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Advancing Agricultural Sustainability in Tropical Climates: Harnessing the Potential of Green Manuring

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Abstract: This review delves into the pivotal role of green manure in advancing agricultural sustainability and enhancing soil fertility. It emphasizes the wide-ranging ecological benefits of green manure practices, particularly in tropical regions, where it fosters multiple biological processes such as nitrogen fixation and nutrient cycling. The text provides an in-depth exploration of specific green manure species, their characteristics, practical considerations, and the physical, biological, and chemical effects they have on soil. It also discusses the practical implementation of green manure techniques, including cropping, intercropping, and strip or alley cultivation. The study emphasizes the critical need for species selection and effective green manure management, shedding light on their profound impact on crop productivity and environmental sustainability. With comprehensive details on various species and their practical implications, the study offers a comprehensive understanding of green manure's potential as an alternative source to mineral fertilizers in tropical agriculture.

Keywords: agroecology; intercropping; legumes; nitrogen cycles; organic matter; organic farming

1. Introduction

In tropical regions, the enhancement of agricultural practices necessitates a shift away from consecutive monocultures towards embracing crop rotation and the integration of green manure, alongside intercropping [1]. Furthermore, safeguarding biomes as biological reserves, implementing animal-vegetable succession, and curbing the indiscriminate use of plows and harrows are imperative. Leveraging on-farm resources, managing soil fertility sans soluble fertilizers or petroleum derivatives, and streamlining production costs through the reduction of external inputs, serve to bolster ecological sustainability across diverse agroecosystems.

Within this paradigm, green manure emerges as a pivotal practice that advances agricultural sustainability by fostering multiple biological processes, notably biological nitrogen fixation and nutrient cycling. Embracing sustainable agricultural practices such as crop rotation, intercropping, and the integration of green manure is crucial for enhancing agricultural resilience in tropical regions. By shifting away from consecutive monocultures and adopting holistic approaches that prioritize soil health and biodiversity, we can ensure the long-term viability of agroecosystems while minimizing environmental impact and reducing production costs (Figure 1).

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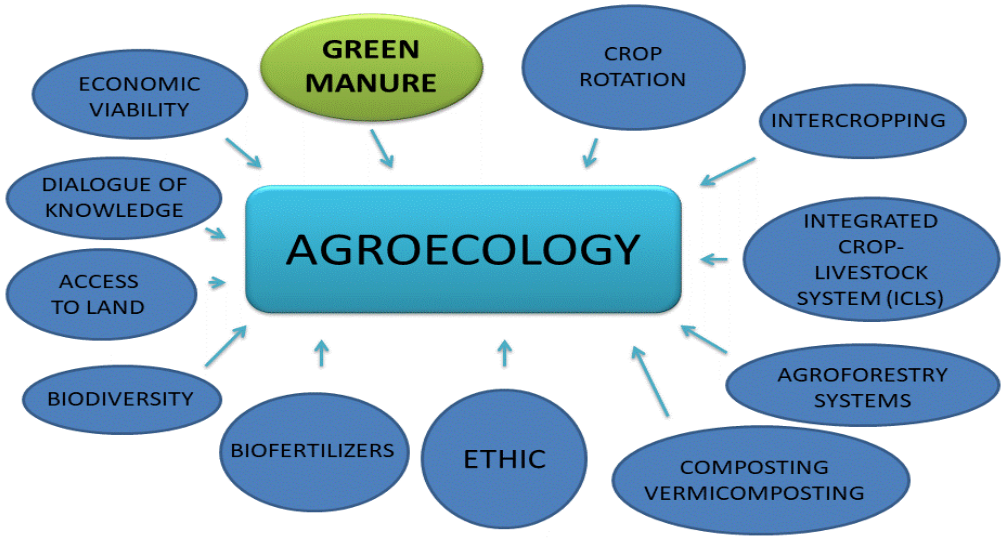

Figure 1. Green manure as a fundamental practice that promotes agricultural sustainability.

2. Green manuring: a sustainable soil enhancement practice

Green manuring, an ecologically driven technique, involves cultivating specific plant species that are subsequently incorporated into or maintained on the soil surface [2]. This practice plays a pivotal role in optimizing humus formation, thereby enhancing both the quantity and quality of organic matter in the soil [3]. Consequently, it improves soil infiltration and water retention capacity while mitigating surface runoff. Moreover, green manuring enhances the physical, chemical, and biological conditions of the soil, thereby augmenting fertility and, consequently, agricultural crop productivity.

Thus, green manuring serves as a mechanism to rehabilitate degraded soils, ameliorate low-fertility conditions, and sustain the fertility of productive soils. With a historical legacy spanning centuries in agriculture, green manuring has demonstrated its efficiency and effectiveness, as evidenced by numerous recent articles and scientific publications [4–6]. Green manure crops can be grown in rotation, succession, or intercropped with agricultural or forestry crops.

According to Souza et al. [7], any plant species, including indigenous plants, crop residues, or forage plants, can be utilized as green manure. However, the benefits derived from green manure vary depending on the plant species and its developmental stage. Cultivating green manure mobilizes mineral nutrients from deeper soil layers, thereby enriching the soil and making nutrients available for subsequent crops. Notably, plants from the Fabaceae family, in association with diazotrophic bacteria, can fix atmospheric nitrogen, enriching the soil with this essential nutrient.

Effects of green manuring on soil fertility include increased organic matter content, greater nutrient availability, enhanced effective cation exchange capacity of the soil, promotion of organic acid production (crucial for mineral solubilization), reduction in exchangeable aluminum content due to complexation, and improved recycling capacity and mobilization of leached or poorly soluble nutrients from deeper soil layers [8] (Figure 2).

Numerous scientific publications highlight various promising plant species for use as green manure [4,9]. Typically, research evaluates species and cultivars best adapted to different soil and climate regions, along with the establishment of management methods in various agroecosystems aimed at soil erosion prevention and crop nutrient provision.

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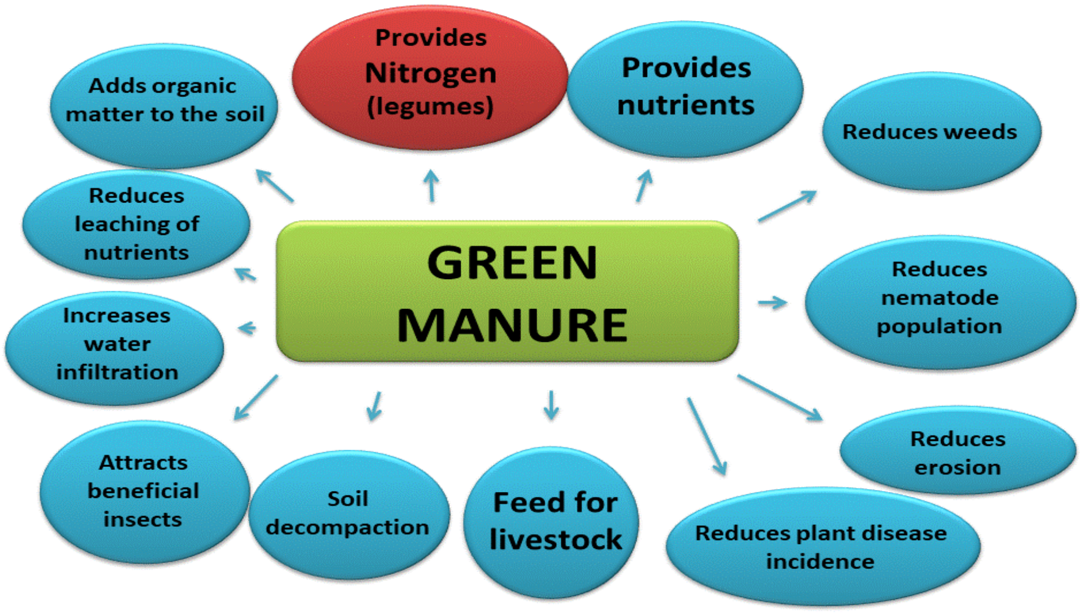

Figure 2. Green manuring fostering multiple biological processes, notably biological nitrogen fixation and nutrient cycling.

3. Practical implementation of green manure techniques

Green manuring, a time-honored agricultural practice dating back to ancient civilizations like the Chinese, Greek, and Roman, has undergone over 2000 years of refinement. Its enduring significance in fostering ecologically sustainable agriculture with high production yields remains evident today. In tropical climates, green manures find utility throughout both winter and summer seasons. The combination of high temperatures and heavy rainfall during summer fosters increased biomass production, greater nutrient availability, and enhanced soil nutrient cycling.

Practical applications of green manure techniques, as elucidated by Espindola et al. [10], encompass three distinct methods: pre-cultivation or crop rotation, intercropping, and strip or alley cultivation.

Pre-cultivation or crop rotation involves employing green manure either before or after the primary crop's cultivation cycle. This technique aims to ameliorate soil quality, providing optimal conditions for subsequent cultivation. Additionally, crop rotation aids in mitigating issues arising from pathogens detrimental to crops [9].

The intercropping approach entails planting green manure concurrently with the primary crop. Upon reaching the flowering stage, the green manure is cut and incorporated into the soil, thereby supplying nutrients for the primary crop. This cutting can occur either at the culmination of the green manure's growth cycle or after the development of the primary crop, ensuring nutrient availability for the subsequent planting [1,11].

Alley cropping represents another method wherein food or commercial crops are grown between rows formed by trees or shrubs. Managed through legume pruning during the primary crop's growing season, this system involves applying the pruned material to the soil. Periodic incorporation of substantial legume biomass between rows enhances the soil's chemical, physical, and biological characteristics, thereby augmenting productivity potential [12].

Spagnollo et al. [13], in an economic analysis of legume utilization in maize cultivation, concluded that cultivating legumes for soil cover presents a viable alternative for significantly augmenting net income from maize cultivation. Notably, they found gray velvet bean and jack beans to be particularly effective species in this context.

4. Characteristics of key species utilized as green manure

Green manuring entails the cultivation of native or introduced species managed through rotation, succession, or intercropping with desired crops. These species exhibit specific characteristics and may be annual, semi-evergreen, or evergreen, offering land coverage for varying durations, ranging from a few months to year-round.

While species from diverse botanical families can serve as green manure, those belonging to the Fabaceae family (legumes) are particularly noteworthy. These plants possess the ability to establish symbiotic associations with nitrogen-fixing bacteria genera such as *Rhizobium* or *Bradyrhizobium* [14].

The legume family encompasses numerous species, both arboreal and herbaceous, boasting traits conducive to their utilization as green manures. These include resistance to pests and diseases, high dry mass production, seeds with favorable germination rates, rapid growth, minimal risk of spreading when well managed, and the capacity, in association with diazotrophic bacteria, to fix substantial amounts of atmospheric nitrogen. Additionally, they facilitate the recycling of significant quantities of nutrients from the soil (Figure 3).

Figure 3. Sunn hemp (*Crotalaria juncea*) management for green manure in sugarcane planting. Photo taken by the authors.

Comprehending characteristics such as the vegetative cycle and growth habit of legumes is pivotal, especially in the context of utilizing herbaceous green manures in intercropping scenarios. Legumes may exhibit erect, prostrate, or climbing growth habits. Underscore the importance of paying special attention to species with climbing habits, as they may potentially impede the development of desired crops. Regarding annual species that complete their vegetative cycle within a few months, the authors note that these species typically experience leaf loss after flowering, contrasting with perennial species that maintain foliage during flowering, thereby providing continuous soil coverage [10].

Achieving success with green manuring hinges on a comprehensive understanding of the phenology of both the green manure and the crop. Inadequate management can lead to adverse effects on crop development, resulting in diminished productivity and heightened susceptibility to pests and diseases. Furthermore, poorly managed green manure species may proliferate as weeds due to insufficient control over their propagation.

Queiroz et al. [15] emphasize the significance of region-specific knowledge concerning the performance of legumes to select the most suitable species for maximizing phytomass production and nutrient recycling within distinct agricultural systems. In their study conducted in the northern region of Rio de Janeiro, Brazil, they assessed the phytomass productivity and nutrient accumulation of seven tree legume species (*Albizia lebbeck, Peltophorum dubium, Leucaena leucocephala, Cajanus cajan, Sesbania virgata, Mimosa caesalpiniaefolia*, and *Gliricidia sepium*) in alley agroforestry systems

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intercropped with maize. Pigeon pea (*Cajanus cajan*) exhibited the highest dry matter productivity and accumulated the most nitrogen, phosphorus, and potassium in its aerial biomass. The authors postulated that pigeon pea may have a symbiotic association with highly efficient mycorrhizae, enabling it to maintain high productivity despite low phosphorus content in the soil.

In another study conducted in the same region, Duarte Júnior and Coelho [16] evaluated the effects of different Fabaceae species, including sunn hemp (*Crotalaria juncea*), jack bean (*Canavalia ensiformis*), and black velvet bean (*Mucuna aterrima*), on sugarcane productivity in a direct planting system. They observed that sunn hemp provided superior soil coverage compared to jack beans and velvet bean. Additionally, sunn hemp and jack beans accumulated more phosphorus in their aerial parts than black velvet bean. Sunn hemp also accumulated higher levels of potassium, magnesium, sulfur, zinc, and iron compared to jack beans and velvet bean.

These studies underscore the importance of understanding species phenology for achieving success with green manures, whether the objectives are soil coverage, organic matter and nutrient inputs, or intercropping systems.

5. Species utilized as green manure: characteristics and practical considerations

Fabaceae plants exhibit a low carbon/nitrogen (C/N) ratio in their plant mass, typically around 20. Optimal cutting timing is recommended during full flowering or the onset of pod formation to facilitate rapid nutrient release, with the pruned material either incorporated into or left on the soil. Decomposition and mineralization commence almost immediately after pruning, leading to the subsequent release of mineral nutrients. These nutrients originate mainly from the soil, particularly deeper layers, and from fixed nitrogen from the atmosphere. Nutrient release to the soil surface is most pronounced within the first five to 10 days after cutting, under ideal humidity and temperature conditions, followed by a slower release thereafter [17].

Among green manure plants, several legume species stand out for their higher crude protein content, lower proportion of cell wall, and higher dry matter digestibility compared to grasses at similar stages of development and cultivation conditions. Notable legume species include sunn hemp (*Crotalaria* sp.), jack bean (*Canavalia ensiformis*), velvet bean (*Mucuna* sp.), pigeon pea (*Cajanus cajan*), leucaena (*Leucaena* sp.), and gliricidia (*Gliricidia sepium*).

5.1. Sunn Hemp

Various species of Crotalaria, such as Crotalaria juncea, Crotalaria spectabilis, and Crotalaria ochroleuca, are cultivated as green manure, thriving in tropical or subtropical climates but lacking frost resistance. Despite species variations, common characteristics include drought tolerance, susceptibility to shading, rapid growth, high biomass production, allelopathic effects aiding weed management, and attractiveness to pollinating insects [18].

Crotalaria juncea is particularly favored as a green manure in tropical regions due to its rapid growth, high biomass productivity, and adaptability to various soil types. Duarte Júnior [19] found that C. juncea provided superior soil coverage and accumulated more phosphorus, potassium, magnesium, sulfur, zinc, and iron in its aerial parts compared to other legume species, contributing to higher main crop productivity.

One potential limitation of using sunn hemp may involve the need to purchase seeds or insufficient knowledge on seed production methods. Eiras et al. [20] evaluated pruning and plant densities for sunn hemp seed production during the rainy season, recommending pruning at a height of one meter 60 days after seedling emergence and a density of 10 plants per meter for optimal seed vigor and reduced seed expenditure.

While sunn hemp may possess toxic properties, Silva et al. [21] concluded that it could aid in dengue fever management by controlling Aedes aegypti mosquito larvae and adults, as observed in research conducted in Ourinhos, Brazil, resulting in increased dragonfly populations, which prey on mosquito larvae and adults.

5.2. Jack beans

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Jack beans, scientifically known as Canavalia ensiformis, are annual herbaceous legumes characterized by an erect growth habit. They exhibit resilience to high temperatures but are susceptible to frost. When appropriately managed, such as through pruning to prevent pod formation, jack beans can persist as perennials in intercropped areas, serving as green manure for extended periods. The remarkable adaptability of C. ensiformis to adverse soil conditions underscores its potential for promoting soil coverage in regions with low agricultural potential [22]. Notably, jack beans are drought-resistant, hardy, and thrive in compacted and clayey soils [8].

Amim [23] evaluated the influence of different soil covers on popmaize cultivation, including black oats, jack beans, jack beans combined with black oats, and native vegetation. Jack beans provided rapid initial soil coverage and exhibited the highest levels of nitrogen, phosphorus, and potassium in their aerial parts. Furthermore, their cultivation reduced the number of native vegetation species in the area.

Jack beans are known for their negative allelopathic effect on nutsedge (*Cyperus rotundus* L.), a common weed in tropical regions. Oliveira [24] observed a lower number of indigenous plant species in maize intercropped with jack beans, possibly due to this allelopathic effect.

However, the coverage rate of jack beans can vary depending on soil and climate conditions. Jesus [25] observed relatively low coverage at 41 days after emergence, whereas Fernandes et al. [26] reported full soil coverage by jack beans at 54 days after emergence. Heinrichs et al. [27] compared various legume species, including jack beans, in intercropping with maize and found that jack beans exhibited greater phytomass production and accumulation of nutrients, resulting in a 23% increase in maize grain productivity over two years.

It's important to note potential drawbacks when using jack beans. Wutke et al. [16] warned about their susceptibility to whiteflies (*Bemisia tabaci*), a vector for various bean viruses. Additionally, jack beans can host root-knot nematodes, favoring their proliferation, making them unsuitable for areas with prior infestations.

5.3. Velvet bean (Mucuna sp.)

Velvet bean species are widely utilized as green manure and encompass black velvet bean (*Mucuna aterrima*), gray velvet bean (*Mucuna cinereum*), and dwarf velvet bean (*Mucuna deeringiana*). Thriving in tropical and subtropical climates, they exhibit resilience to diverse soil types and climatic conditions.

Black velvet bean, also known as velvet bean, flourishes in both sandy and clayey soils, displaying resistance to high temperatures but susceptibility to waterlogging and frost. Its rapid growth and ability to generate abundant green mass make it particularly valuable for weed management and reduces populations of plant-parasitic nematodes [28].

On the other hand, gray velvet bean thrives in sandy and clayey soils, showcasing resistance to acidity and low fertility. Despite its relatively lower phytomass production compared to other velvet bean species, it serves as a valuable cover crop. Dwarf velvet bean, recommended for intercropping in perennial crops like coffee and citrus, displays determined growth and independence from support from the main crop. It enhances nodulation in bean crops, leading to increased nitrogen and dry matter accumulation [8].

Scivittaro et al. [29] observed significant increases in maize productivity with the use of black velvet bean as green manure, underscoring its potential to bolster grain and bean crop yields. Overall, velvet bean species play a pivotal role in soil improvement and nutrient cycling, offering varied levels of phytomass production and nutrient accumulation. Their suitability hinges on specific soil and climatic conditions

5.4. Pigeon pea (Cajanus cajan)

Pigeon pea, also known as *Cajanus cajan*, is a semi-perennial tree legume belonging to the Fabaceae family. Boasting a woody stem and a deep-penetrating main root, it thrives in tropical and subtropical climates. Despite its slow initial growth, pigeon pea eventually flourishes in clayey and sandy soils, due to its drought tolerance and adaptability to various soil types. Thanks to its deep-

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rooting capability, pigeon pea facilitates enhanced water absorption and nutrient recycling, which in turn contribute to soil recovery and increased dry biomass production. Studies have underscored its significant potential for enhancing soil fertility and supporting higher crop productivity [8].

Various studies have demonstrated pigeon pea's capacity for dry biomass production, with notable increases in grain productivity observed in intercropping systems with maize. For example, in tropical conditions, Queiroz [30] identified pigeon pea as the most productive among several legume species in terms of dry biomass production and nutrient accumulation. Its symbiotic association with mycorrhizae further augments productivity, even in soils with low phosphorus content.

However, caution is warranted when using pigeon pea due to its propensity to become invasive and harbor pests and diseases, such as whiteflies and root-knot nematodes. Nevertheless, pigeon pea remains a valuable green manure option for improving soil quality.

5.5. Leucaena (Leucaena leucocephala)

Leucaena, a perennial shrubby legume native to Central America, is highly esteemed for its substantial forage potential and adaptability to tropical and semi-arid regions. Flourishing in acidic soils, Leucaena demonstrates minimal nutrient requirements, making it an ideal candidate for areas with low soil fertility. Its deep-rooting system enables it to tap into water reserves in deeper soil layers, rendering it resilient to drought conditions [8,31] .

Despite its slower initial growth, Leucaena exhibits the capability to sustain lush foliage with high nutritional value, even under successive pruning. It has proven efficacy in intercropping systems, such as with coffee plants, where it aids in soil fertility improvement, acts as a windbreak, and provides shade [8].

Research has underscored the viability of incorporating Leucaena into intercropping with crops like maize and beans, resulting in significant forage production and serving as an alternative source for firewood production on small properties, particularly in regions like the Brazilian Northeast [32].

The application of Leucaena leaves contributes to soil fertility enhancement, with studies reporting substantial increases in nitrogen availability and maize productivity upon their incorporation into agricultural systems. Positive impacts on maize productivity have been observed across various regions, such as southern Nigeria, where Leucaena alley systems sustainably bolstered maize yields while reducing reliance on nitrogen fertilizers [33].

In Kenya, Heineman et al. [34] found that Leucaena, alongside other leguminous trees, markedly boosted maize productivity, with maize yields positively correlated with the amount of leaves integrated into the soil. Its rapid decomposition further amplifies its efficacy as a green manure.

5.6. Gliricidia (Gliricidia sepium)

Gliricidia, an arboreal legume indigenous to Central America, boasts diverse applications, serving as a windbreak, hedge, forage crop, and source of green manure. Flourishing in tropical regions, gliricidia thrives in acidic and impoverished soils, rendering it invaluable for soil amelioration in degraded areas. Its resilience to water stress renders it suitable for cultivation in semi-arid regions [5].

As a green manure, gliricidia stands out for its capacity to yield copious nitrogen-rich leaves. The swift decomposition of these leaves expedites nutrient release into the soil, augmenting soil fertility. Gliricidia's high phytomass productivity and nutritional richness render it a prime choice for alley cropping systems and agroforestry [35].

Studies evince gliricidia's ability to infuse substantial nitrogen into the soil, thereby enriching soil fertility and enhancing crop productivity, especially in intercropping scenarios with crops like maize [15]. Its adoption in alley systems has yielded commendable maize yields alongside ancillary benefits such as shade and wind protection. Its propagation commonly occurs via cuttings, with notable success rates observed under both direct planting and nursery conditions.

Research validates gliricidia's positive influence on soil characteristics, microclimate, and crop performance. The accumulation of fallen leaves beneath gliricidia trees fosters heightened soil

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organic matter and nutrient levels, fostering propitious conditions for crop growth [5,15]. Furthermore, gliricidia's capacity to modulate microclimatic conditions can confer additional advantages for crop production within agroforestry systems.

6. Physical, biological, and chemical effects of green manures

Carvalho et al. [36] conducted a study evaluating the impact of eleven cover plant species on soil density and porosity. Their findings indicated no immediate influence of these species on soil characteristics within a 90-day period post-planting. Instead, the benefits of green manures typically manifest after cutting the plants and incorporating them into the soil.

Thus, it's apparent that the advantages of green manures necessitate a long-term perspective. Residues resulting from green manure pruning contribute to soil organic matter, with decomposition occurring at varied rates. Consequently, mineral nutrients may undergo immobilization, rendering them temporarily unavailable for plant uptake, or mineralization, where they become readily accessible [37]. This dynamic system undergoes continuous change over time, necessitating extended evaluation periods.

Green manure usage elevates soil organic matter levels, thereby enhancing physical properties such as aggregate stability, porosity, bulk density, water infiltration rate, and moisture retention [38]. The robust root systems of legumes penetrate compacted soil layers, leaving channels upon decomposition that facilitate water infiltration and gas diffusion, thereby ameliorating soil physical quality [39]. Additionally, root proliferation contributes to organic matter enrichment across the soil profile, fostering aggregate stabilization and mitigating soil compaction vulnerability.

Sustained vegetation cover afforded by green manures enhances surface water retention and diminishes thermal fluctuations in the upper soil layer [40]. Biologically, the presence of organic material from green manures fosters soil organism activity, providing energy and nutrients, thereby aiding in nutrient cycling. Certain soil organisms, like arbuscular mycorrhizal fungi, enhance water and nutrient absorption, conferring resistance to pathogens and promoting soil particle aggregation.

Green manures can induce shifts in native plant populations via allelopathic effects and competitive interactions, potentially suppressing indigenous species [24,41]. Chemical effects are linked to allelopathy, wherein chemical compounds released by organisms influence neighboring organisms' physiological processes, hindering the germination and growth of indigenous plants.

7. Choosing plant species for green manure use

When selecting green fertilizer species, factors such as growth habit (creeping, semi-erect, erect, or climbing), cycle (perennial or annual), drought and frost tolerance, robust biomass and root system development, and pest and disease resistance merit consideration. Optimal species selection hinges on intended purposes, with indigenous or locally adapted plants often proving superior due to their acclimatization to specific environmental conditions.

Green manures provide habitat for natural enemies, attracting pollinators and beneficial insects that aid in pest control. Alternative nematode management strategies, like intercropping with legumes such as sunn hemp and black velvet bean, have shown promise in curbing nematode proliferation [42]. Additionally, green manures can serve as supplementary animal feed, contributing to dietary enrichment and promoting sustainable agrosilvopastoral systems [43].

8. Green Manure Management

Optimal green manure establishment and early growth necessitate pre-management of autochthonous plant populations. The timing of green manure cutting or management hinges on plant phenological stage and intended use. Grasses are typically cut at "milky" grain stage, while herbaceous Fabaceae are pruned at full bloom to maximize nutrient content while seeds remain non-viable, mitigating potential seed dispersal risks.

Incorporating or maintaining green manure biomass on the soil surface depends on intended outcomes. To preserve seed production, green manures may be allowed to complete their growth

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cycle. Reis et al. [44] compared different management systems for sunn hemp and gray velvet, finding no significant differences in biomass decomposition. Fernandes [45] successfully implemented direct planting of sugarcane after managing sunn hemp with a tractor equipped with a "bumper" to break down plants, facilitating subsequent furrowing without clogging (Figure 4).

Incorporating green manures into the soil serves multiple purposes, primarily aimed at supplying nutrients for subsequent crops and protecting against erosion while inhibiting the growth of native plants [24]. This practice also facilitates nutrient recycling, promotes straw production, enhances water retention, and fosters beneficial soil organisms and natural enemies of invasive pests (Figure 5).

Figure 4. A. Detail of the "bumper"; B. Furrowing for direct planting of sugar cane on *Crotalaria juncea* [42].

Figure 5. A. Crotalaria in the Simultaneously Occurring Interrotational System (MEIOSI) [42]; B. Green manure with sunn hemp in the "MEIOSI" system in sugarcane; C. Planting sugarcane in soil enriched with sunn hemp green manure. B and C: Photos taken by the authors.

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The decision to incorporate green manure biomass or leave it on the ground depends on the desired outcome. If soil cover is the goal, species with higher carbon-to-nitrogen (C/N) ratios are preferred, resulting in slower decomposition. Conversely, for a faster nutrient release to benefit subsequent crops, species with lower C/N ratios are recommended, and incorporation of plants or pruning is advised. However, it is recommended intercropped species with C/N ratio > 30 to minimize risks of contamination with nitrate in the soil [46]

For green manures to effectively supply nutrients to subsequent crops, they should be incorporated into the soil while still green or succulent, facilitating rapid decomposition. Delayed incorporation, after the material has dried, slows decomposition since soil microorganisms require moisture for efficient breakdown. Alternatively, if the objective is to gradually release nutrients and maintain higher organic matter levels in the soil, dried green manure material can be incorporated after exposure to sunlight. This approach allows for a slower release of nutrients over time, promoting long-term soil health and fertility. Pereira et al. [47] found in the Jaguaribe-Apodi region, Ceará, Brazil, that *Crotalaria spectabilis* and *Canavalia ensiformes* showed higher decomposition and nutrient release rates, although, for greater persistence of residues in the soil, *Crotalaria juncea* was more recommended.

Prellwitz and Coelho [48] conducted a study assessing the impact of cultivating Crotalaria juncea between rows of sugarcane ratoon. Their findings revealed that in the treatment where two rows of sunn hemp were sown, 51 days after cutting the cane, followed by the cutting of sunn hemp 110 days after sowing, similar productivity to that achieved in monoculture sugarcane with mineral fertilization and weed management was attained. Moreover, the productivity of sugarcane intercropped with sunn hemp surpassed that of monoculture sugarcane without fertilization and weed management. Additionally, the authors noted higher nitrogen levels in sugarcane leaves in systems intercropped with legumes (Figure 6).

Figure 6. Green manure with intercropping of sunn hemp and sugar cane: A – Sunn hemp sown between the rows of sugar cane; B – Initial growth stage of sunn hemp; C – Intercropped Crotalaria and sugarcane; D – Crotalaria already cut between the sugarcane rows. Photos taken by the authors.

In soybean crop production, the use of black velvet bean, sunn hemp, and pigeon pea as green fertilizers has significantly increased soybean productivity [49]. An experiment conducted in

Maringá, Brazil, investigated various green manure species, including dwarf pigeon pea (*Cajanus cajan*) and white lupine (*Lupinus albus*). Direct planting system on green manure residues resulted in a 10% increase in productivity, with pigeon pea and white lupine residues showing the highest productivity for soybean crops [50].

In northern Rio de Janeiro, Brazil, was observed that managing the cover without mowing led to an average soybean productivity increase in successions with black oat (3,161 kg ha^{-1}), which was 46% higher than those with millet (2,026 kg ha^{-1}), sorghum (2,017 kg ha^{-1}), teosinte (2,349 kg ha^{-1}), turnip (2,383 kg ha-1), velvet bean (1,946 kg ha^{-1}), lupins (2,380 kg ha^{-1}), and pigeon pea (2,059 kg ha^{-1}). In successions with native vegetation, soybean productivity (2,890 kg ha^{-1}) was 44% higher than those obtained in successions with millet (2,026 kg ha^{-1}), sorghum (2,017 kg ha^{-1}), velvet bean (1,946 kg ha^{-1}), and pigeon pea (2,059 kg ha^{-1}) [51]. Conversely, was found that mowing increased grain productivity by 57% (an increase of 1,154 kg ha^{-1}) in the succession with millet compared to management without mowing. Lima et al. [51] noted that native vegetation provided productivity similar to the best soil covers, regardless of straw management. They suggested that this occurred because the experiment was irrigated since the implementation of the cover crops, leading them to conclude that, for the evaluated region's conditions, native vegetation, with water availability for growth, can result in good coverage for direct soybean planting.

The application of green manure in coffee crop production can yield highly beneficial results. Pereira and Lemos [52] observed that using *Crotalaria juncea* and *Crotalaria spectabilis* between coffee tree lines resulted in increased dry matter weight and organic carbon accumulation, respectively. Green manure with *C. juncea* led to nitrogen accumulation, while *C. spectabilis* increased potassium accumulation, directly influencing crop productivity. According to Zacarias et al. [53], green manure practice through the conilon coffee intercropping (*Coffea conephora*) with four legume species: pigeon pea, black velvet bean, jack bean, and mexican daisy (*Tithonia diversifolia*), exhibited promising cost/benefit ratios and high crop economic viability, especially from the third year of cultivation onward, demonstrating increased productivity.

Moreira et al. [54] evaluated coffee trees intercropped with pigeon peas, jack beans, black velvet bean, and mexican daisy, in both adjacent rows (100%) and only in the upper row (50%), along with a control treatment (conventional fertilizer). The experimental unit comprised a coffee plant, clonal variety "Incaper 8142" Conilon Vitória variety 12 V (early), spaced at 2.30 x 2.60 m. Management of 50% pigeon pea was superior to conventional management for most evaluated characteristics, prompting the authors to recommend this management and species for the initial year of transitioning from conventional to organic systems.

9. Conclusions

A deeper understanding of green manuring brings numerous benefits to those adopting this technique. Often, a lack of crucial details regarding green manure management can lead to its improper utilization. Generally, difficulty in acquiring green manure species seeds poses a challenge; however, farmers can plan seed production in their areas to meet their needs or those of the local community. Green manure, besides making nitrogen available, plays a vital role in recovering nutrients from deep soil layers and making them accessible to agricultural crops, serving as an alternative source to soluble mineral fertilizers in tropical agriculture.

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References

1. Meirelles, F. C.; Cavalcante, A. G.; Gonzaga, A. R.; Filla, V. A.; Coelho, A. P.; Lemos, L. B.; Arf, O. Intercropping of upland rice with green manures in the Brazilian Cerrado. *Archives of agronomy and soil science* **2023**, 69, 7, 1146-1160. https://doi.org/10.1080/03650340.2022.2068795

 doi:10.20944/preprints202402.1573.v1

2. Tomar, D.; Pali, N. Advantages to agroecosystem by green manures and cover crops. *Journal of Pharmacognosy and Phytochemistry* **2023**, 12, 2, 146-149. https://www.phytojournal.com/archives/2023/vol12issue2/PartB/12-2-17-122.pdf
3. Pimentel, M. L.; Reis, I. M. S.; Romano, M. L. P. C.; Castro, J. S.; Vildoso, C. I. A.; Gasparin, E.; Sai, E. F.; Sousa, L. S. Green manure, a sustainable strategy to improve soil quality: A case study in an oxisol from Northern Brazil. *Australian Journal of Crop Science* **2023**, 17, 6, 488-497. https://www.cropj.com/pimentel_17_6_2023_488_497.pdf
4. Lyu, H.; Li, Y.; Wang, Y.; Wang, P; Shang, Y.; Yang, X.; Wang, F.; Yu, A. Drive soil nitrogen transformation and improve crop nitrogen absorption and utilization-a review of green manure applications. *Front. Plant Sci.* **2024**, 14:1305600. https://doi:10.3389/fpls.2023.1305600
5. Alamu, E.O.; Adesokan, M.; Fawole, S.; Maziya-Dixon, B.; Mehreteab, T.; Chikoye, D. Gliricidia sepium (Jacq.) Walp applications for enhancing soil fertility and crop nutritional qualities: a review. *Forests* **2023**, 14, 635. https://doi.org/10.3390/f14030635
6. Akshit; Kumar, S.; Sheoran, N.; Devi, P.; Sharma, K.; Kamboj, E.; Kumar, P. Legumes in cropping systems: a way toward agricultural sustainability and diversification. *Communications in Soil Science and Plant Analysis* **2024**, 55, 4, 596-608 https://doi.org/10.1080/00103624.2023.2274035
7. Souza, C. M.; Pires, F. R.; Partelli, F. L.; Assis, R. L.; Adubação verde e rotação de culturas. Viçosa, MG: Ed. UFV, **2012**. https://www.locus.ufv.br/bitstream/123456789/7780/1/texto%20completo.pdf
8. Lima Filho, O. F.; Ambrosano, E. J.; Wutke, E. B.; Rossi, F.; Carlos, J. A. D. Adubação verde e plantas de cobertura no Brasil : fundamentos e prática. 2. ed. rev. atual. - Brasília, DF: Embrapa **2023.** https://ainfo.cnptia.embrapa.br/digital/bitstream/item/249436/1/ADUBACAO-VERDE-VOL-01-ed02-2023.pdf
9. Zhang, W.; Surigaoge, S.; Yang, H.; Yu, R.; Wu, J.; Xing, Y.; Chen, Y.; Li, L. Diversifed cropping systems with complementary root growth strategies improve crop adaptation to and remediation of hostile soils. *Plant Soil* **2024**, https://www.researchgate.net/publication/377264560_Diversified_cropping_systems_with_complementary_root_growth_strategies_improve_crop_adaptation_to_and_remediation_of_hostile_soils
10. Espindola, J. A.; Guerra, J. G.; De-Polli, H.; Almeida, D. L. De., Abboud, A. D. S. Adubação verde com leguminosas. Brasília: Embrapa Informação Tecnológica 2005,49p. https://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/117975
11. Huang, D.; Liu, X.; Huan H, Liu G, Hu A Intercropping of stylosanthes green manure could improve the organic nitrogen fractions in a coconut plantation with acid soil. *PLoS ONE* **2023** 18(3): e0277944. https://doi.org/10.1371/journal.pone.0277944
12. Magalhães, R. B.; Silva, E. S.; Lima, B. M.; Rodrigues, A. M. S.; Dias, C. T. S.; Blum, J.; Costa, M. C. G. Leguminous species at distinct planting densities and rainfed coconut intercropping for green manuring in sandy soil of sub-humid region. *Journal of Soils and Sediments* **2024**, 24, 32-46. https://doi.org/10.1007/s11368-023-03623-7
13. Spagnollo, E.; Bayer, C.; Wildnerp, L. P.; Ernani. R.; Albuquerque, J. A.; Nadal, R. Análise econômica do uso de leguminosas estivais intercalares à cultura do milho, na ausência e na presença de adubação nitrogenada, no oeste de Santa Catarina. *Rev Bras Ci Solo* **2001**, 25, 709-715. https://www.scielo.br/j/rbcs/a/NMTDb8qq5HtQRKmhf5tWt5S/?lang=pt
14. Espindola, J.A.A.; Almeida, D.L.; Guerra, J.G.M. Estratégias para utilização de leguminosas para adubação verde em unidades de produção agroecológica. Documentos, n.174, Embrapa-Agrobiologia **2004**, 14p. https://www.embrapa.br/busca-de-publicacoes/-/publicacao/627829/estrategias-para-utilizacao-de-leguminosas-para-adubacao-verde-em-unidades-de-producao-agroecologica
15. Queiroz, L. R.; Coelho, F. C.; Barroso, D. G.; Galvão, J. C. C. Cultivo de milho consorciado com leguminosas arbustivas perenes no sistema de aléias com suprimento de fósforo. *Rev. Ceres* **2008**, 55, 5, 409-41. www.redalyc.org/pdf/3052/305226814020.pdf
16. Duarte Júnior, J.B.; Coelho, F.C. Adubos verdes e seus efeitos no rendimento da cana-de-açúcar em sistema de plantio direto. *Bragantia* **2008**, 67, 3, 723-732. https://www.scielo.br/j/brag/a/PZD87C54PJHqyW9VC9q96tR/?lang=pt
17. Wutke, E. B.; Ambrosano, E.J.; Razera, L.F.; Medina, P.F.; Carvalho, L.H.; Kikuti, H. (Coord.). Bancos comunitários de sementes de adubos verdes: informações técnicas. Brasília, Ministério da Agricultura, Pecuária e Abastecimento. **2007**, 52p. https://www.ufrb.edu.br/biblioteca/documentos/category/30-publicacoes-digitais?download=310:bancos-comunitarios-de-sementes-de-adubos-verdes-informacoes-tecnicas

18. Silva, L. L. Socialização de informações sobre leguminosas tropicais utilizadas para a adubação verde a partir de um aplicativo para dispositivo móvel. Magister Sciense, Universidade Federal Rural do Rio de Janeiro, Seropédica, RJ, **2018**, 116p. https://rima.ufrrj.br/jspui/handle/20.500.14407/10436?mode=full
19. Duarte Júnior, J. B. Avaliação agronômica da cana-de-açúcar, milho e feijão em sistema de plantio direto em comparação ao convencional em Campos dos Goytacazes - RJ. Doctor Sciense, Universidade Estadual do Note Fluminense Darcy Ribeiro, Campos dos Goytacazes, RJ **2006**, 284p. https://uenf.br/posgraduacao/producao-vegetal/wp-content/uploads/sites/10/2017/12/Jos%C3%A9-Barbosa.pdf.
20. Eiras, P. P.; Coelho, F. C. Avaliação de diferentes densidades de semeadura e da poda na produtividade de sementes de *Crotalaria juncea* L. *Rev. Ceres* **2012**, 59, 5, 668-676. https://doi.org/10.1590/S0034-737X2012000500012
21. Silva, B. R.; Spada, L.; Polido, C. G. Contiero, W. Crotalária e o controle do dengue. *Brazilian Journal of Development* **2021**, 7, 7, 67024-67034. https://ojs.brazilianjournals.com.br/ojs/index.php/BRJD/article/view/32493
22. Zanella, F.; Watanabe, T. M.; Lima, A. L. S.; Schiavinato, M. A. Photosynthetic performance in Jack Bean (*Canavalia ensiformis*) under drought and after rehydratation. *Brazilian Journal of Plant Physiology* **2004**, 16, 3, 181-184. https://www.scielo.br/j/bjpp/a/wXDT5zmMjgVWxrPkmHmK6BH/?lang=en
23. Amim, R. T. Influência de plantas de cobertura do solo na dinâmica de plantas autóctones no desempenho do milho-pipoca em plantio direto. Magister Sciense, Universidade Estadual do Norte Fluminense Darcy Ribeiro, Campos dos Goytacazes **2010**, 79 p. https://uenf.br/posgraduacao/producao-vegetal/wp-content/uploads/sites/10/2014/09/Reynaldo.pdf
24. Oliveira, A. C. S. Produção de milho e de sementes de fabaceae destinadas a adubos verdes, em consórcio, em Campos dos Goytacazes - RJ, Magister Sciense, Universidade Estadual do Note Fluminense Darcy Ribeiro, Campos dos Goytacazes, RJ **2013**, 64 p. https://uenf.br/posgraduacao/producao-vegetal/wp-content/uploads/sites/10/2014/06/Tese-Anna-Christina-Sanazario-de-Oliveira.pdf
25. Jesus, V. P. Produção de minimilho em diferentes sistemas de manejo. Magister Sciense, Universidade Estadual do Norte Fluminense Darcy Ribeiro, Campos dos Goytacazes- RJ **2009**, 63p. https://uenf.br/posgraduacao/producao-vegetal/wp-content/uploads/sites/10/2014/10/Vanessa-Jesus.pdf
26. Fernandes, J.C.; Rezende, J.O.; Diamantino, M.S.A.S.; Rezende, V.J.R.P. Antunes, R.J.B. et al. Identificação de espécies para cobertura do solo e rotação de culturas no vale do Iuiu, Região Sudoeste da Bahia. *Magistra* **2007**, 19, 2, 163-169. https://periodicos.ufpa.br/index.php/agroecossistemas/article/download/1216/1649
27. Heinrichs, R.; Vitti, G. C.; Moreira, A.; Figueiredo, P. A. M.; Fancelli, A. L.; Corazza, E. J. Características químicas de solo e rendimento de fitomassa de adubos verdes e de grãos de milho, decorrente do cultivo consorciado. *Rev. Brasileira de Ciência do Solo* **2005**, 29, 1, 71-79. https://www.scielo.br/j/rbcs/a/yc5XYz7ksxYppJjxkLhyqqj/
28. Zasada, I. A.; Klassen, W.; Meyer, S. L. F.; Codallo, M.; Abdul-Baki, A. A. Velvet bean (*Mucuna pruriens*) extracts :impact on *Meloidogyne incognita* survival and on *Lycopersicon esculentum* and *Lactuca sativa* germination and growth. Pest Manag Sci **2006,** 62:1122 – 1127. DOI: 10.1002/ps
29. Scivittaro, W.B.; Muraoka, T.; Boaretto, A.E.; Trivelin, P.C.O. Utilização de nitrogênio de adubos verdes e mineral pelo milho. *Rev. Brasileira de Ciência do Solo* **2000**, 24, 917-926. https://www.scielo.br/j/rbcs/a/7hhvqgyCCQVfXMxVkFQPGTf/?lang=pt
30. Queiroz, L. R. Leguminosas como fonte de nitrogênio para a cultura do milho, em Campos dos Goytacazes, RJ. Doctor Sciense, Universidade Estadual do Norte Fluminense Darcy Ribeiro, Campos dos Goytacazes **2006**, 72 p. https://uenf.br/posgraduacao/producao-vegetal/wp-content/uploads/sites/10/2017/12/Luciano-Queiroz.pdf
31. Câmara, C. S.; Alves, A. A.; Moreira Filho, M. A.; Garcez, B. S.; Azevêdo, D. M. M. R. Diets containing leucaena or estilosantes hay in lactating mixed-breed Anglo-Nubian goats. *Revista Ciência Agronômica* **2015**, 46, 2, 443-450. DOI: 10.5935/1806-6690.20150025
32. Cruz, J. C.; Konzen, E. A.; Marriel, I. E.; Cruz, I.; Duarte, J. O.; Oliveira, M. F.; Alvarenga, R. C. Produção de milho orgânico na agricultura familiar. Circular Técnica, 81. Embrapa **2006**, 17 p. ISSN 1679-1150. https://www.infoteca.cnptia.embrapa.br/bitstream/doc/490413/1/Circ81.pdf
33. Akinnifesi, F.K.; Kang, B.T.; Sanginga, N.; Tijani-Eniola, H. Nitrogen use efficiency and N-competition between Leucaena hedgerows and maize in an alley cropping system. *Nut. Cycl. Agroecosyst*. **1996**, 47, 71–80. https://link.springer.com/article/10.1007/BF01985720
34. Heineman, A.M; Otieno, H.J.O; Mengich, E.K; Amadalo, B.A. Growth and yield of eight agroforestry tree species in line plantings in Western Kenya and their effect on maize yields and soil properties. *Foresty Ecology and Managment* **1997**, 91, 1, 0-135. https://www.sciencedirect.com/science/article/pii/S0378112796038856

35. Figueiredo, C. C.; Moreira, T. N.; Coser, T. R.; Silva, L. P.; Leite, G. G.; Carvalho, A. M.; Malaquias, J. V.; Marchão, R. L.; Urquiaga , S. Nitrogen use efficiency in an agrisilviculture system with *Gliricidia sepium* in the cerrado region. *Plants* **2023**, 12(8), 1647. https://doi.org/10.3390/plants12081647
36. Carvalho, C. A.; Ferreira, R. L. F; Andrade, R. A.; Brito, R. S.; Pereira, T. C. R.; Lima, T. J. L. Atributos físicos em solos cultivados com plantas de cobertura. *Scientia Naturalis* **2020**, 2, 1, 38-41. https://periodicos.ufac.br/index.php/SciNat/article/view/3655/2173
37. Abranches, M. O.; Silva, G. A. M.; Santos, L. C.; Pereira, L. F.; Freitas, G. B. Contribuição da adubação verde nas características químicas, físicas e biológicas do solo e sua influência na nutrição de hortaliças. *Research, Society and Development* **2021**, 10, 7, e7410716351. http://dx.doi.org/10.33448/rsd-v10i7.16351.
38. De-Polli, H.; Guerra, J.G.M.; Almeida, D.L.; Franco, A.A. Adubação verde: Parâmetros para avaliação de sua eficiência. In:Castro Filho, C. de; Muzilli, O., eds. Manejo integrado de solos em microbacias hidrográficas. Londrina: IAPAR/SBCS **1996**, 225-242. https://www.bdpa.cnptia.embrapa.br/consulta/busca?b=pc&id=620956&biblioteca=vazio&busca=(autoria:%22ALMEIDA.%20D.%20L.%20de%22)&qFacets=(autoria:%22ALMEIDA.%20D.%20L.%20de%22)&sort=&paginacao=t&paginaAtual=2
39. Foloni, J. S. S.; Lima, S. L.; Bull, L. T. Crescimento aéreo e radicular da soja e de plantas de cobertura em camadas compactadas de solo. *Rev. Brasileira de Ciência do Solo* **2006**, 30, 1, 49-57. https://www.scielo.br/j/rbcs/a/9n7tpgSpgpWSzdphw5VFdsz/?lang=pt
40. Carlson, S . Research Priorities for Advancing Adoption of Cover Crops in Agriculture-intensive Regions. Journal of Agriculture. *Food Systems, and Community Development* **2013**, 3, 125-129. https://foodsystemsjournal.org/index.php/fsj/article/download/196/191
41. Prellwitz, W. P. V. Intercultivo em cana-de-açúcar com *Crotalaria juncea*. Magister Sciense, Universidade Estadual do Norte Fluminense Darcy Ribeiro, Campos dos Goytacazes, RJ **2010**, 79p. https://uenf.br/posgraduacao/producao-vegetal/wp-content/uploads/sites/10/2014/09/Willy-Pedro.pdf
42. Ritzinger, C. H.; Ritzinger, R, Cultivar hortaliças e frutas. *Fruticultura em Revista* **2003**, 19.
43. Santana Neto, J.A.; Oliveira, V.S.; Valença, R.L. Leguminosas adaptadas como alternativa alimentar para ovinos no semiárido-revisão. *Rev. de Ciências Agroveterinárias* **2015**, 14, 2, 191-200. https://revistas.udesc.br/index.php/agroveterinaria/article/view/5786
44. Reis, G.N.; Silva, R.P.; Furlani, C.E.A.; Cavalin Neto, J.; Grotta, D. C. C. Decomposição de culturas de cobertura no sistema plantio direto, manejadas mecânica e quimicamente. *Engenharia Agrícola* **2007**, 27, 1, 194-200. https://www.scielo.br/j/eagri/a/8dCxShnwjjpntKtKQWq9HSM/?lang=pt
45. Fernandes, P. G. Formas de plantio de mudas de cana-de-açúcar no sistema MEIOSI. Magister Sciense, Universidade Estadual do Norte Fluminense Darcy Ribeiro, Campos dos Goytacazes, RJ **2009**, 48 p. https://uenf.br/posgraduacao/producao-vegetal/wp-content/uploads/sites/10/2014/10/Pedro.pdf
46. Leite, M. H. S.; Couto, E. G.; Blesh, J. M. Interactions between green manure and rock phosphate on soil nutrient cycling on family farms. *Rev. Caatinga* **2022**, 35, 1, 14–25. http://dx.doi.org/10.1590/1983-21252022v35n102rc
47. Pereira, N. S.; Soares, I.; Miranda, F. R. Decomposition and nutrient release of leguminous green manure species in the Jaguaribe-Apodi region, Ceará, Brazil. *Ciência Rural* **2016**, 46, 6, 970-975. http://dx.doi.org/10.1590/0103-8478cr20140468
48. Prellwitz, W. P. V.; Coelho, F. C. Produtividade de colmos, índice de área foliar e acúmulo de N na soca de cana-de-açúcar em cultivo intercalar com *Crotalaria juncea* L. *Rev. Ceres* **2011**, 58, 6, 773-780. https://www.scielo.br/j/rceres/a/3ypdLKYMspwwT4Wh9Bbv3KS/?lang=pt
49. Wutke, E.B.; Fancelli, A.L.; Pereira, J.C.V.N.A.; Ambrosano, G.M.B. Produtividade do feijoeiro irrigado em rotação com culturas graníferas e adubos verdes. *Bragantia* **1998**, 57, 325-338. https://www.scielo.br/j/brag/a/JcnMTP7SLWtHZ7TcPwsFRhK/?lang=pt
50. Cardoso, R. A.; Bento, A. S.; Moreski, H. S.; Gasparotto, F.; Influência da adubação verde nas propriedades físicas e biológicas do solo e na produtividade da cultura de soja. Semina: Ciências Biológicas e da Saúde **2014**, 35, 2, 51-60. https://www.uel.br/revistas/uel/index.php/seminabio/article/download/17752/16228
51. Lima, E. A.; Coelho, F. C.; Lima, A. A.; Dornelles, M. S.; Garcia, R. F. Semeadura direta de soja sobre diferentes plantas de cobertura e manejos de palhada, na região Norte Fluminense. *Rev. Ceres* **2009**, 56, 6, 790-795. https://www.embrapa.br/busca-de-publicacoes/-/publicacao/630970/semeadura-direta-de-soja-sobre-diferentes-plantas-de-cobertura-e-manejos-de-palhada-na-regiao-norte-fluminense
52. Pereira, T. A. R.; Lemos, E. F. Influência da adubação verde em café (*Coffea arabica* L.) no sul de Minas Gerais. In: Congresso Brasileiro de Pesquisas Cafeeiras, 43., 2017, Poços de Caldas. Anais... Brasília, DF: Embrapa Café, **2017**. 2 p. https://www.embrapa.br/busca-de-publicacoes/-/publicacao/597347/influencia-da-adubacao-verde-sobre-o-crescimento-estado-nutricional-e-produtividade-do-cafe-coffea-arabica-cultivado-no-sistema-organico

 doi:10.20944/preprints202402.1573.v1

53. Zacarias, A. J.; Pereira, I. M.; Rocha , E. M.; Jaeggi, M. E. P. C.; Rangel, O. J. P.; Lima, W. L.; Guidinelle, R. B.; Capetini, S. A.; Domingos, M. O.; Coelho, F. C.; Rocha, J. G.; Rocha, R. S.; Silva, R. K. G.; Oliveira, T. R. A.; Cruz, D. P.; Souza, A. G.; Gravina, G. A.; Daher, R. F.; Batista, J. N.; Sant'anna, C. Q. S. S. Cost / benefit of the consortium green fertilization in conilon coffee. *Research, Society and Development* **2020**, 9, 11. https://rsdjournal.org/index.php/rsd/article/view/9746
54. Moreira, T. R.; Jaeggi, E. P. C. M.; Coelho, C. F.; Pereira, I. M.; Zacarias, A., J.; Gravina, G.A.; Lima, W. L;, Souza, A. O.; Pereira, L. L.; Silva, S. F.; Parajara, M. C.; Santos, A. R. Desempenho do café conilon consorciado com adubos verdes em área de transição agroecológica. *Revista Ifes Ciência* **2020**, 6, 3, 171-182. https://doi.org/10.36524/ric.v6i3.863