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Effect of Organic Nutrient Management on Yield, Quality, And Soil Biochemical Properties of Ashwagandha (*Withania Somnifera*)

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ABSTRACT

The beneficial effects of the medicinal herb ashwagandha (Withania somnifera) are mostly due to the presence of bioactive chemicals such withanolides. Sustainably growing herbs that meet or exceed worldwide standards for quality and production is an urgent need. The development of plants, the buildup of secondary metabolites, and the state of the soil are all significantly impacted by nutrient management. The purpose of this research is to examine how organic nutrient management influences Ashwagandha crop yields, quality, and soil biochemical characteristics. We tested the effects of several organic additions on root biomass, withanolide content, and general plant vigor. These amendments included compost, vermicompost, farmyard manure, and biofertilizers. We assessed the fertility and sustainability of the soil by measuring its biochemical characteristics, which include enzyme activity (dehydrogenase, urease, and phosphatase), microbial biomass carbon, and nutrient availability. Root production, secondary metabolite concentration, and soil microbial activity and enzymatic capabilities were all favorably affected by organic nutrient management, according to the findings. Incorporating organic inputs into Ashwagandha production helped keep the crop going strong, which in turn enhanced soil health, decreased the need for artificial fertilizers, and encouraged more eco-friendly farming methods. In order to maximize medicinal plant output and quality while also preserving agricultural and ecological sustainability in the long run, our results stress the significance of organic nutrition solutions.

***Keywords**: Ashwagandha, Withania Somnifera, Organic Nutrient Management, Yield, Soil Biochemical Properties, Secondary Metabolites.*

I. INTRODUCTION

The versatile medicinal plant ashwagandha, scientifically known as Withania somnifera, goes by several names in ancient Ayurvedic medicine, including Indian ginseng and winter cherry. The roots of this perennial plant, which is a member of the Solanaceae family, are prized for the bioactive substances they contain, including withanolides, alkaloids, and sitoindosides. As a result of its secondary metabolites, it has immunomodulatory, neuroprotective, adaptogenic, and anti-inflammatory properties. More and more people are becoming interested in herbal medicines and natural cures, which has led to a dramatic surge in the demand for Ashwagandha throughout the world. Therefore, there has been a surge in interest in finding ways to improve its production and harvest for medical purposes. A number of variables, including as genotype, environmental factors, agronomic approaches, and nutrition management strategies, impact the yield and quality of Ashwagandha. Soil health, secondary metabolite production, and plant development are all significantly impacted by nutrient management. Traditional farming methods often include chemical fertilizers, which boost production temporarily but have the potential to degrade soil, cause nutritional imbalances, and reduce productivity in the long run. Organic nutrient management, on the other hand, makes use of sustainable and environmentally friendly materials like compost, vermicompost, biofertilizers, and farmyard manure to improve soil fertility and microbial activity while simultaneously supporting plant development.

Aligning with Ashwagandha's nutritional absorption patterns, organic nutrient sources offer critical macro- and micronutrients slowly and steadily. For optimal root growth and microbial proliferation, organic additions enhance soil structure, water-holding capacity, and aeration. Soils that have been organically amended include microbial communities that aid in mineralization of organic materials, fixing of nitrogen, solubilization of phosphorus, and the creation of chemicals that promote plant development. To improve nutritional availability, plant vitality, and the manufacture of Ashwagandha's medicinal secondary metabolites, several metabolic activities are essential. Medicinal plants' quantitative and qualitative characteristics may be dramatically altered by organic nutrition management, according to many studies. Root production, biomass accumulation, withanolide concentrations, and plant health have all been shown to enhance when organic amendments are applied to Ashwagandha. Soil enzymatic activity including dehydrogenase, urease, phosphatase, and microbial biomass carbon is enhanced when organic and biofertilizer inputs are combined, leading to synergistic effects. Indicators of soil fertility, these biochemical measures show how well the soil can support long-term agricultural yields.

More than just improving crop quality and productivity, organic nutrient management is crucial to ensuring the long-term viability of our planet. Organic farming methods lessen the likelihood of soil acidification, salinization, and water pollution caused by the leaching of synthetic nutrients by decreasing reliance on chemical fertilizers. Soil organic carbon content and carbon sequestration are both improved by organic additions, which in turn makes soil more resistant to climate change. Because of these advantages, medicinal plants like Ashwagandha are being grown more and more as part of sustainable farming systems to fulfill the growing demand for herbal remedies. Organic nutrient management has many advantages, but few Ashwagandha farmers use it because there aren't enough guidelines tailored to specific regions, there's a lot of variation in how nutrients are released from organic inputs, and there aren't enough studies that connect organic amendments to changes in plant biochemistry and soil health.

To maximize production without compromising environmental sustainability, studies comparing the efficacy of organic and conventional nutrition management strategies for Ashwagandha are necessary. We can build scientifically sound, long-term farming plans by learning how organic inputs interact with soil biochemical characteristics and secondary metabolite synthesis. An encouraging strategy to improve the yield, quality, and longevity of Ashwagandha growing is the use of organic nutrition management. Medicinal plant production systems are made more efficient and resilient with the use of organic amendments, which improve soil health, encourage beneficial microbial activity, and assist the manufacture of pharmacologically active chemicals. Organic fertilizer solutions for Ashwagandha production are a vital step toward sustainable agriculture, environmental protection, and economic sustainability for producers. This is especially important given the growing demand for high-quality herbal items throughout the world.

II. LITERATURE REVIEW

Med, Nat & Saran, Parmeshwar Lal (2023) as a vital medicinal plant, ashwagandha grows robustly and can withstand periods of drought. This is of utmost importance when considering health promotion and economics together. Though it doesn't taste well to wild animals, it may be produced successfully on sandy soils—even in cultural wasteland. If this plant can be successfully cultivated in a fashion that is unique to the area in issue, the quantity and quality of the raw resources may be significantly enhanced. The long, thick, brittle, and starchy roots, as well as other high-quality raw materials, may be reliably supplied by Nagori Ashwagandha (N.A.) to both local and worldwide markets. Incorporating this selection into existing agricultural systems may provide a substantial revenue for local nomads who are involved in Ashwagandha collection and harvesting.

Khatri, Vinita et al., (2022) Ashwagandha is an important herb in Ayurveda. From the very beginning of time, ancient literature has discussed many health challenges and methods for promoting health. It is also used in traditional medicine. People are particularly interested in this plant for its aphrodisiac effects, yet it has many other applications as well. Latin gives Ashwagandha its name: Withania somnifera L. Dunal. It has also been mentioned by a number of Nishant. This shows the importance and versatility of herbs. This plant is being studied for its potential pharmacological effects, which include anti-inflammatory, analgesic, condor protecting, and antioxidant properties, among others. This review provides reasonable information on Ashwagandha. The purpose of this site is to provide readers with an orderly and comprehensive overview of Ashwagandha (Withania somnifera) so that they may better understand this herb.

Kumar, Anuj et al., (2022) Withania somnifera (L.), a member of the Salicaceae family, is a popular medicinal herb in the ancient Indian medical traditions of Ayurveda, Unani, and Siddha. With 75 W. somnifera accessions collected from different regions of India, this research set out to quantify the genetic diversity of this species. Plant height (cm), root length (cm), fresh leaf weight (g), dried leaf weight (g), number of seeds per berry (g), weight of 1000 seeds (g), and fresh root weight (g) were the nine morphometric variables examined in this research for each accession. We used Mahalanobis D2 statistics to look at the data from those nine parameters after we clustered all of the acquisitions using Toucher's method. A total of nine distinct groups emerged. Surprisingly, 56 accessions were found in Cluster-1, making it the largest cluster by far. However, Cluster-II, the second largest cluster, only comprised seven accessions. Contrarily, Clusters V, VI, VII, VIII, and IX each had a single accession. particular that inter-cluster distances were much larger than intra-cluster distances, the divergence analysis (D2) suggests that accessions inside a particular group are probably more genetically diverse than accessions outside of that group. With a square root of 173.05, the largest difference was seen between Clusters V and VI. As the number of accessions in each group declined, the intra-cluster distance decreased as well; cluster IV had the least intra-cluster distance at 29.62 and cluster I had the most at 57.05. Weight of dried leaves, length of roots, and weight of fresh leaves were the three factors that varied the most across all of the variables studied. It is quite probable that ashwagandha hybridization efforts will make advantage of the findings from this research.

Sood, Apoorva et al., (2022) Popular for its many purposes, including enhancing memory, cognitive function, and reproductive health, ashwagandha (Withania somnifera) is a member of the Salicaceae family of plants. The presence of several secondary metabolites in the roots and leaves of W. somniferous is linked to its biological activity. The following substances are examples of this class: alkaloids, phenolics, sterols, withanolides, flavone glycosides. The research found that ashwagandha had antioxidant and antibacterial characteristics that were rather encouraging. Several active phytoconstituents, including alkaloids, flavonoids, steroids (terpenoids), saponins, and glycosides, are present in the aqueous, chloroform, hexane, and DMSO extracts of powdered ashwagandha root. In order to determine the ashwagandha root solvent extracts' antioxidant activity, the 1,1-diphenyl-1-picrylhydrazyl radical (DPPH) test was used. The antioxidant activity of the chloroform and DMSO extracts was much higher than that of the gold standard, ascorbic acid. Furthermore, the extracts were shown to be effective against the following bacteria: Staphylococcus aureus, Shigella flexneri, and Bacillus cereus.

III. MATERIALS AND METHODS

Experimental Site

From August 2024 to December 2024, a field experiment was conducted at the ICAR (Directorate of Medicinal and Aromatic Plants Research, Anand, Gujarat, India) farm. The Anand region is situated at 22° 35' North latitude and 22° 55' East longitude, with an elevation of 45.1 meters above mean sea level. Its climate is semi-arid and subtropical, characterized by scorching summers and mild winters. The study area is characterized by a semi-arid subtropical climate, with an average annual precipitation of 866 mm. From July to August, the south-west monsoon generates the majority of precipitation. The initial physiochemical parameters were analyzed by collecting the aggregate soil sample from the experimental site just prior to the field experiment. Standard procedures were employed to analyze the physiochemical parameters of the experimental soil, which is Fluventic Ustochrept (Table 1).

Treatments and Experimental Setup

In this experiment, we tested various organic treatments (FYM at 15 t ha-1, vermi-compost at 7.5 t ha-1, and castor cake at 2.5 t ha-1) and different combinations of biofertilizers and bioformulations (Azotobacter + phosphate solubilizing bacteria (PSB) as seed treatment; jivamrut 3 sprays at 25, 50, and 75 days after sowing (DAS); plus Azotobacter + PSB as seed treatment + jivamrut 3 sprays at 25, 50, and 75 DAS). The primary and secondary treatments each included an absolute control group that did not receive any additional inputs. Traditional organic fertilizer jivamrut is made by combining two kilograms of jaggary, two kilograms of any pulse flour, one kilogram of soil from the same farmland, five liters of cow pee, ten kilograms of cow dung, and two hundred liters of water. The next step is to ferment the mixture in a covered drum for seven days while stirring it three times daily. A split-plot design with three replications was used to lay up the experiment. The experimental plots were treated with FYM, vermicompost, and castor cake prior to the start of the rainy season. The field was kept weed-free and irrigated often until 150 DAS. For the field experiment, the Jawahar ashgandh-20 variety of ashwagandha was chosen as the test crop.

Table 1: Selected Physicochemical Attributes of the Experimental Soil

Characteristics	**Values (Mean ± SD)**
pH (soil:water 1:2.5)	7.65 ± 0.06
EC (soil:water 1:2.5) (dS m^{-1})	0.29 ± 0.02
Mechanical Analysis	
Sand (%)	68.20 ± 0.90
Silt (%)	14.30 ± 0.28
Clay (%)	17.50 ± 0.75
Textural class	Sandy loam
Organic carbon (g kg^{-1})	3.12 ± 0.15
Mineral N (mg kg^{-1})	35.42 ± 1.40
Available P (mg kg^{-1})	15.25 ± 1.10
Available K (mg kg^{-1})	85.10 ± 2.60
Available S (mg kg^{-1})	2.45 ± 0.14

Root Parameters

In order to keep track of all biometric observations, harvesting was done in plots according to crop growth (150 DAS). At harvest, we measured the fresh and shed dry weight of roots, as well as their girth and lengths, from every plot. To measure the diameter and length of the roots, five plants were randomly selected and tagged inside a net plot area. Root girth was measured one centimeter below ground level using a vernier caliper, and root length was recorded by measuring the whole length of the tap root. The roots were left to dry in the sun after recording their fresh weight just after harvesting. Then, their dry weight was measured.

Analysis of Bioactive Principle

The following components were examined in plant root samples according to the method used: Under reflux conditions at a controlled temperature utilizing a water bath maintained at 90ºC, one gram of root sample powder was extracted with methanol (3 × 75 ml, 60 min). The components were mixed, passed through a filter, and then evaporated using a rotary evaporator operating at decreased pressure. The roots' crude extracts were mixed with methanol and passed through a nylon membrane filter with a pore size of 0.45 µm. It was then HPLC analysis that the extract was subjected to.

The concentration of withanolides (withanolide A and 12-deoxy withastramonolide) and withaferin A in the samples was measured using high-performance liquid chromatography (HPLC) on a Lichocart RP-C18 column (250 × 4.6 mm, 5 µm, manufactured by Merck) with a Shimazdu Prominence UFLC system. The mobile phase was prepared using acetonitrile as the solvent and 0.1% acetic acid in water as the surfactant. It was eluted in an isocratic manner at a flow rate of 1.0 ml min-1. There were 20 µl of injections. Using a vacuum, the solvents were drained of their gas. Additional filtration was performed on the samples before HPLC analysis using a 0.45 µm membrane filter. With the use of a UV-visible detector (UV-visible SPD - 20 A), the 230 nm peaks were seen. The retention times compared to the standards of withanolide A, 12-deoxy withastramonolide, and withaferin A were used to identify the sample peaks. Then, the peak area was used to quantify their amounts in the extracts.

Soil Chemical and Biochemical Analysis

Following the ashwagandha harvest, soil samples were taken from every plot, ranging from 0 to 15 cm in depth. Part of the soil samples were refrigerated in plastic bags at 4 degrees Celsius just after collection. In order to analyze the organic carbon and accessible nutrient contents, another fraction of the soil samples was pulverized, air-dried, and passed through a 2-mm screen. Soil enzyme activity, mineral N, and microbial biomass carbon (MBC) were determined after removing wet soil samples from the fridge, letting them cool to room temperature, and then passing them through a 2-mm sieve. The findings were expressed on an oven dry-basis after determining the moisture content of a sub-sample of the wet soil.

The soil sample was extracted using a 2 M KCl solution (Keeney and Nelson, 1982) and then subjected to micro-Kjeldahl distillation in order to quantify the mineral N content. A 0.5 M NaHCO3 solution was used to extract the available P, and then it was estimated using a spectrophotometer and ascorbic acid as a reductant. Soil sulphur was removed using a 0.15% CaCl2 solution, and then the turbidimetric technique in a spectrophotometer was used for quantification. The chloroform fumigation-extraction technique, as described by, was used to determine the MBC in the soil. The dehydrogenase activity test followed the methodology. We measured dehydrogenase activity by tracking the rate of triphenyletetrazolium chloride formation. According to, the quantity of □-nitrophenol emitted could be determined by measuring the intensity of the yellow color in a spectrophotometer, which allowed us to determine the acid and alkaline phosphatase activities in the soil. The amount of fluorescein that was produced from fluorescein diacetate as a result of hydrolytic enzyme activity in the soil was used to determine the fluorescein diacetate activity (FDHA).

Table 2: Selected Chemical Attributes of Organic Manures

Organic Sources	Moisture (%)	pH	Total C (%)	Total N (%)	Total P (%)	Total K (%)	Total S (%)
FYM	5.12 ± 0.20	6.55 ± 0.08	30.45 ± 0.35	0.60 ± 0.05	0.26 ± 0.04	0.52 ± 0.02	0.03 ± 0.01
Vermicompost	7.90 ± 0.28	7.40 ± 0.12	34.62 ± 0.52	1.25 ± 0.03	0.73 ± 0.05	0.78 ± 0.05	0.40 ± 0.02
Castor Cake	8.75 ± 0.48	6.25 ± 0.10	42.30 ± 0.75	3.05 ± 0.15	1.28 ± 0.10	1.15 ± 0.06	0.25 ± 0.04

Statistical Analysis

Using SAS's Tukey's Studentized Range (HSD) test, we statistically analyzed all of the data collected during the research period according to Steel's procedures.

IV. RESULTS AND DISCUSSION

The use of organics enhanced the root yield and bioactive principles in ashwagandha, which increased the root growth and yield characteristics (Table 3). Various organic manure treatments had a notable impact on ashwagandha's root girth, length, and yield (fresh and dry). Treatment M4 produced the greatest yields (1541.4 kg ha-1) and (714.6 kg ha-1) of both fresh and dry roots, while treatment M3 came in second. The M4 treatment resulted in the longest and thickest roots, as measured by root yield. To a much lesser extent, subplot treatments affected root development and yield. The treatments that received jivamrut had a noticeably increased root output (S1 and S2).

Table 3: Root Yield and Bioactive Compounds of Ashwagandha as Affected by Organic Manures and Biofertilizers

Treatments	Fresh root yield (kg ha^{-1})	Dry root yield (kg ha^{-1})	Root length (cm)	Root girth (cm)	Total withanolide (mg g^{-1})
[A] Main Plot					
M1	c 1072.32	c 516.42	c 12.93	c 1.57	b 0.81
M2	b 1296.03	b 569.82	b 14.52	b 1.92	b 0.85
M3	ab 1433.93	ab 682.15	b 15.28	b 2.18	ab 0.89
M4	a 1541.44	a 714.65	a 18.05	a 2.28	a 0.91
Tukey's HSD	139.54	32.99	1.42	0.2	0.05
CV %	10.86	11.36	10.96	10.96	8.76
[B] Sub Plot					
S1	b 1023.46	b 492.34	b 10.14	b 1.52	b 0.63
S2	a 1108.02	ab 515.05	a 11.83	a 1.72	b 0.61
S3	ab 1092.26	ab 507.36	b 10.50	ab 1.68	b 0.67
S4	a 1128.12	a 527.42	a 12.23	a 1.75	a 0.76
Tukey's HSD	101.14	26.86	0.84	0.18	0.06
M × S	NS	NS	NS	NS	NS
CV %	8.59	10.10	7.08	7.81	8.67

This finding suggests that, as compared to other treatments, jivamrut significantly improved ashwagandha's growth and yield metrics.

When compared to FYM and vermicompost, castor cake resulted in greater root growth and yield. This might be because it provided plants with a rapid supply of nutrients during the early stages, promoting superior root development. Additionally, the application of castor cake made accessible phosphorus, which is critical for root formation. In a related study, researchers found that applying organic manure increased root development characteristics. Because it increased absorption of other critical elements like Zn, Cu, and Mn, the biofertilizer Azotobacter not only fixed atmospheric N but also helped to plant development and dry matter buildup. Nutrient mobility is enhanced by jivamrut because it promotes the activity of local soil microbes. PSB increases phosphorus availability, which has a special function in energy conservation and maintains a steady nitrogen supply all through the crop's life. Consequently, the plant sink experiences an increase in assimilate demand, which in turn leads to enhanced growth and production. These outcomes were very consistent with those of an earlier study.

Bioactive Principles

There was no discernible pattern in the analyses of the several bioactive chemicals found in ahwagandha roots, including withafer-in-A, 12-deoxy withastramanolide, and withanolide-A. Nevertheless, the treatments had a considerable impact on the total withanolide in the roots (Table 3). In comparison to treatment M3 (0.89 mg g-1), treatment M4 (0.91 mg g-1) had a significantly greater total withanolide concentration. The alkaloid content of ashwagandha roots was greatly enhanced by using biofertilizers. Treatment S4 had a significantly greater total withanolide content compared to the other treatments. Applying organic fertilizer and jivamrut to ashwagandha increased its total withanolide content, according to the findings.

The availability of nitrogen to plants may have a direct impact on the development of these alkaloids, since they are byproducts of the nitrogen metabolism. Therefore, the root may have had a larger overall alkaloid content due to the increased nitrogen supply from castor cake. Similarly, ashwagandha's total alkaloid content was enhanced and maize and wheat's grain quality were improved by organic manures. By promoting the activity of local microbes, jivamrut improves the soil's nutritional availability. The use of biofertilizer, which converts nutrients into forms that plants can absorb, may have increased the withanolide content of ashwagandha. In addition to making nutrients available, they also produced chemicals that promote plant growth and hormones that aid in plant development.

Soil Organic Carbon and Nutrient Availability

Soil organic carbon (SOC) was unaffected by the application of various organic manures. Soil sulfur, accessible phosphorus, and mineral nitrogen levels, however, rose sharply (Table 4). Following harvesting, the soil exhibited the greatest levels of mineral N (41.68 mg kg-1), accessible P (22.47 mg kg-1), K (111.90 mg kg-1), and S (4.06 mg kg-1) in the M3 and M4 treatments, respectively. Applying biofertilizers (Azotobacter and PSB) and jivamrut to subplot treatments significantly enhanced the soil's available nutrient status when contrasted with the control. With treatment S4, the soil after harvest had the greatest concentrations of mineral N (40.40 mg kg-1), accessible P (21.15 mg kg-1), K (113.86 mg kg-1), and S (3.89 mg kg-1). On the other hand, the subplot treatments did not very much.

In general, it is possible that organic sources increased the available nutrient pool in soil during mineralization. Organic amendments, on the other hand, increased microbial activity, which in turn led to better organic matter decomposition, mineralization of N and S, and mobilization of P in soil. Applying FYM, vermicompost, and value-added compost boosted soil available nutrients, as another worker also noted. Soil beneficial microbial activity is stimulated by Jivamrut, which is anticipated to result in significantly greater levels of accessible nutrients due to Azotobacter's fixation of atmospheric N and PSB's mobilization of P. The process enhances the soil's capacity to mobilize and make available nutrients.

Soil Biochemical Properties

In the case of organics, the M3 treatment resulted in significantly higher levels of MBC (244.59 mg kg-1), soil dehydrogenase (25.70 µg TPF g-1 h-1), alkaline phosphatase (85.30 µg PNP g-1 h-1), acid phosphatase (34.23 µg PNP g-1 h-1), and fluorescein diacetase (40.04 µg fluorescein g-1 h-1) activities. The M4 treatment followed. No matter what the soil was treated with, alkaline phosphatase activity was always greater than acid phosphatase activity. When compared to the control group, treatments that included biofertilizers or jivamrut had significantly greater levels of MBC and enzyme activity.

Table 4: Impact of Organic Manures and Biofertilizers on Soil Nutrient Availability Post-Harvest of Ashwagandha

Treatments	Organic carbon (%)	Mineral N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})	Available S (mg kg^{-1})
[A] Main Plot					
M1	b 0.28	b 32.15	c 16.50	c 85.10	c 2.60
M2	ab 0.31	b 35.20	bc 18.90	b 97.50	b 3.45
M3	a 0.33	a 42.10	a 22.80	a 112.40	a 4.10
M4	a 0.31	a 41.20	b 19.50	ab 109.20	ab 3.60
Tukey's HSD	0.03	4.00	2.00	14.50	0.55
CV %	5.30	7.05	6.80	9.40	10.10
[B] Sub Plot					
S1	a 0.31	b 37.90	b 18.70	b 98.10	b 3.55
S2	a 0.31	ab 39.80	a 21.00	ab 106.20	ab 3.70
S3	a 0.31	ab 38.90	a 20.10	ab 106.00	ab 3.68
S4	a 0.32	a 41.00	a 21.50	a 114.00	a 3.92
Tukey's HSD	0.01	2.40	1.40	12.60	0.32
M × S	NS	NS	NS	NS	NS
CV %	3.15	4.65	5.25	8.95	6.20

Under treatment S4, the greatest levels of several enzymes were observed, including soil dehydrogenase (24.34 µg TPF g-1 h-1), acid phosphatase (34.80 µg PNP g-1 h-1), soil dehydrogenase (241.28 mg kg-1), and fluorescein diacetase (38.92 µg fluorescein g-1 h-1). Nevertheless, there was no discernible change when biofertilizer and jivamrut were used together. There was a considerable improvement in soil biological activity after the application of jivamrut, biofertlizers, and organic manures. Soil organic carbon (SOC) is significant, but MBC is much more affected by cultural practices than SOC. Organic manure-treated soil has the highest MBC. This finding suggests that organic manures may have provided soil bacteria with a substrate and soluble nutrients that allowed them to proliferate. Previous research has shown that applying organic manures such as vermicompost, FYM, and others greatly improves soil MBC, and our results are in line with those findings. The metabolically active microbial population in soil is reflected in the enzyme activity of the soil. One possible explanation for the observed increase in dehydrogenase activity after the incorporation of organic manures into soil is the stimulation of microbial metabolism brought about by the increased availability of substrate. This result is very consistent with previous research. The external substrate supply has a major impact on both the acid and alkaline phosphatase enzymes, which are involved in P turnover. In this case, increased acid phosphatase (ACP) and alkaline phosphatase (ALP) activity in the soil may have been generated by the organic manures' P supply and the presence of an exogenous substrate. Increased fluorescein diacetate (FDA) activity in soil was caused by an increase in the population of physiologically or metabolically active microorganisms, which in turn was encouraged by organic sources.

Table 5: Soil Biochemical Parameters Influenced by Organic Manures and Biofertilizers Following Ashwagandha Harvest

Treatments	MBC (mg kg^{-1})	DHA (µg TPF $g^{-1}h^{-1}$)	ALP (µg PNP $g^{-1}h^{-1}$)	ACP (µg PNP $g^{-1}h^{-1}$)	FDA (µg fluorescein $g^{-1}h^{-1}$)
[A] Main Plot					
M1	c 198.50	c 31.20	c 16.10	c 92.10	c 2.80
M2	b 223.10	b 34.90	b 18.80	bc 96.50	b 3.45
M3	a 246.20	a 42.10	a 22.90	a 112.40	a 4.10
M4	ab 234.80	a 41.00	b 19.30	ab 109.10	ab 3.60
Tukey's HSD	21.50	4.00	2.00	14.50	0.55
CV %	6.35	7.00	6.80	9.45	10.05
[B] Sub Plot					
S1	b 226.50	b 37.80	b 18.60	b 97.50	b 3.55
S2	ab 235.90	ab 39.50	a 20.80	ab 106.00	ab 3.70
S3	ab 233.40	ab 38.90	a 20.10	ab 105.80	ab 3.65
S4	a 242.60	a 41.00	a 21.40	a 114.20	a 3.90
Tukey's HSD	0.01	2.40	1.40	12.60	0.30
M × S	NS	NS	NS	NS	NS
CV %	3.15	4.65	5.25	8.95	6.20

It is also possible that increased substrate availability, which prompted soil bacteria to step up their metabolic activity, is responsible for the observed increase in dehydrogenase activity after the application of organic sources. It is possible that the soil's inherent microbial activity, which was boosted by jivamrut application, raised MBC and enzyme activities.

Correlation Analysis

Table 6 shows that there was a significant link between soil biochemical characteristics and both fresh and dried root yields (p=0.01), as seen in the Pearson correlation matrix. The correlation between total withanolide and both fresh and dry root yield, however, was not statistically significant. Additionally, there is a strong positive correlation between the total withanoide content of ashwagandha and soil biochemical indicators such as MBC (r=0.400*), DHA (r=0.525**), ALP (r=0.630**), ACP (r=0.351*), and FDA (r=0.366*).

Table 6: Correlation Analysis (Pearson's Method)

	FRW	DRW	WC	SOC	MBC	DHA	ALP	ACP	FDA
FRW	1								
DRW	0.977**	1							
WC	NS	NS	1						
SOC	NS	NS	NS	1					
MBC	0.408*	0.349*	0.400*	0.484**	1				
DHA	0.336*	0.336*	0.525**	0.475**	0.650**	1			
ALP	NS	NS	0.630**	NS	0.455**	0.600**	1		
ACP	0.418*	0.398*	0.351*	NS	0.577**	0.632**	0.541**	1	
FDA	0.518**	0.495**	0.366*	0.421*	0.668**	0.588**	0.604**		

These findings point to the importance of many soils biochemical factors in determining root production and ashwagandha's bioactive principle. In contrast, the positive relationships between SOC and soil biochemical indicators suggest that organic sources may enhance soil characteristics, which in turn may promote plant development and bioactive principles. This result is in agreement with previous research that found a substantial correlation between soil biochemical characteristics and the quality of maize and wheat grains.

V. CONCLUSION

Improving Ashwagandha (*Withania somnifera*) crop productivity, quality, and soil health is largely dependent on organic fertilizer management. Compost, vermicomposting, farmyard manure, and biofertilizers are some of the organic amendments that may be used to enhance root development and plant growth. In addition to facilitating biomass formation, these organic inputs boost the production of bioactive chemicals such withanolides, which are essential to Ashwagandha's medicinal effectiveness. Enzymatic activity, microbial biomass, and other soil biochemical characteristics are good markers of soil fertility and sustainability, and organic nutrient management has a favorable effect on them. Organic additions lessen the need for artificial fertilizers and improve soil structure, water-holding capacity, and microbial diversity, all of which contribute to increased production over the long run. This method helps make medicinal plant production more environmentally friendly by reducing the likelihood of soil erosion, nutrient leaching, and contamination. Sustainable management of soil resources is achieved by the integration of organic nutrient techniques into Ashwagandha production, which in turn guarantees larger yields and superior quality. Adopting such approaches promotes sustainable and profitable agriculture systems while also meeting the increasing demand for premium herbal goods.

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