



Sprouting Percentage and Growth Enhancement of Hawaiian Ginger (*Zingiber Officinale*) Rhizome Treated with Various Bio-Inoculants

Mark Angelo Galvan
Quirino State University

ABSTRACT

This study evaluates the effectiveness of bio-inoculants, specifically Arbuscular Mycorrhizal Fungi (AMF) and *Azospirillum*, in overcoming the physiological dormancy and uneven sprouting of Hawaiian ginger (*Zingiber officinale*) in Quirino Province. The primary purpose is to establish a sustainable biological protocol that enhances early stage vigor and provides a cost effective, eco-friendly alternative to synthetic fertilizers. By utilizing a controlled experimental design, the research tested 135 rhizome setts planted in a 1:1 garden soil and coco-peat medium to determine sprouting percentage, assess growth parameters including shoot length, leaf number, rhizome circumference, and biomass and calculate the Cost-Benefit Ratio of each treatment. Results at 35 days indicated that while vertical growth was statistically limited by the plant's reliance on internal nutrient reserves, numerical trends favored the bio-inoculant groups. Specifically, AMF demonstrated superior root proliferation and rhizome circumference, providing a resilient physiological foundation for field survival. Meanwhile, *Azospirillum* emerged as the most economically efficient treatment with a Marginal Benefit-Cost Ratio of 1.83. The study concludes that although the initial 35 days window is a heterotrophic lag phase, microbial interventions significantly improve long term crop resilience and sustainability. This research is highly significant for the agricultural community of Quirino as it aligns local practices with Sustainable Development Goals (SDGs 2, 12, and 15), offering a Climate-Smart framework that protects soil integrity while potentially uplifting the socio-economic status of small scale farmers through improved resource efficiency.

Keywords: *Zingiber officinale*, Bio-inoculants, Arbuscular Mycorrhizal Fungi, *Azospirillum*, Nursery Establishment, Quirino Province, Sustainable Agriculture.

INTRODUCTION

Hawaiian ginger (*Zingiber officinale*) is a high value medicinal crop and a vital economic driver for smallholder farmers in the Philippines. However, its expansion in provinces like Quirino is significantly hindered by prolonged physiological dormancy and a 30 to 60 days lag phase (Kim, 2024; Bian et al., 2021). This slow emergence makes seed pieces vulnerable to soil-borne pathogens like Rhizome Rot (*Pythium aphanidermatum*) and often leads to the excessive use of synthetic fertilizers, which causes soil acidification and environmental degradation (Denish et al., 2015; Bian et al., 2021). Relevant literature suggests that bio-inoculants, such as Plant Growth-Promoting Rhizobacteria (PGPR) and Arbuscular Mycorrhizal Fungi (AMF), offer sustainable solutions. Inoculants like *Azospirillum* and AMF act as biological triggers, enhancing nutrient acquisition and secreting essential phytohormones like Indole-3-Acetic Acid (IAA) and Gibberellins to break dormancy (Sun et al., 2024; Basu et al., 2021). Integrating these with a porous 1:1 garden soil and coco-peat medium provides the ideal substrate for microbial activity. This study aims to evaluate the early stage development of Hawaiian ginger under local conditions



to establish a biological protocol that reduces nursery time and ensures crop uniformity. Specifically, the objectives are to: (1) determine the sprouting percentage of ginger setts 35 days after planting; (2) assess growth enhancement during the establishment phase measuring shoot length, leaf number, new rhizome circumference, and fresh weight; and (3) determine the cost-benefit ratio of utilizing *Azospirillum* and AMF. By providing a localized scientific basis for bio-organic interventions, this research supports Sustainable Development Goals (SDGs 2, 12, and 15) and fosters climate-smart agriculture for upland farming communities.

METHODOLOGY

The methodology for this study followed a Completely Randomized Design (CRD), utilizing 135 experimental units divided into three treatments with three replications each. Conducted in Balligui, Maddela, Quirino, the research focused on the 35 days nursery establishment phase of Hawaiian ginger (*Zingiber officinale*). The biological material consisted of disease free, 8–10 month old rhizomes sourced from Nagtipunan, Quirino, which were sectioned into 50-gram setts containing two to three viable buds. A sterilized 1:1 mixture of garden soil and cocopeat served as the growth medium, stabilized for 48 hours to ensure a pathogen free environment. The experimental procedure employed a Direct Plant approach, simulating common local practices where rhizomes are planted immediately after cutting. Experimental treatments involved a 30 minutes submersion of setts in specific microbial slurries: T₁ served as the untreated control which does not received any Bio-inoculants, T₂ utilized an *Azospirillum* bacterial slurry at 200g per 4L of water, and T₃ utilized an Arbuscular Mycorrhizal Fungi (AMF) concentrated powder at 500g per 4L of water. Following inoculation, the setts were planted in nine 48cm x 36cm x 17cm fruit crates lined with mesh and filled with the sterilized medium. The nursery was maintained under uniform conditions with irrigation applied to maintain field capacity, strictly excluding synthetic fertilizers or chemical pesticides.

Data collection occurred 35 days after planting, focusing on critical morphological parameters including sprouting percentage, shoot length, leaf count, root count, and new rhizome circumference to assess structural development. Biomass was measured through total fresh weight, while the economic viability of each microbial intervention was evaluated using the Marginal Benefit-Cost Ratio. All resulting data were subjected to Analysis of Variance (ANOVA) for CRD to determine the statistical impact of the bio-inoculants on early ginger growth and structural establishment.

RESULT AND DISCUSSION

The results and discussion of this study highlight the complex early stage physiological dynamics of Hawaiian ginger (*Zingiber officinale*) under the influence of bio-inoculants. At 35 days after planting, the final count of shoot emergence showed that *Azospirillum* (T₂) achieved the highest numerical mean (0.29), followed by the control (0.22) and Arbuscular Mycorrhizal Fungi (0.13). Despite these visible trends, the results were not statistically significant due to high internal variability in bud dormancy, a finding that aligns with previous research suggesting that short duration trials often struggle to overcome the statistical noise inherent in rhizome sprouting. This



underscores the challenge of establishing uniform ginger stands in the initial month of growth, regardless of microbial intervention.

In terms of morphological vigor, the study revealed distinct growth pathways triggered by the different inoculants. *Azospirillum* (T_2) produced the tallest shoots (4.14 cm) and the highest leaf count, likely due to the secretion of Indole-3-Acetic Acid (IAA) which prioritizes vertical elongation. In contrast, Arbuscular Mycorrhizal Fungi (T_3) demonstrated a bottom-up strategy, leading in root production (3.42 roots) and new rhizome circumference (11.05 mm). These findings suggest that while vertical growth is a priority for some microbes, AMF focuses on strengthening storage organs and root networks, providing a superior physiological foundation for field survival. The lack of overall statistical divergence across height and weight parameters is supported by the theory that ginger remains in a heterotrophic state for the first 35 to 45 days, relying primarily on internal starch reserves rather than external inputs.

Economically, the assessment identified *Azospirillum* (T_2) as the most efficient treatment, yielding a Cost-Benefit Ratio of 0.0191 and a Marginal Benefit-Cost Ratio of 1.83. This reflects a value to cost efficiency approximately 74% higher than the control. Although the 35 days trial captured only a transitional phase where symbiosis was still forming, the numerical advantages in biomass and structural development confirm that bio-inoculants provide a scientifically sound basis for Climate-Smart agriculture in Quirino. By offering a sustainable alternative to synthetic chemicals, these microbial interventions align with Global Sustainable Development Goals for soil integrity and resource efficiency, potentially uplifting the socio-economic status of upland farming communities through improved crop resilience.

SUMMARY, CONCLUSION AND RECOMMENDATIONS

This research evaluated the impact of microbial inoculants on the early stage development and economic viability of Hawaiian ginger (*Zingiber officinale*) in Quirino Province. The study sought to address the challenges of uneven sprouting and heavy reliance on synthetic fertilizers by testing the efficacy of Arbuscular Mycorrhizal Fungi (AMF) and *Azospirillum*. Using a Completely Randomized Design (CRD), 135 rhizome setts were treated via a 30 minutes submersion in microbial slurries and planted in a sterilized 1:1 garden soil and cocopeat medium. Over a 35 days trial, the study monitored sprouting percentage, morphological growth: shoot height and leaf count, root proliferation, and biomass accumulation. These parameters were selected to determine the biological and economic effectiveness of transitioning from conventional chemical intensive methods to bioorganic interventions.

The scientific findings revealed that while the 35 days duration was statistically insufficient to override the plant's reliance on internal starch reserves a hallmark of the heterotrophic phase clear numerical trends emerged. *Azospirillum* (T_2) demonstrated superior vertical vigor and biomass accumulation, yielding a Marginal Benefit-Cost Ratio of 1.83, making it the most cost-efficient short term treatment. Conversely, Arbuscular Mycorrhizal Fungi (T_3) prioritized structural establishment, leading in root count and new rhizome circumference. These results indicate that while microbes do not immediately override the internal dormancy of the mother rhizome, they



initiate distinct physiological pathways either prioritizing immediate shoot biomass or establishing a robust root-rhizome network for long-term survival.

In conclusion, the integration of bio-inoculants provides a robust, Climate Smart foundation for ginger nursery establishment. The study confirms that biological triggers can reduce the need for synthetic nitrogen while preparing the plant for the autotrophic transition. This approach aligns with Sustainable Development Goals 2, 12, and 15 by promoting soil health and resource efficiency. Although the nursery phase is a period of transition where symbiosis is still forming, the numerical lead in root and rhizome development suggests that microbial treatments offer a critical biological shield that enhances the crop's resilience against environmental stressors upon field transplantation.

Based on these conclusions, it is recommended that farmers in Quirino adopt Arbuscular Mycorrhizal Fungi (AMF) as a nursery starter. While *Azospirillum* shows faster initial biomass gain, the superior root proliferation provided by AMF offers better long term protection against the soil-borne pathogens and moisture stress common in upland farming. Furthermore, future researchers should extend the observation window to 60 or 90 days to capture the phase where the plant fully transitions to microbial assisted nutrient uptake. It is also recommended to implement a standardized curing or suberization period for rhizome setts before inoculation to synchronize bud emergence and reduce statistical variability. Finally, local agricultural offices should incorporate these bio-organic protocols into regional high value crop development programs to foster a more sustainable and economically resilient agricultural sector in Quirino.

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Corresponding author: mikogalvan@gmail.com

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Figures and Tables

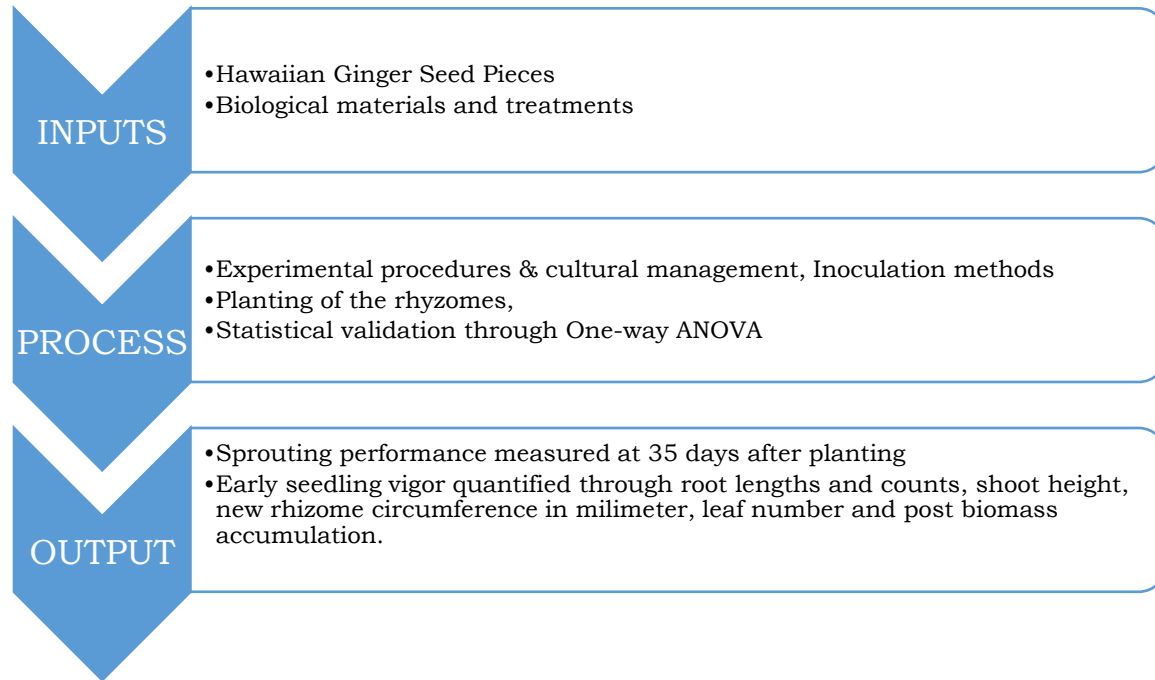


Figure 1. Conceptual Framework of the Study

Table 1. Mean Number of Roots of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Means
T ₁ – Untreated	2.85
T ₂ – Azospirillum	2.09
T ₃ – Arbuscular Mycorrhizal Fungi	3.42
ANOVA Result	ns
CV (%)	39.63

Table 2. Mean Length (cm) of Roots of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Means
T ₁ – Untreated	1.73
T ₂ – Azospirillum	3.29
T ₃ – Arbuscular Mycorrhizal Fungi	2.75
ANOVA Result	ns

Corresponding author: mikogalvan@gmail.com

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CV (%)	56.93
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Table 3. Mean Weight (g) of Rhizomes after the Experiment of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Means
T ₁ – Untreated	52.24
T ₂ – Azospirillum	54.68
T ₃ – Arbuscular Mycorrhizal Fungi	53.45
ANOVA Result	ns
CV (%)	2.11

Table 4. Mean New Rhizome Sett Counts of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Means
T ₁ – Untreated	1.42
T ₂ – Azospirillum	1.38
T ₃ – Arbuscular Mycorrhizal Fungi	1.29
ANOVA Result	ns
CV (%)	5.75

Table 5. Mean Circumference of New Rhizome of Hawaiian of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Means
T ₁ – Untreated	10.50
T ₂ – Azospirillum	10.89
T ₃ – Arbuscular Mycorrhizal Fungi	11.05
ANOVA Result	ns
CV (%)	7.44

Table 6. Mean Final Count of Shoot Emergence of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Means
T ₁ – Untreated	0.22
T ₂ – Azospirillum	0.29
T ₃ – Arbuscular Mycorrhizal Fungi	0.13
ANOVA Result	ns
CV (%)	77.28



Table 7. Mean Final Height (cm) of Shoot Emergence of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Means
T ₁ – Untreated	1.75
T ₂ – Azospirillum	4.14
T ₃ – Arbuscular Mycorrhizal Fungi	2.90
ANOVA Result	ns
CV (%)	79.85

Table 8. Mean Leaf Count of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Means
T ₁ – Untreated	0.00
T ₂ – Azospirillum	0.15
T ₃ – Arbuscular Mycorrhizal Fungi	0.13
ANOVA Result	ns
CV (%)	107.86

Table 9. Mean Biomass Weight (g) of Shoot and Developed Rhizome of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Means
T ₁ – Untreated	2.24
T ₂ – Azospirillum	4.68
T ₃ – Arbuscular Mycorrhizal Fungi	3.45
ANOVA Result	ns
CV (%)	32.71



Appendix Tables

Table 1. Mean Number of Roots of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Replication			Total	Mean
	I	II	III		
T ₁ – Untreated	1.87	3.80	2.87	8.54	2.85
T ₂ – Azospirillum	3.27	1.47	1.53	6.27	2.09
T ₃ – Arbuscular Mycorrhizal Fungi	1.93	4.07	4.27	10.27	3.42
Grand Total				25.08	
Grand Mean					2.79

Table 1a. ANOVA for Mean Number of Roots of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Source	DF	SS	MS	F	P
Treatment	2	2.6829	1.34143	1.10 ns	0.3918
Error	6	7.3187	1.21979		
Total	8	10.0016			

CV (%) = 39.63

^{ns} not significant

Table 2. Mean Length (cm) of Roots of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Replication			Total	Mean
	I	II	III		
T ₁ – Untreated	0.79	2.66	1.75	5.20	1.73
T ₂ – Azospirillum	4.81	0.98	4.08	9.87	3.29
T ₃ – Arbuscular Mycorrhizal Fungi	2.76	1.51	3.97	8.24	2.75
Grand Total				23.31	
Grand Mean					2.59

Table 2a. ANOVA for Mean Length (cm) of Roots of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Source	DF	SS	MS	F	P
Treatment	2	3.7453	1.87263	0.86 ns	0.4690
Error	6	13.0455	2.17426		
Total	8	16.7908			

CV (%) = 56.93

^{ns} not significant



Table 3. Mean Weight (g) of Rhizomes after the Experiment of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Replication			Total	Mean
	I	II	III		
T ₁ – Untreated	52.14	52.65	51.93	156.72	52.24
T ₂ – Azospirillum	55.85	52.74	55.44	164.03	54.68
T ₃ – Arbuscular Mycorrhizal Fungi	53.98	52.39	53.97	160.34	53.45
Grand Total				481.09	
Grand Mean					53.45

Table 3a. ANOVA for Mean Weight (g) of Rhizomes after the Experiment of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Source	DF	SS	MS	F	P
Treatment	2	8.9063	4.45314	3.49 ns	0.0988
Error	6	7.6591	1.27652		
Total	8	16.5654			

CV (%) = 2.11

^{ns} not significant

Table 4. Mean New Rhizome Sett Counts of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Replication			Total	Mean
	I	II	III		
T ₁ – Untreated	1.40	1.47	1.40	4.27	1.42
T ₂ – Azospirillum	1.33	1.33	1.47	4.13	1.38
T ₃ – Arbuscular Mycorrhizal Fungi	1.40	1.20	1.27	3.87	1.29
Grand Total				12.27	
Grand Mean					1.36

Table 4a. ANOVA for Mean New Rhizome Sett Counts of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Source	DF	SS	MS	F	P
Treatment	2	0.02747	0.01373	2.23 ns	0.1886
Error	6	0.03693	0.00616		
Total	8	0.06440			

CV (%) = 5.75

^{ns} not significant



Table 5. Mean Circumference (cm) of New Rhizome of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Replication			Total	Mean
	I	II	III		
T ₁ – Untreated	10.40	10.69	10.41	31.5	10.50
T ₂ – Azospirillum	11.76	9.32	11.58	32.66	10.89
T ₃ – Arbuscular Mycorrhizal Fungi	10.76	11.20	11.20	33.16	11.05
Grand Total				97.32	
Grand Mean					10.81

Table 5a. ANOVA for Mean Circumference (cm) of New Rhizome of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Source	DF	SS	MS	F	P
Treatment	2	0.48347	0.24173	0.37 ns	0.7031
Error	6	3.88113	0.64686		
Total	8	4.36460			

CV (%) = 7.44

^{ns} not significant

Table 6. Mean Final Count of Shoot Emergence of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Replication			Total	Mean
	I	II	III		
T ₁ – Untreated	0.27	0.27	0.13	0.67	0.22
T ₂ – Azospirillum	0.33	0.00	0.53	0.86	0.29
T ₃ – Arbuscular Mycorrhizal Fungi	0.20	0.07	0.13	0.40	0.13
Grand Total				1.93	
Grand Mean					0.21

Table 6a. ANOVA for Mean Final Count of Shoot Emergence of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Source	DF	SS	MS	F	P
Treatment	2	0.03562	0.01781	0.65 ns	0.5559
Error	6	0.16480	0.02747		
Total	8	0.20042			

CV (%) = 77.28

^{ns} not significant



Table 7. Mean Final Height (cm) of Shoot Emergence of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Replication			Total	Mean
	I	II	III		
T ₁ – Untreated	0.49	3.39	1.36	5.24	1.75
T ₂ – Azospirillum	7.08	0.00	5.34	12.42	4.14
T ₃ – Arbuscular Mycorrhizal Fungi	3.39	2.02	3.29	8.70	2.90
Grand Total				26.36	
Grand Mean					2.93

Table 7a. ANOVA for Mean Final Height (cm) of Shoot Emergence of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Source	DF	SS	MS	F	P
Treatment	2	8.5958	4.29791	0.79 ns	0.4976
Error	6	32.8191	5.46984		
Total	8	41.4149			

CV (%) = 79.85

^{ns} not significant

Table 8. Mean Leaf Count of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Replication			Total	Mean
	I	II	III		
T ₁ – Untreated	0.00	0.00	0.00	0.00	0.00
T ₂ – Azospirillum	0.33	0.00	0.13	0.46	0.15
T ₃ – Arbuscular Mycorrhizal Fungi	0.20	0.07	0.13	0.40	0.13
Grand Total				0.86	
Grand Mean					0.10

Table 8a. ANOVA for Mean Leaf Count of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Source	DF	SS	MS	F	P
Treatment	2	0.04169	0.02084	1.96 ns	0.2210
Error	6	0.06373	0.01062		
Total	8	0.10542			

CV (%) = 107.86

^{ns} not significant



Table 9. Mean Biomass Weight (g) of Shoot and Developed Rhizome of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Treatments	Replication			Total	Mean
	I	II	III		
T ₁ – Untreated	2.14	2.65	1.93	6.72	2.24
T ₂ – Azospirillum	5.85	2.74	5.44	14.03	4.68
T ₃ – Arbuscular Mycorrhizal Fungi	3.98	2.39	3.97	10.34	3.45
Grand Total				31.09	
Grand Mean					3.45

Table 9a. ANOVA for Mean Biomass Weight (g) of Shoot and Developed Rhizome of Hawaiian Ginger (*Zingiber officinale*) Rhizome Treated with Various Bio-Inoculants

Source	DF	SS	MS	F	P
Treatment	2	8.9063	4.45314	3.49 ns	0.0988
Error	6	7.6591	1.27652		
Total	8	16.5654			

CV (%) = 32.71

^{ns} not significant