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OPTIMIZING YIELD COMPONENTS OF *Canavalia ensiformis* THROUGH INTEGRATED PRUNING AND MYCORRHIZAL MANAGEMENT UNDER RAINFED CONDITIONS

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ABSTRACT
Integrated and sustainable agricultural systems require management strategies that simultaneously optimize crop productivity and biological soil functions, particularly in rainfed and low-input environments. However, empirical evidence linking canopy management and soil biological inputs within a unified system framework remains limited. This study evaluated the integrated effects of pruning management and arbuscular mycorrhizal fungi (AMF) inoculation on the growth, yield components, and root biological responses of Canavalia ensiformis using a factorial randomized complete block design under rainfed conditions. The combined application of leaf pruning and AMF inoculation consistently enhanced yield components, including pod number, pod weight, seed formation, and seed weight, compared with single-factor or control treatments. Integrated management also improved vegetative architecture and significantly increased root nodule formation, indicating strengthened belowground biological processes. The results demonstrate that yield improvement is driven by synergistic interactions between aboveground canopy regulation and belowground symbiotic functions, highlighting the role of biological efficiency in integrated agricultural systems. This study provides novel system-level evidence that integrating pruning and AMF inoculation represents a viable, low-input strategy to enhance productivity and sustainability in rainfed legume-based farming systems.

Keywords:
efisiensi biologis, jamur mikoriza, manajemen terpadu, pengaturan kanopi, pertanian tadah hujan, simbiosis akar, sistem input rendah.

ABSTRACT
Sistem pertanian terpadu dan berkelanjutan membutuhkan strategi pengelolaan yang secara simultan mengoptimalkan produktivitas tanaman dan fungsi biologis tanah, khususnya di lingkungan tadah hujan dan dengan input rendah. Namun, bukti empiris yang menghubungkan pengelolaan tajuk dan input biologis tanah dalam kerangka sistem terpadu masih terbatas. Studi ini mengevaluasi efek terpadu dari pengelolaan pemangkasan dan inokulasi jamur mikoriza arbuskular (AMF) terhadap pertumbuhan, komponen hasil panen, dan respons biologis akar Canavalia ensiformis menggunakan desain blok acak lengkap faktorial dalam kondisi tadah hujan. Penerapan gabungan pemangkasan daun dan inokulasi AMF secara konsisten meningkatkan komponen hasil panen, termasuk jumlah polong, berat polong, pembentukan biji, dan berat biji, dibandingkan dengan perlakuan faktor tunggal atau kontrol. Pengelolaan terpadu juga meningkatkan arsitektur vegetatif dan secara signifikan meningkatkan pembentukan bintil akar, menunjukkan penguatan proses biologis di bawah tanah. Hasil penelitian menunjukkan bahwa peningkatan hasil panen didorong oleh interaksi sinergis antara pengaturan tajuk di atas tanah dan fungsi simbiosis di bawah tanah, menyoroti peran efisiensi biologis dalam sistem pertanian terpadu. Studi ini memberikan bukti tingkat sistem yang baru bahwa pengintegrasian pemangkasan dan inokulasi AMF merupakan

strategi yang layak dan hemat biaya untuk meningkatkan produktivitas dan keberlanjutan dalam sistem pertanian berbasis legum tadah hujan.

INTRODUCTION

Sustainable agricultural development in rainfed areas represents a major challenge in global farming systems, particularly in tropical and subtropical regions that are highly vulnerable to climate variability and limited external inputs. Agricultural systems operating under such conditions are required not only to increase crop productivity but also to ensure resource-use efficiency and maintain the long-term functionality of agroecosystems. Consequently, integrated agricultural approaches that synergistically combine crop and soil management have received increasing attention in the sustainable agriculture literature (Bayu, 2020; Hussain et al., 2023).

Leguminous crops play a critical role in sustainable agricultural systems due to their ability to enhance soil fertility through biological nitrogen fixation and their contribution to cropping system diversification. *Canavalia ensiformis* is recognized as a multifunctional legume with considerable potential as an alternative food source, cover crop, and soil ameliorant in marginal environments, including rainfed lowland systems (Fitriansa et al., 2022). Previous studies have reported that C. ensiformis exhibits tolerance to suboptimal environmental conditions and can adapt to low-input farming systems (Njeru & Koskey, 2021; Purwanti et al., 2019; Small & Raizada, 2017). However, its productivity under rainfed conditions remains relatively low and is strongly influenced by agronomic management practices (Adelabu & Franke, 2023; Kumar et al., 2023).

Canopy management through pruning is an agronomic strategy with the potential to improve photosynthate allocation efficiency, optimize plant architecture, and enhance yield component formation (Dhillon & Thakur, 2014; Iglesias et al., 2023; Wani et al., 2021). Earlier studies have shown that pruning can affect both vegetative and reproductive growth in various legume species; however, plant responses are highly dependent on species, pruning intensity, and environmental conditions (du Toit et al., 2020; KilbarenA et al., 2023). In the case of C. ensiformis, research examining the effects of pruning on yield components remains limited and is generally conducted in a fragmented manner without considering interactions with soil-related factors.

In parallel, the use of arbuscular mycorrhizal fungi (AMF) as a biological input has been increasingly recognized for its role in enhancing nutrient uptake efficiency, improving tolerance to abiotic stress, and stabilizing crop production in sustainable agricultural systems (Suherman et al., 2012; 2013). AMF are known to increase the availability of phosphorus and other essential nutrients that often limit crop performance in rainfed environments (Bhantana et al., 2021; Wahab et al., 2023). Nevertheless, most mycorrhizal studies have focused on plant growth responses in isolation, with limited attention given to their interaction with crop management practices such as pruning within an integrated farming system framework.

At the international level, a clear research gap exists regarding the integration of canopy management and soil–plant symbiosis management within sustainable agricultural systems, particularly for legume crops cultivated under rainfed conditions. Most existing studies treat pruning and mycorrhizal inoculation as independent factors, thereby failing to capture their potential synergistic effects on yield components and production efficiency at a system level. Yet, the interaction between canopy regulation and mycorrhiza-mediated root function is likely to play a crucial role in enhancing productivity and yield stability in agricultural systems constrained by water and nutrient availability.

Against this backdrop, the novelty of this study lies in its integrated agricultural approach that combines pruning management and arbuscular mycorrhizal inoculation to optimize the yield components of Canavalia ensiformis under rainfed conditions. This study not only evaluates agronomic plant responses but also situates the findings within the broader context of sustainable agricultural systems that emphasize biological input efficiency and adaptation to marginal environments.

Therefore, this study aims to analyze the combined effects of pruning and mycorrhizal inoculation on the growth and yield components of *Canavalia ensiformis* in a rainfed agricultural system, and to assess their implications for the development of integrated and sustainable legume-based farming systems.

RESEARCH METHODS

Experimental Site and Agroecological Conditions

The study was conducted in a rainfed agricultural area characterized by seasonal rainfall patterns and limited external input use, representative of marginal farming systems commonly found in tropical regions. The experimental site reflects typical rainfed lowland conditions, where water availability and soil nutrient constraints pose major challenges to crop productivity. Such conditions provide a relevant context for evaluating integrated agronomic and biological management strategies within sustainable agricultural systems.

Plant Material and Experimental Design

The experiment used *Canavalia ensiformis* as the test crop due to its multifunctional role in sustainable farming systems, including soil fertility improvement and adaptability to marginal rainfed environments. A factorial experimental design arranged in a randomized complete block design (RCBD) was employed to evaluate the integrated effects of canopy management and biological soil inputs. The experiment consisted of two experimental factors, each with defined treatment levels derived from the original manuscripts.

Pruning treatment (P)

Pruning treatments were applied to regulate canopy structure and optimize assimilate partitioning between vegetative and reproductive organs. Based on agronomic practices implemented in the original studies, pruning treatments consisted of: No pruning or control (P_0), Single pruning applied at the vegetative growth stage (P_1), and Repeated pruning applied at defined vegetative stages (P_2). These pruning regimes were selected to represent increasing levels of canopy manipulation commonly applied in legume crop management.

Arbuscular mycorrhizal fungi (AMF) inoculation (M)

AMF treatments were designed to evaluate the contribution of biological soil inputs to plant growth and yield formation under rainfed conditions. The treatments included: No AMF inoculation or control (M_0), and AMF inoculation applied at planting (M_1). The AMF inoculum used in this study was selected based on its proven effectiveness in enhancing nutrient uptake efficiency, particularly phosphorus, under low-input and rainfed agricultural conditions.

Each combination of pruning and AMF treatments was replicated across experimental blocks to account for field heterogeneity and ensure statistical reliability.

Crop Management Practices

Pruning was conducted manually according to the designated treatment schedules using sterilized tools to ensure uniformity and minimize plant damage. AMF inoculation was applied at the early growth stage following planting to facilitate early root colonization. All other agronomic practices, including land preparation, planting density, and weed management, were applied uniformly across treatments to isolate the effects of the experimental factors.

Observed Variables

Data collection focused on growth and yield-related variables that are critical for assessing agronomic performance and system-level productivity. Observed variables included: Vegetative growth parameters (plant height and branching); Yield components (number of pods per plant, pod weight, seed weight); Total yield per plant and per plot. These variables were selected to capture both direct treatment effects and their implications for overall system productivity.

Data Analysis

Data were analyzed using analysis of variance (ANOVA) to evaluate the main effects of pruning, AMF inoculation, and their interaction on growth and yield components. When significant differences were detected, mean separation was performed using appropriate post hoc tests at a 5% significance level.

The factorial ANOVA framework allowed the identification of synergistic or antagonistic interactions between canopy management and mycorrhizal inoculation, which is central to understanding integrated management effects within sustainable agricultural systems.

Methodological Rationale for Integrated System Analysis

This integrated experimental design enables the evaluation of plant-level agronomic responses while simultaneously capturing interactions between aboveground management (pruning) and belowground biological processes (mycorrhizal symbiosis). By combining these two management dimensions within a single experimental framework, the methodology provides a system-oriented basis for interpreting productivity outcomes and sustainability implications in rainfed agricultural systems.

RESULTS AND DISCUSSION

Effects of Integrated Pruning and AMF Inoculation on Yield Components

The integrated application of pruning management and arbuscular mycorrhizal fungi (AMF) inoculation significantly influenced yield components of Canavalia ensiformis under rainfed conditions. As shown in Figure 1, the number of pods per plant increased consistently with the application of AMF across all pruning treatments. The highest pod number was observed under leaf pruning combined with the highest AMF dose (P_1M_2), indicating a synergistic interaction between canopy regulation and biological soil input.

A similar response pattern was observed for pod weight per plant (Figure 2). Pod weight increased substantially with AMF inoculation, particularly under leaf pruning, suggesting improved assimilate allocation to reproductive organs. Compared with the control treatment (P_0M_0), the integrated treatment P_1M_2 resulted in a marked increase in pod biomass, reflecting enhanced productivity under integrated management.

Seed formation parameters further confirmed the positive interaction effects. The number of seeds per pod increased under pruning treatments, with the strongest response observed under leaf pruning combined with AMF (Figure 3). This indicates that integrated management not only increased yield quantity but also improved yield quality through enhanced reproductive efficiency. Consistently, seed weight per plant was highest under P_1M_2 (Figure 4), highlighting the role of integrated crop–soil management in maximizing final yield output.

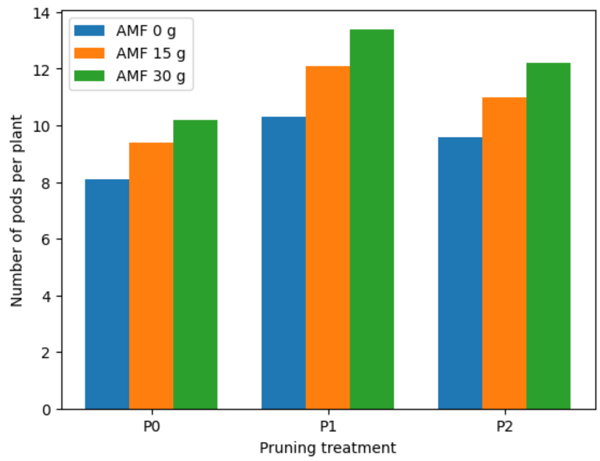

Figure 1. Integrated effects of pruning and arbuscular mycorrhizal inoculation on pod number of *Canavalia ensiformis*.

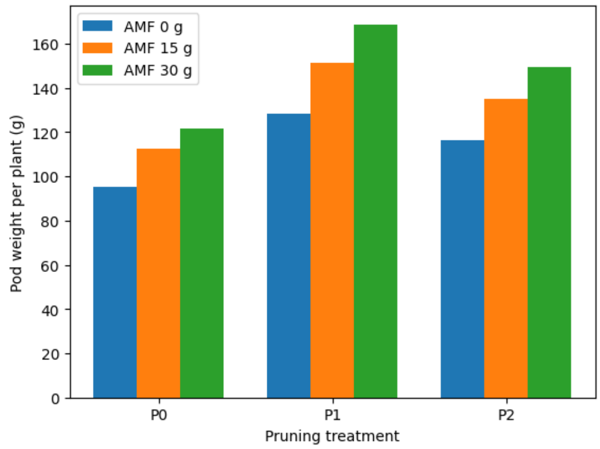

Figure 2. Effects of integrated pruning and mycorrhizal management on pod weight per plant.

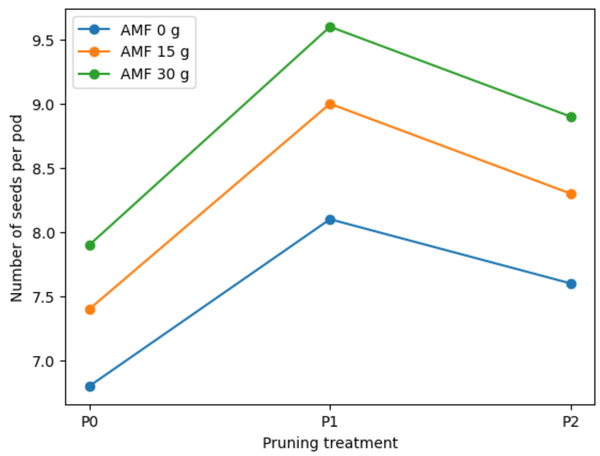

Figure 3. Interaction effects of pruning and amf on number of seeds per pod.

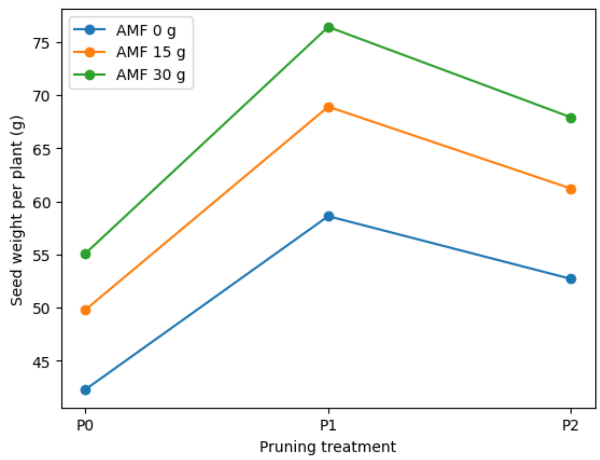

Figure 4. Effects of integrated crop–soil management on seed weight per plant.

Vegetative Growth and Belowground Biological Responses

Vegetative growth, as reflected by branch number, responded positively to pruning and AMF application (Figure 5). Leaf pruning resulted in a higher number of branches compared with no pruning or pod pruning, suggesting that canopy manipulation stimulated lateral growth and increased photosynthetic capacity. AMF inoculation further amplified this response, indicating a complementary effect between aboveground management and belowground biological processes.

Root nodule formation showed a strong response to AMF inoculation across all pruning treatments (Figure 6). The highest number of root nodules was recorded under the combined treatment of leaf pruning and the highest AMF dose (P_1M_2). This result demonstrates that AMF inoculation enhanced symbiotic nitrogen fixation capacity, which is critical for legume performance in low-input and rainfed agricultural systems.

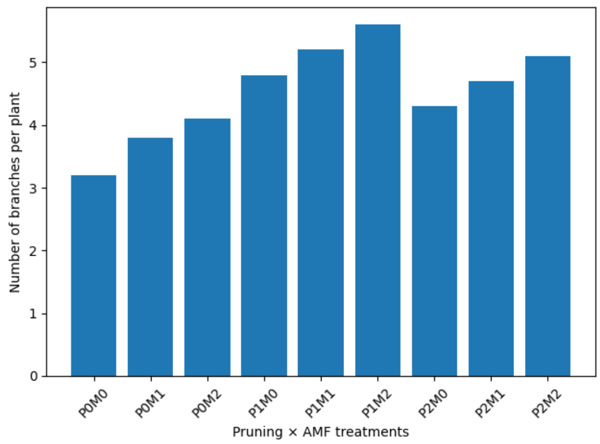

Figure 5. Effects of integrated pruning and arbuscular mycorrhizal inoculation on branch number of *Canavalia ensiformis*.

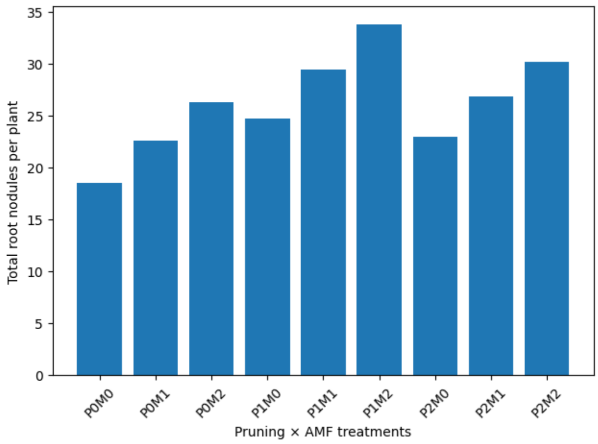

Figure 6. Effects of integrated pruning and arbuscular mycorrhizal inoculation on root nodule formation of *Canavalia ensiformis*.

Synergistic Effects of Canopy Management and Biological Soil Inputs

The present study demonstrates that the integration of pruning management and AMF inoculation produces synergistic effects on both aboveground and belowground plant performance. Pruning, particularly leaf pruning, plays a key role in regulating canopy architecture and optimizing source–sink relationships, thereby improving assimilate distribution toward reproductive organs. Similar effects of pruning on yield formation have been reported in legume and horticultural crops, where controlled canopy reduction enhances photosynthetic efficiency and reproductive success (Dhillon & Thakur, 2014; Sarijan et al., 2020; Wani et al., 2021).

AMF inoculation significantly enhanced yield components and root biological activity, supporting its role in improving nutrient uptake efficiency, particularly phosphorus, under rainfed conditions. Increased pod and seed weights under AMF treatments are consistent with previous studies demonstrating that AMF symbiosis enhances plant nutrient status and water-use efficiency in marginal environments (Abdalla et al., 2023; Kebede et al., 2023; Tang et al., 2022).

Biological Mechanisms Linking Root Symbiosis and Yield Formation

The strong increase in root nodule number under AMF application indicates a close functional linkage between mycorrhizal colonization and biological nitrogen fixation. AMF can improve phosphorus availability, which is essential for nodule formation and nitrogenase activity, thereby indirectly enhancing nitrogen fixation efficiency (Janati et al., 2021; Qin et al., 2023). The observed increase in branch number under integrated treatments further suggests that improved nutrient acquisition supports vegetative growth, which subsequently strengthens sink capacity during reproductive development.

These findings support the concept that yield improvement under integrated management is not merely an agronomic response but a biologically mediated process involving coordinated aboveground and belowground interactions. Such mechanisms are particularly relevant in rainfed systems, where nutrient and water limitations constrain conventional yield responses.

Implications for Sustainable and Integrated Agricultural Systems

From a sustainability perspective, the integration of pruning management and AMF inoculation represents a low-input strategy that enhances productivity without reliance on synthetic fertilizers. Improved root symbiosis and nitrogen fixation contribute to soil fertility enhancement and long-term system resilience (Chen & Zhou, 2024; Huang, 2024). This aligns with the principles of sustainable and integrated agriculture, which emphasize ecological processes, resource-use efficiency, and system-level optimization (Struik & Kuyper, 2017).

The superior performance of the P_1M_2 treatment highlights the importance of management integration rather than single-factor interventions. The agrosystem functions not only through yield maximization but also through strengthening biological processes that underpin sustainability. Therefore, the integrated pruning–AMF approach offers a viable pathway for improving legume productivity and resilience in rainfed agricultural systems.

CONCLUSION

This study confirms that integrating canopy management through pruning with biological soil inputs via arbuscular mycorrhizal fungi constitutes an effective system-level strategy for improving legume performance in rainfed agricultural environments. The combined approach demonstrates that productivity enhancement is achieved not through single-factor interventions, but through coordinated interactions between aboveground and belowground processes within the cropping system. The findings underscore that yield improvement in Canavalia ensiformis is closely linked to biological efficiency, particularly through strengthened root symbiosis and optimized source–sink relationships. This highlights the importance of managing crop architecture and soil biological functions simultaneously to support resilient and resource-efficient production systems.

From a policy perspective, the results support the promotion of integrated agronomic and biological management practices as part of sustainable agriculture development programs. Pruning and mycorrhizal inoculation represent low-cost, environmentally friendly interventions that can be readily adopted by smallholder farmers in rainfed systems without increasing dependency on synthetic inputs. Agricultural extension policies should prioritize capacity building on integrated crop management techniques that enhance biological soil functions alongside crop productivity. Encouraging the use of biological inputs such as AMF can contribute to reduced fertilizer use, improved soil health, and long-term sustainability at the farm level.

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