with higher crude protein and moisture content in the leaf, which reflected in cocoon production and silk quality (Singh *et al*. 2021) [15]. Similar results were also found to be relevant for acidic rainfed soils, where integrated application of NPK, farmyard manure, lime and Boric Acid improved the leaf yield, along with increment in concentration of N, P, K and B while simultaneously improving soil pH, organic carbon and available nutrient status (Ray *et al*. 2021) [14].

Collectively these studies suggest that Self productivity lies one plan to tuition, driven by the soil fertility. However, since the nutrient availability depends heavily on the physiochemical factors, resolving the soil acidity and organic matter deficits, play as a critical component as that of adding NPK in the soil. Consequently, modern fertilisation must be transition from the nutrition application to the site specific soil diagnostics.

2.2. *Antheraea Mylitta* As A Model for Semi-Wild Tasar Rearing

The soil to silk relationship becomes considerably more complex in tropical Tasar based on *Antheraea mylitta* Drury. Unlike *B. mori*, which is maintained within an intensively managed agricultural system, *A. mylitta* is associated with forest and agroforestry landscapes, where native people rear it almost outside in the wild. The principal host plants include *Terminalia tomentosa* (Arjun), *T. arjuna* (Asan) and *Shorea robusta* (Sal), where the nutrient availability depends not only on soil fertility but also on geology of the landscape, litter decomposition, plant species, rainfall, soil moisture and anthropogenic disturbances in its 'Ecozones'. Giri and Misra (2018) provided one of the most direct demonstrations of nutrient movement from soil to silk in any silkworm system through Mn. When they measured Mn, Fe, Cu and Zn in tasar-rearing soil, and followed them through host plant, larva, litter, pupa, excreta and cocoon shell, they found that in soil the Mn concentration to be at 82.79 ± 9.78 mg/kg, yet two different host plants showed different concentrations in their leaf. Terminalia tomentosa leaves contained approximately 50-100 ppm Mn, which is considered suitable for successful tasar production, but in Sal the level was at 353-2543 ppm, considerably high leading to the severe crop failure through toxicity. This study fundamentally changes the simplistic assumption that increasing nutrient availability necessarily increases silk productivity, rather soil to silk relationship is governed by nutrient balance, where deficiency impairs physiological processes, optimal availability supports healthy growth and silk production, while excess in availability may induce toxicity and reduce productivity of the silk production. Building upon this principle of precise nutrient balance, a recent multi-regional investigation by Giri *et al*. (2024) further quantified the impact of favourable nutrient profiles in *T. tomentosa*. Analysis of soil and foliage Major Tasar producing areas in the states of Jharkhand, Odisha and Chhattisgarh revealed highly significant positive correlation between essential micro and macro nutrients such as NPK, calcium, magnesium and Zinc and economically important characters such as overall leaf yield, cocoon yield, cocoon weight, and shell weight. Translating the soil to silk relationship also reveals another bottleneck in the ecozones. Currently major tasar producing ecozones lack critical nutrients required for the optimal growth of the host plants. In Mayurbhanj district of Odisha, host plant soils have been found to be highly acidic, with 99% deficient in available nitrogen,which is a serious depletion that cascades off to trophic chain and eventually impairs the foliage quality and economic traits (Pandiaraj *et al*., 2019). Similarly, all the soil samples from Purulia district are uniformly deprived of nitrogen, even though highly acidic soil conditions facilitate the high micronutrient transfer, such as zinc, iron, and boron (Pandiaraj *et al*., 2018; Pandiaraj *et al*., 2020) [13, 12]. Since this micronutrient sufficiency cannot offset the severe macronutrient starvation, it eventually restricts the fundamental silk synthesis procedure. All theses regional specific studies shed light on how a successful soil to silk transfer is currently broken at its root. Hence underscores the need for a site-specific nutrient management, including organic manures and bio fertilisers to restore the commercial productivity in major of the ecozones.

Even in other oak tasar species such as *A. pernyi* and *A. yamamai*, studies are majorly focused on nutritional composition across different developmental stages, silkworm genetics, physiology, food value and production (Li *et al*. 2020). Hence a substantial gap still exists in exotic species relation with respect to soil to silk continuum as well.

2.3. *Antheraea Assamensis*: Muga Silk and Host-Plant Nutritional Quality

In the semi-domesticated Muga silkworm *A. assamensis*, the production pathway is strongly coupled with the ecological condition of its host plant Som and Soalu, just like *A. mylitta*. hence serves as another suitable model to understand endemic soil to silk continuum. Just like *A. mylitta* hostplant identity and leaf developmental stages significantly influence the feeding preferences and larval survival with major variation in the protein and other compounds with respect to the host plant and life maturity ages (Neog *et al*. 2011) [11]. Since manipulation of selected leaf chemical constituents eventually alter the larval survival, cocoon weight, shell weight, and pupal weight indicates that variation in host plant biochemical composition can infect propagate to insert and cuckoo performances in future, when silk production happens. another study by Borah and Goswami (2026), also suggest that muga silk productivity depends on synchrony between seasonal availability and nutritional quality of host plant leaves and silkworm developmental stages under favourable weather conditions. Hence, disruption in any of those components can cascade into reduced level performance and poor cocoon traits. Host plans stress also can alter the leaf biochemical and water related traits, thereby modifying the nutritional resource available to the larva. For example, prolonged wetness and high humidity in the environment can reduce the feeing opportunities and increase disease pressure among various Muga populations, which indicates that environment factors, impact the genetic background of the muga silkworm, determining the economic production outcomes (Kalita & Dutta, 2020) [6].

Table 1: Research Progress till the timeline and gaps

Species	Country/region	Evidence investigated	Principal finding	Evidence level
B. mori	China	Soil/fertilizer → mulberry → silkworm	Balanced NPK + micronutrients improved mulberry nutritional production	Direct
B. mori	Japan	Leaf N/amino acids → cocoon	Leaf N and amino acids correlated with cocoon-shell production efficiency	Plant–silkworm
B. mori	India	Soil → leaf → cocoon	Higher soil fertility associated with higher leaf protein and cocoon production	Direct
B. mori	India	Acid soil + NPK/FYM/lime/B → leaf	Integrated management improved soil health and leaf nutritional quality	Soil–plant
B. mori	Korea	Soil → leaf minerals	Regional soil variation associated with variation in leaf mineral composition	Soil–plant
B. mori	Brazil	NPK/micronutrients → silkworm	Fertilization treatments evaluated for weight gain, cocoon and silk	Direct/experimental
A. mylitta	India	Soil → leaf → larva → cocoon	Mn transferred through trophic pathway; excessive Mn reduced production	Direct
A. assamensis	India	Host plant → silkworm	Protein and secondary metabolites varied among hosts and leaf ages	Plant–silkworm
A. pernyi	China	Oak host → silkworm	Strong production ecology, but limited direct soil-to-silk measurements	Research gap
A. yamamai	Japan/East Asia	Oak host → silkworm	Strong host/ecological association, limited direct soil evidence	Research gap

3. Conclusion

Evidences across all the species Defines that self production as a complex ecological continuum follows soil to silk paradigm. Across domesticated *Bombyx mori* and semi domesticated *A. mylitta and A. assamensis* Soil health regulates. The host plans biochemical profile, which directly influence the larval performance and silk gland protein synthesis However, while intensive *Bombyx mori* systems, Benefits from controlled agricultural interventions, there wild models require a far more delicate ecological balance in the environment. Species like *A. mylitta* (tropical tasar) and *A. assamensis* (muga) are exclusively endemic to specific Indian ecozones, possessing evolutionarily adapted needs tied to native forests. Further, efforts to geographically expand their rearing areas are also severely bottlenecked by the soil constraints. Wild silk production, heavily relies on native nutrient harmony as demonstrated by the manganese toxicity in certain host plants Planting in an unsuitable soil hence inevitably leads to severe crop failure, outside of the ecozone. Therefore, practitioners must exercise extreme caution, rigorously evaluating baseline soil properties before initiating any plantation programmes. Even if these profound soil constraints are successfully remediated, the strict climatic requirements such as specific temperature, humidity, and seasonal rhythms possess constraints over exsitu practices. Hymns to secure Industry's future And agricultural management. It must evolve holistically, including Strategies Which needs to be shifted from generalised fertilisation to cite specific interventions using organic manures on bio fertilisers to optimise a leaf nutrition without disrupting the local ecologies beyond repair. Future research must bridge existing gaps by evaluating the entire continuum by measuring soil properties, plant biochemistry, and silk-fibre traits within single experimental frameworks to give better understanding of the whole ecosystem nutrient flow.

Acknowledgement

The authors sincerely acknowledge Odisha State Higher Education Council (OSHEC), Government of Odisha.

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How to Cite This Article

Barala B, Ray PP, Dash P. From earth to textile: exploring the soil-to-silk continuum. J Soil Future Res. 2026;7(2):61-64. doi:10.54660/JSFR.2026.7.2.61-64.