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Optimizing Organic Manure Application for Enhanced Root Yield of Ashwagandha (*Withania Somnifera*) in Agroforestry Systems

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ABSTRACT

This research looked at how different organic manures affected the root output of agroforestry-grown Ashwagandha (Withania somnifera) on soil obtained from Vertisol. Black, clayey, fine-textured soil with organic carbon enrichment from yearly litter deposition and naturally low to medium amounts of potassium, phosphorus, and nitrogen made up the experimental soil. The field study was conducted using a randomized block design with many replications. It included various organic amendments, including vermicompost, neem cake, and farmyard manure, which were given either alone or in combinations. A control group did not receive any manure. To provide equal growth conditions within the agroforestry system, the manures were mixed with the soil in small dosages before the Ashwagandha seeds were sown on ridges at the prescribed spacing. Applying organic manures considerably increased Ashwagandha's fresh and dry root yields in comparison to the control, showing that organic amendments have a favorable impact in increasing crop output. Vermicompost and farmyard manure were the two treatments that increased root biomass the greatest; this shows how important it is to use organic sources that are rich in nutrients to enhance plant development. As a whole, the research shows that a sustainable way to increase Ashwagandha output and quality without negatively impacting soil fertility or ecological balance is to use organic manures into agroforestry systems, especially vermicompost.

Keywords: *Ashwagandha, Organic manure, Root yield, Agroforestry, Sustainability.*

I. INTRODUCTION

A notable and well researched medicinal herb from the Solanaceae family, ashwagandha (Withania somnifera L. Dunal) is also known as winter cherry, Indian ginseng, or simply Ashwagandha. For ages, this evergreen herb's wide range of medicinal uses has made it an essential part of ancient medical systems like Ayurveda, Unani, and Siddha. The adaptogenic, anti-inflammatory, antioxidant, and immunomodulatory properties of ashwagandha make it highly prized. The roots, which contain the plant's bioactive chemicals called withanolides, are the most essential portion of the plant since they are responsible for the pharmacological activity. These chemicals find widespread use in the manufacturing of herbal tonics, pills, powders, and extracts, meeting the needs of both conventional and alternative medicine. Ashwagandha roots of the highest quality are in great demand due to the growing demand in the herbal medicine industry worldwide. As a result, researchers in the fields of agriculture and pharmacology are concentrating on ways to increase root production while simultaneously improving their quality. An increasingly popular and environmentally friendly method of growing Ashwagandha and other medicinal plants is the agroforestry system. For the benefit of both the environment and the economy, agroforestry brings together tree planting, crop rotation, and, in some cases, livestock in a unified land-use system. These systems keep biodiversity high, increase soil fertility, boost land productivity, and provide farmers more money in their pockets by growing both annual and perennial crops alongside perennial trees. Because Ashwagandha may survive in semi-arid climates and grow well in soils with little fertility on its own, it is beneficial to intercrop with other tree species that have similar needs. Improved soil moisture retention, reduced erosion, and enhanced nutrient cycling may be achieved via the shade, organic litter, and microclimatic modulation that trees provide. On the other hand, nutrient competition between trees and understory crops is one of the unique problems of agroforestry systems. For medicinal plants to thrive in these environments, it is essential to control soil fertility.

In order to keep agroforestry systems ecologically balanced, organic manure is essential for improving soil nutrient availability. Compost, vermicompost, green manure, farmyard manure (FYM), and other sources enhance soil physical characteristics, microbial activity, and water-holding capacity while providing critical macro- and micronutrients. Organic manures improve soil fertility and sustainability in the long run, unlike synthetic fertilizers that release nutrients quickly but could have harmful environmental implications and short-term repercussions. Sustainable medicinal plant production in agroforestry relies on a number of factors, including increased soil organic carbon content, increased populations of helpful microbes, and improved nutrient recycling, all of which are improved by organic amendments. Properly applying organic manure to Ashwagandha plants has a direct impact on their ability to accumulate root biomass, root thickness, and produce secondary metabolites, particularly withanolides. Thus, the production and medicinal quality of the collected roots are highly dependent on the kind and amount of manure, as well as the technique of application. Although organic manures are known to have several advantages, the best way to employ them when growing Ashwagandha in an agroforestry setting is still up for debate. Multiple studies have shown that Ashwagandha's response to varied organic inputs varies with soil type, moisture availability, and the presence or absence of certain tree species. For example, vermicompost and other nitrogen-rich organic sources are known to promote vegetative growth, but compost and FYM, which are more balanced manures, may improve root development and bioactive component accumulation. By combining several organic sources in the right amounts, you may create synergistic effects that boost nutrient availability all season long, which is great for above-ground growth as well as root development. Moreover, while growing Ashwagandha, it is crucial to time the application of manure so that it coincides with the plant's vital development phases, such as when its roots are thickening and when it is producing secondary metabolites.

Ecological compatibility is another important factor to consider when using organic manure in agroforestry systems. Inadequate or imbalanced manure application may reduce system production by favoring one component over another, which can happen when trees and medicinal crops compete for water, light, and nutrients. Without interfering with tree development or leading to nutrient leakage, which might eventually diminish soil quality, optimal manure management makes sure that Ashwagandha plants have access to nutrients when they need them. Keeping to an organic nutrient regime also helps the system's ecological resilience, boosts soil biology, and encourages long-term nutrient cycling. When water and nutrients are few, as they often are in semi-arid and marginal soils, this strategy takes on added significance. Organic farming is significant for reasons other than those of an agronomic or environmental nature. Organically made herbal medications are seeing a surge in demand throughout the world as more and more people seek out items that are chemical residue free. In order to satisfy both regulators and customers, pharmaceutical and herbal supplement firms are placing a greater emphasis on using organically certified raw ingredients. Producing Ashwagandha roots that meet the standards for organic certification is possible when farmers use organic manures like FYM, compost, or green manure. This increases the roots' marketability and may even lead to premium pricing. Organic farming methods also help keep ecosystems balanced, protect soil health, and lessen the likelihood of chemical runoff, all of which add up to a safer environment. In the context of agroforestry, organic manures enhance the system's resistance to climatic variability, soil erosion, and degradation while complementing natural nutrient recycling mechanisms.

Because of these many advantages, there is great scientific, economic, and ecological importance in finding the best way to use organic manures in agroforestry systems to grow Ashwagandha. Root production, bioactive chemical content, and soil fertility may all be improved with proper manure management. At the same time, it helps farmers secure their livelihoods, encourages sustainable farming techniques, and follows worldwide trends in medicinal plant and organic production. This area of study is vital for understanding how soil nutrient management, crop development, and ecological sustainability interact with one another, which in turn aids in the creation of integrated cultivation systems that strike a good balance between agricultural production and environmental protection. Soil health and biodiversity can be preserved while high-quality medicinal plant material is produced through the optimization of Ashwagandha cultivation in agroforestry systems by determining the most effective types, combinations, and dosages of organic manures. This will allow us to meet market demand and ecological objectives simultaneously. A comprehensive strategy for the long-term viability of medicinal plant production may be achieved by the coordinated application of agroforestry techniques, organic manures, and Ashwagandha cultivation. Improving agricultural productivity and quality while protecting the environment are both addressed by this. Improving the production and medicinal value of Ashwagandha, as well as developing ecologically responsible and economically sustainable agricultural practices, hinges on optimizing the use of organic manure. This study adds to our knowledge of these interconnected processes and provides useful suggestions for the long-term viability of one of India's most prized medicinal plants.

II. LITERATURE REVIEW

Mazeed, Abdul et al., (2022) Because of its various medical uses, the herb ashwagandha plays a significant role in the pharmaceutical business. To meet the demand in the industrial sector, ashwagandha has to be agronomically improved in terms of both quality and yield. Using pot experiments, researchers in 2020 and 2021 looked at how weed leaf extracts (WLE) as bio-stimulants affected the yield and quality of ashwagandha roots. Weed extracts from four species—Cyperus rotundus L., Amaranthus viridis L., Echinochloa colona (L.) Link, and Digera arvensis Forsk—were combined with four distinct commercial microorganism biofertilizers. As part of the treatments, four distinct biofertilizers were administered: a biofertilizer containing zinc, a biofertilizer containing azotobacter, a biofertilizer containing PSB, and a biofertilizer including potash. Ashwagandha dry root production was higher in the treated plants compared to the control group, a result of growth and physiological stimulatory reactions. The combined effects of Amaranthus viridis WLE, Digera arvensis WLE, and PSB solubilizing biofertilizer were much more beneficial than the sum of their individual effects in increasing yield. When treated with Pusa PSB liquid biofertilizer and Amaranthus viridis WLE, ashwagandha plants produced the most dry matter per plant (157.3 g/plant), as well as the freshest roots (65.0 g/plant), and the driest roots (23.1 g). Ashwagandha root output and quality were enhanced by this treatment, which increased levels of withanoloides A, Wwithanosides IV, and withanone, among other beneficial substances. As a result, there may be a greener way to cultivate ashwagandha, and extracts from weed leaves may offer biostimulant properties.

Jat, R.s et al., (2021) Ashwagandha, a medicinal plant with many therapeutic uses, is facing problems with quality and safety due to nutritional deficiencies in the soil. During a 2-year field trial, a control treatment, biostimulants (Azotobacter, phosphate-solubilizing bacteria [PSB], and Jivamrut), and several organic manures (castor cake, vermicompost, and farmyard manure) were tested for their effects on ashwagandha production and quality. By combining castor cake with the biostimulant consortia (biofertilizers+Jivamrut), the untreated control group saw a decrease in dry root output of just under 36.4 percent ($p = .05$). Root yield, root length/girth, biomass, branch density, and plant height were all positively correlated ($p = .01$). When several types of withanolide (withaferin-A, 12-Deoxy withastramanolide, and withanolide-A) and total withanolide were added, the root yield was 29% greater when vermicompost and Jivamrut were used combined compared to the control group. The association between root C and withaferin-A content was negative ($p = .05$), although the link between total withanolides content and plant biomass and different withanolide forms was positive (p =.01). The chemical and biological indices of soils that were treated with vermicompost showed an increase (p =.05) in soil organic carbon (SOC), nitrogen, phosphate, and sulfur. The biostimulant consortia (Azotobacter+PSB+Jivamrut) considerably increased SOC, N, P, MBC, FDH, DHA, and alkaline phosphatase; however, Jivamrut's impact on S was the greatest. Vermicompost and castor cake treated with biostimulants (Azotobacter+PSB+Jivamrut) led to better soil health, increased root production, and higher quality roots.

Basak, Biraj et al., (2020) Withania somnifera L. Dunal, often known as ashwagandha, is a medicinal plant and root that is abundant in bioactive withanolides and has great economic value. Two consecutive years of field experiments looked at how different organic nutrient management techniques affected ashwagandha yield and quality. This study used a randomized block design (RBD) for its execution. A range of organic manures, microbial consortiums, quantities of fertilizer according to prescription, and a control group were all part of the treatments. Castor cake, vermicompost, and farmyard manure were among the manures. Organic manure and microbial consortium treatments significantly altered ashwagandha root yield indices such as root length, girth, and fresh and dry root weight. Both the fresh root yields (1505 kg ha−1) and the total withanolide contents (0.947 mg g−1) were highest in the treatments that received castor cake + microbial consortia (T7) and vermicompost + microbial consortium (T8, respectively). Castor cake and vermicompost treatments greatly enhanced soil fertility (mineral N, accessible P, and S) and biochemical parameters (enzymes and microbial biomass). Correlations between soil parameters, withanolide concentration, and dry root production were shown to be positive ($r = 0.34\text{-}0.64$, < 0.01). The results show that vermicompost and castor cake may increase soil quality, which means they can be used to cultivate high-grade medicinal plants.

Shrivastava, Atul et al., (2018) Researchers at the Dusty Acres Farm, Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Jabalpur, Madhya Pradesh, examined how the Jawahar Ashwagandha variety of Withania somnifera (L.) Dunal, a spice plant, responded to integrated nutrition management (134). Plants reached their maximum height of 49.35 cm at harvest, while the maximum number of branches per plant was 5.78 on the 90th day after sowing (DAS) using T11. T11 at 90 DAS resulted in 125.40 leaves per plant and an average LAI of 10.345 while growing W. somnifera. On the other hand, W. somnifera's mean RGR peaked at 0.098 gg-1 day-1 and CGR at 90 DAS. Following this, they started to decline at 120 DAS and in T11, they were at harvest stage. The mean dry matter production of W. somnifera was 1,392.60 kg/ha throughout the harvesting stage of the crop utilizing T11. In comparison to the other treatments, W. somnifera's roots under T11 were noticeably longer (16.30 cm), thicker (2.26 cm), and more productive (612.8 kg/ha). The average seed yield (194.17) and berry yield (30.78) of W. somnifera were both significantly increased under T11. W. somnifera had a greater harvest index (43.61% of seeds collected) and mean seed yield (62.6

kg/ha) under T11 compared to the other treatments. Here is the schedule that was shown to be the most beneficial for W. somnifera cultivation in terms of integrated nutrient management: In T11, the full recommended dose of NPK was applied using fertilizers containing vermicompost (2.5 t/ha), FYM (5.0 t/ha), and ZnSO4 (20 kg/ha). In T12, half of that dose was applied using vermicompost (2.5 t/ha), FYM (5.0 t/ha), and ZnSO4 (20 kg/ha). In T10, the full recommended dose of NPK was applied using vermicompost (2.5 t/ha) and $ZnSO_4$ (20 kg/ha).

Chaudhary, S.R. et al., (2017) A field experiment was conducted to examine the effects of organic fertilizer management on ashwagandha (Withania somnifera) yield, quality, and soil biochemical parameters. The experimental design consisted of a split plot with three replications. Diverse mixes of biofertilizers and jivamrut were used in the subplot treatments, while organic manures such as farmyard manure, vermicompost, and castor cake were used in the main plot treatments. The results showed that ashwagandha's root growth, yield, and total withanolide content were all enhanced by organic fertilizers. Although both vermicompost and castor cake produced a lot of dry roots (714.6 kg ha^{-1}), castor cake contained 0.91 mg g^{-1} more withanolide. The biochemical properties of the soil and the quantity of nutrients available to plants were improved by adding vermicompost and castor cake. Because of this, ashwagandha cultivated in organic soils may benefit nutritionally from vermicompost and castor cake, two forms of organic manures.

III. MATERIALS AND METHODS

In order to accurately compare the effects of various organic manure applications on Ashwagandha growth, while also controlling for variability in soil and environmental conditions, the experiment was carried out using a Randomized Block Design (RBD) with eight treatments and three replications. Using the Karaj-based Agroforestry approach, which prioritizes integrated soil management and sustainable agriculture methods, the research, was conducted over the course of one growing season, according to a one-split yearly cycle. Each plot in the experimental field included two Ashwagandha plants, and each plot was 4×3.25 m^2, for a total of 13 m^2. To promote healthy root growth and optimal nutrient absorption, plants were spaced 30 cm apart in ridge-sown rows and 60 cm apart in rows. To make sure the seedlings had the best possible start by incorporating all of the nutrients, we meticulously mixed the soil in each plot with the specific organic manure mixture for each treatment before planting.

T1, T2, and T3 were treated with different amounts of organic manures, with T1 receiving 10 tons of farm yard manure (FYM), 5 tons of vermicompost (T2), and 4 tons of neem cake (T3), respectively, according to the approved agronomic rates. The purpose of the mixed treatments was to assess the synergistic effects: The fourth treatment, T4, mixed half FYM (5 tons/ha) with half vermicompost (2.5 tons/ha); the fifth treatment, T5, mixed half FYM (5 tons/ha) with half neem cake (2 tons/ha); the sixth treatment, T6, mixed half vermicompost (2.5 tons/ha) with half neem cake (2 tons/ha); and the seventh treatment, T7, mixed half FYM (5 tons/ha) with a quarter of vermicompost (1.25 tons/ha) and a quarter of neem cake (1 ton/ha). As a control group, T8 did not receive any organic manure and served as a benchmark against which the treatments were measured. To facilitate the manures' incorporation into the soil and their subsequent rapid and steady nitrogen release, all treatments were administered prior to ridge and furrow preparation and planting. With this experimental setting, we were able to measure the effects of various organic amendments on Ashwagandha growth, fresh root production, and dry root yield. We made sure that all plots were managed consistently and similarly.

Fresh Root Yield (Kg Ha^{-1})

The fresh root yield was calculated using a representative sample approach. At the outset, five plants were meticulously chosen and tagged from every treatment plot to be studied in depth. We measured the root weight of each plant and estimated the soil's adherence by harvesting these plants first. Afterwards, we removed every last plant from the net patch. Care was taken to remove superfluous dirt during harvesting while maintaining the root biomass, once roots were separated from the soil. The first labelled plants and the remaining net plot had their fresh root weights recorded using a precision scale.

The nett plot's fresh root weight was converted to a per-hectare basis for scaling reasons. To do this, we took the net plot fresh root production and multiplied it by the area conversion factor, which is the ratio of the net plot area to 1 hectare. A standardized measure of fresh root output across multiple treatments was provided by the findings, which were reported in kilograms per hectare (Kg Ha^{-1}). This method allows for a precise comparison of fresh root production between treatments by accounting for changes in plant density and plot size.

Dry Root Yield (Q Ha^{-1})

To evaluate the crop's true useable biomass, devoid of water content, dry root yield was calculated. After each net plot's roots were harvested, they were sun-dried until they reached a consistent weight. This process ensured that all moisture was removed while limiting deterioration of the root material. Since root moisture content varies greatly and fresh weight isn't always a reliable indicator of actual yield, this is an essential step to take.

After that, we noted the root weight per net plot in terms of dry weight. The net plot's dry weight was multiplied by the same area conversion factor used for fresh yield in order to determine the dry root yield per hectare. One quintal is equivalent to 100 kilograms, and the dry yield was reported as Q Ha^{-1}. In order to compare the efficacy of treatments under various agronomic practices, this metric gives a credible estimate of the root biomass that may be sold or stored.

IV. RESULT AND DISCUSSION

Fresh Weight

There was a considerable difference in Ashwagandha fresh root production among the various organic manure treatments, suggesting that root biomass accumulation is heavily influenced by the kind and quality of organic input. T2 (vermicompost 100%), T1 (FYM 100%), and T8 (control or least organic input) were the treatments that produced the best and lowest fresh root yields, respectively, as indicated in Table 1 and Figure 1.

There are a number of interconnected reasons why plots treated with vermicompost perform better. Improved root penetration and nutrient and water availability are two outcomes of using vermicompost, which is proven to improve soil structure, porosity, and aeration. Furthermore, it enhances the activity of microorganisms that fix nitrogen and phosphate, which speeds up the process of nutrient mineralization and makes more of both naturally occurring and artificially supplied nutrients available. Hormones, enzymes, and vitamins included in vermicompost also encourage plant growth by fostering root formation and general plant expansion. Hence, fresh root biomass was larger in the vermicompost-treated plots compared to the other treatments because the plants absorbed more of the macro- and micronutrients.

Plots treated with traditional organic manures, including FYM, had delayed nutrient release, lower microbial activity, and a lower availability of growth-promoting chemicals, which likely contributed to their inferior effectiveness compared to vermicompost in improving root development. Based on the findings, vermicompost seems to be the best organic amendment for increasing fresh root output, which in turn affects soil fertility and Ashwagandha productivity.

Table 1: Impact of Organic Manure on Fresh Root Yield of Ashwagandha in Agroforestry System

Treatments	Fresh wt. (kg ha^{-1})	Fresh wt. (q ha^{-1})
T1 - FYM 100%	1,228.85	12.29
T2 - VC 100%	1,355.77	13.56
T3 - NC 100%	1,093.72	10.94
T4 - FYM 50% + VC 50%	1,153.21	11.53
T5 - FYM 50% + NC 50%	1,090.64	10.91
T6 - VC 50% + NC 50%	1,115.77	11.16
T7 - FYM 50% + VC 25% + NC 25%	1,136.03	11.36
T8 – Control	1,053.97	10.54
SEm ±	**2.24**	
CD (at 5%)	**6.79**	

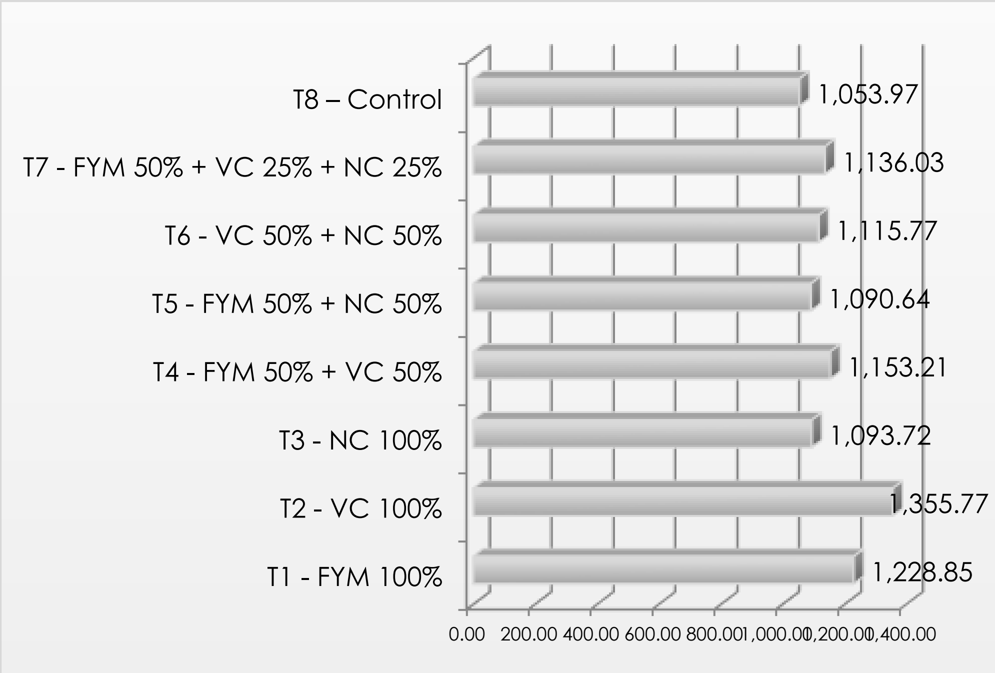

Figure 1: Impact of Organic Manure on Fresh Root Yield of Ashwagandha in Agroforestry System

<u>Dry Weight</u>

There was also a significant difference in dry root yield (the amount of biomass that could be harvested after removing water) across the different treatments. According to Table 2 and Figure 2, the treatments with the greatest dry root weight were T2 (vermicompost 100%), T1 (FYM 100%), and T8 (the lowest). Root development and biomass accumulation were both affected by the quality of the organic manure, as shown by the patterns in dry weight, which were very similar to those in fresh weight.

The increased nutrient availability, soil microbial activity, and root zone environment in vermicompost-treated plots all contribute to better nutrient translocation to roots, which is why the dry root yield is better. Improved root system design, made possible by vermicompost, allows for more nutrient and water absorption by the roots. Additionally, vermicompost's regulated breakdown guarantees a gradual release of nutrients, which supports plant development and adds to greater dry matter buildup.

Variations in nutritional content, microbial stimulation, and growth-promoting chemicals in the manure likely explain why Ashwagandha reacts differently to different organic additions, as seen by the variances in dry root output across treatments. These results highlight the fact that vermicompost is an excellent component for long-term Ashwagandha production as it increases root yields (fresh and dried).

Table 2: Effect of Organic Manure on Dry Root Yield (q ha^{-1}) of Ashwagandha Intercropped in Agroforestry System

Treatments	Dry root wt. (q ha^{-1})
T1 - FYM 100%	3.31
T2 - VC 100%	3.71
T3 - NC 100%	2.93
T4 - FYM 50% + VC 50%	3.09
T5 - FYM 50% + NC 50%	2.87
T6 - VC 50% + NC 50%	2.99
T7 - FYM 50% + VC 25% + NC 25%	3.03
T8 – Control	2.84
SEm ±	**0.01**
CD (at 5%)	**0.03**

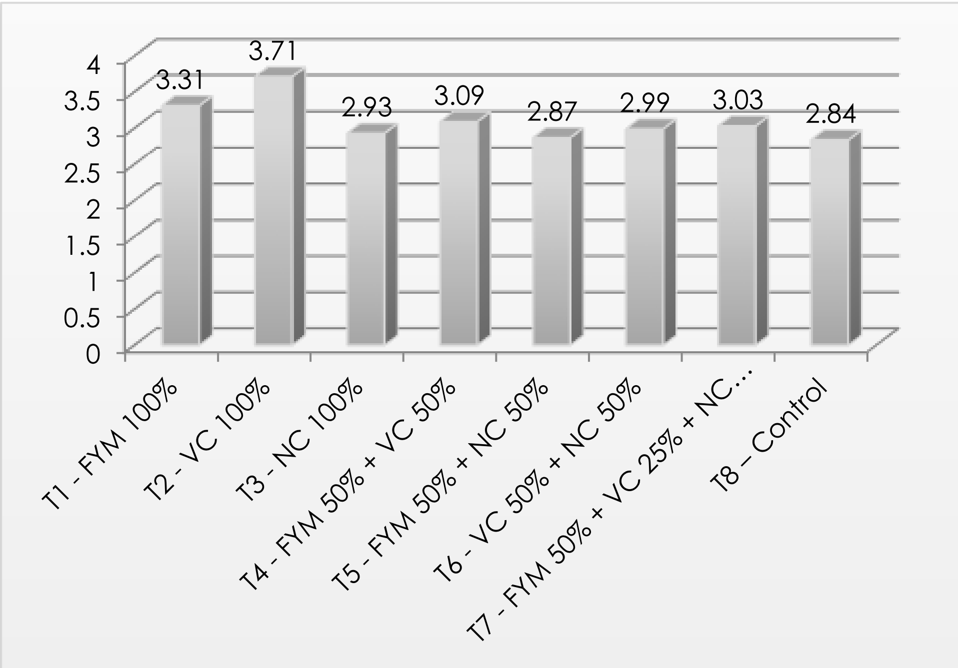

Figure 2: Effect of Organic Manure on Dry Root Yield (q ha^{-1}) of Ashwagandha Intercropped in Agroforestry System

V. CONCLUSION

Optimizing the use of organic manure for Ashwagandha grown under agroforestry systems is a sustainable and scientifically viable way to increase root yield and quality. Because they improve soil fertility, structure, and microbial activity, organic manures are crucial for Ashwagandha to have robust root systems that are rich in bioactive compounds like withanolides. Agroforestry methods that use organic inputs are suitable because, in contrast to artificial fertilizers, they maintain soil health over time while reducing environmental impacts. With careful planning of the kind, quantity, and timing of manure application, growers may optimize root biomass and therapeutic value without compromising environmental sustainability. Additionally, these approaches align with the increasing demand for organically cultivated herbal drugs, which boosts Ashwagandha's competitiveness in the market. Carbon sequestration, biodiversity preservation, and rural livelihoods are just a few of the many advantages that accrue to the whole system when manure is handled properly in an agroforestry system, which also benefits ashwagandha and other plants. Thus, by integrating organic farming with modern sustainable agriculture, this strategy offers a way to sustainably cultivate important medicinal plants. Further study focusing on optimization unique to regions and long-term trials will further increase the viability and eco-friendliness of the Ashwagandha industry grown under agroforestry.

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