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Research article

Influences of *Enterobacter asburiae*, Vermicompost Rates and Irrigation Water Types on the Soil Fertility, Peanut Yield and Quality

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Abstract

The effects of vermicompost (VC) application combined with *Enterobacter asburiae* inoculation and river water irrigation significantly improved soil fertility in order to promote growth, yield and quality, and reduce arsenic uptake by peanuts, which were grown on As-contaminated soils and irrigation water. This research was conducted in Phuochung, Anphu town, Angiang province, Vietnam. The field research was performed in a 2x2x2 factorial randomized complete block design with four replications. Treatments were designed in three factors such as factor (A): VC (0.0 and 10.0 t/ha application); factor (B): *E. asburiae*, (inoculation and non-inoculation); and factor (C): irrigation water (river and deep well water), respectively. The results showed that applying 10t VC per ha combined with *E. asburiae* inoculation and non-As-contaminated water irrigation increased soil chemical properties, agronomic indicators, yield components, yield, and quality, and reduced As accumulation in peanut stems and seeds compared to control (non VC application, non *E. asburiae* inoculation, and deep well water irrigation). Moreover, the three factors, VC, *E. asburiae* inoculation and type of irrigation water, showed strong interaction among the agronomic traits, yield components, and yield of peanuts.

Keywords: arsenic; peanut; *E. asburiae*; vermicompost; deep well water; river water

1. Introduction

Peanut (*Arachis hypogaea* L.) is a key plant that provides essential nutrients for humans, contains high levels of oil, essential amino acid, and various types of vitamins (Asante et al., 2020). It is planted all over the world to be used as food for people and animals due to its high nutrient concentrations (Taru et al., 2010). Although, global peanut yield has gradually reached 1.74 tons/ha/year and is increasing by millions of tons annually worldwide (CSA, 2017). However, the peanut farmland in Phuoc Hung Commune, An Phu District, An Giang Province, Vietnam has yearly decreased due to severe land degradation and As contamination of peanut cultivation areas (Chuong, 2024a,b; Nguyen & Tri, 2024).

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Peanut productivity and nutritional attributes have been remarkably reduced by loss of soil nutrients and arsenic (As) accumulation in the soils and plants (Nguyen, 2024). Soils deficient in macronutrients and micronutrients, and soils that receive insufficient nutrient supplementation produce low peanut output and inferior quality (Nguyen et al., 2021). Nonetheless, agricultural soils lack essential nutrition, especially macronutrients (Buri et al., 2010). The highly toxic and carcinogenic properties of As can affect the living environment, agricultural practices and consumer health when farmland and irrigation water are highly contaminated with As. Exposure to low levels of As in plants can alter plant appearance, physiology and biochemistry (Abbas et al., 2018). Furthermore, consumption of agricultural products containing low As concentration over long time periods could lead to cancer (Boazar et al., 2019). Peanut productivity in Anphu district has generally been low due to poor soil fertility, and the high As content of farmland and irrigation water (Chuong et al., 2021).

The price of chemical fertilizers has been very high in recent years. Associatively, production costs have increased along with low peanut productivity, leading to a reduction of peanut farmer profits. Therefore, applying animal fertilizers with high available nutritional contents in combination with endogenous nitrogen-fixing bacterial inoculation can be an optimal technology to improve the quality and yield of peanuts (Tairo & Ndakidemi, 2013). Endogenous nitrogen-fixing bacteria, which has the potential to form nodules on groundnut roots, take nitrogen from the air and live in a symbiotic relationship with the peanut roots (Mmbaga et al., 2014). Vermicompost, which has been discovered to have a highly decomposed level from the digestive system of VC, and making it easy for plants to absorb, helped to reduce the use of inorganic fertilizers, improved soil fertility, and increased peanut yield on low nutrient soil (Aipa & Michael, 2018; Uko et al., 2018).

Co-application of VC with endogenous nitrogen-fixing bacteria has been shown to promote the available nutrients in farmland and raise the productivity of groundnut plants (Bekele et al., 2019). The addition of VC manure can reduce the As uptake of peanut plants because it can render the As immobile in the soils, making it a practicable and positive method. The association of organic manure and chemical fertilizers may immobilize As in farmland soil, raising plant output and farmland nutrition (Lwin et al., 2018; Chalwe et al., 2019). This increase in peanut output and decrement in As availability in farmland was made possible by the addition of VC to the soil, which helped improve aeration, allowing soil solution to transport nutrients better. Vermicompost also increased organic matter and nutrients in the soil, which in turn increased the number of beneficial microorganisms in the farmland including various endogenous nitrogen-fixing bacterial strains (Chuong, 2024a; Van, 2024a,b). The aim of this study was to find the benefits of the addition of VC, *Enterobacter asburiae* inoculation on the growth, output and quality of peanut plants that were planted on farmland and irrigation water of high As concentration.

2. Materials and Methods

The field research was conducted in a 2x2x2 factorial randomized complete block design (Table 1). The two aims of research were: (i) an evaluation of the N2- fixing ability of *E. asburiae*, and (ii) an evaluation of the efficiency of VC application and *E. asburiae* inoculation on As uptake and the output of peanut plants, when planted on As contaminated farmland and irrigation water (Tables 1 & 2). Study time was from May, 1st to September, 1st of 2023 at the Phuochung commune of Anphu town, Angiang province, Vietnam. Underground water was used to water the plants during the experiment.

Table 1. Kind of irrigation water* and VC rates with *E. asburiae* inoculation

Treatments	E. *asburiae* (10^8 CFU g^{-1})	Irrigation Water	Vermicompost (t ha^{-1})	Inorganic Fertilizer (kg ha^{-1})
1	Non inoculation	Deep well water	0	40N-60P-60K
2		River water		
3		Deep well water	10.0	
4		River water		
5	Inoculation	Deep well water	0	
6		River water		
7		Deep well water	10.0	
8		River water		

(*) Irrigation water**:** the deep well water had high As content; As was not detected in river water.

Table 2. Farmland water attributes before the experimental design (n=10)

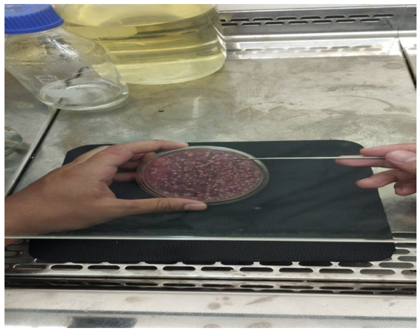
Attributes	**Results**	**Attributes**	**Results**
Total N (%)	0.120	As in soil (μg kg^{-1})	98.3
Available P (mg $100g^{-1}$)	20.10	As in river water (μg L^{-1})	undetected
Exchangeable K (mg kg^{-1})	80.1	As in deep well water (μg L^{-1})	560
pH of river water	5.7	pH_{soil}	5.4
$CaCO_3$ (%)	2.5	pH of underground water	4.7

Soil texture: silt sand

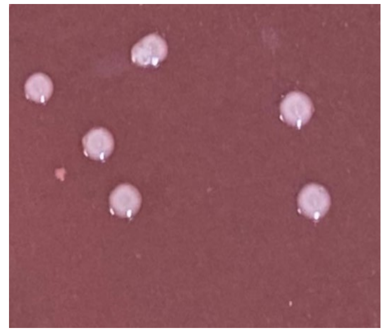
Sand (%)	Silt (%)	Clay (%)
61.0	36.0	3.0

The farmland was enclosed in a dike and the whole studied area was 640 m^2 (1 m x 20 m x 04 repeats x 08 treatments). Details of the materials used in the experiments were presented in Table 1. Soil samples were collected at 0-20 cm in depth before and after according to the experimental design. NIAST methods were used to determine all soil chemical traits (NIAST, 2000). Atomic absorption spectrophotometric was used to determine total As concentration in the soil, irrigation water and plant samples. Agronomic attributes were observed during the developmental period of groundnut plants. Productivity traits, yield and quality of peanut plants were counted at harvest. All quality properties were determined by the AOAC method. The average As content of ten underground water samples (560 μg L^{-1}) exceeded both the Vietnam and WHO standards (50 and 10 μg L^{-1}, respectively). On the contrary, As content was not detected in river water samples. Farmland samples in the study area had high levels of As (84.0 mg kg^{-1}), which exceeded the allowed standard of Vietnam (12 mg ha^{-1}) by 7 times (Table 2). The peanut seeds (SVL1) that were bought from Quangbinh Co-operation, Vietnam.

Enterobacter asburiae isolated from the peanut root and nodule that was taken local fields in Phuoc Hung commune. Pure strains were checked by biochemical attributes, and then identified by Nam Khoa Company, Vietnam. *Enterobacter asburiae* in YEMA medium showed that the 16S rRNA nucleotide sequences had 100% homology with the consultative rhizobium, based on the NCBI database (https://www.ncbi.nlm.nih.gov/genbank/) (Figure 1).



(a)



(b)

ACGCTGGCGGCAGGCCTAACACATGCAAGTCGAGCGGTAGCACAGGGAGCTTGCTCCTGGGTGACGAGCGGC
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AACGTCGCAAGACCAAAGAGGGGGACCTTCGGGCCTCTTGCCATCAGATGTGCCCAGATGGGATTAGCTAGTAG
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CACGGTCCAGACTCCTACGGGAGGCAGCAGTGGGGAATATTGCACAATGGGCGCAAGCCTGATGCAGCCATGC
CGCGTGTATGAAGAAGGCCTTCGGGTTGTAAAGTACTTTCAGCGGGGAGGAAGGCGATAAGGTTAATAACCTTG
TCGATTGACGTTACCCGCAGAAGAAGCACCGGCTAACTCCGTGCCAGCAGCCGCGGTAATACGGAGGGTGCAA
GCGTTAATCGGAATTACTGGGCGTAAAGCGCACGCAGGCGGTCTGTCAAGTCGGATGTGAAATCCCCGGGCTCA
ACCTGGGAACTGCATTCGAAACTGGCAGGCTAGAGTCTTGTAGAGGGGGGTAGAATTCCAGGTGTAGCGGTGAA
ATGCGTAGAGATCTGGAGGAATACCGGTGGCGAAGGCGGCCCCCTGGACAAAGACTGACGCTCAGGTGCGAAA
GCGTGGGGAGCAAACAGGATTAGATACCCTGGTAGTCCACGCCGTAAACGATGTCGACTTGGAGGTTGTGCCCT
TGAGGCGTGGCTTCCGGAGCTAACGCGTTAAGTCGACCGCCTGGGGAGTACGGCCGCAAGGTTAAAACTCAAAT
GAATTGACGGGGGCCCGCACAAGCGGTGGAGCATGTGGTTTAATTCGATGCAACGCGAAGAACCTTACCTACTC
TTGACATCCAGAGAACTTTCCAGAGATGGATTGGTGCCTTCGGGAACTCTGAGACAGGTGCTGCATGGCTGTCG
TCAGCTCGTGTTGTGAAATGTTGGGTTAAGTCCCGCAACGAGCGCAACCCTTATCCTTTGTTGCCAGCGGTCCGG
CCGGGAACTCAAAGGAGACTGCCAGTGATAAACTGGAGGAAGGTGGGGATGACGTCAAGTCATCATGGCCCTTA
CGAGTAGGGCTACACACGTGCTACAATGGCGCATACAAAGAGAAGCGACCTCGCGAGAGCAAGCGGACCTCATA
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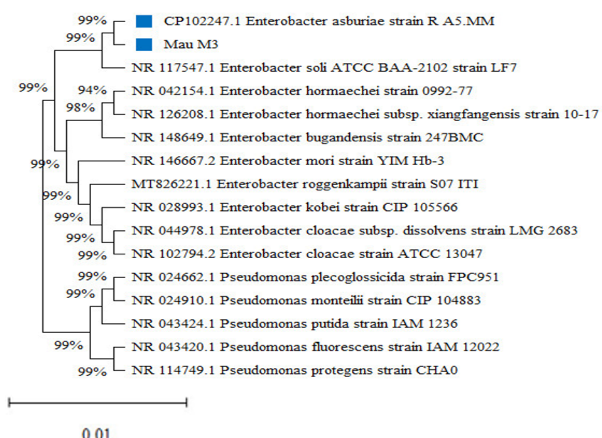

(c)

Figure 1. (a) Colony morphology of *E. asburiae* on YEMA medium*;* b) Pure colony of *E. asburiae;* c) *E. asburiae* 16S ribosomal RNA gene, partial sequence; Chloroplast; and large subunit ribosomal RNA gene, partial sequence (99,63% similarly); *(*d*):* Phylogenetic tree of partial 16S rRNA sequences of *E. asburiae* species isolated from peanut nodules along with the sequences from selected references strains. The tree was constructed by the neighbor-joining method using MEGA 11. The scale bar corresponded to 0.01 substitutions per nucleotide position. Numbers on the branches were bootstrap percentages. GenBank accession numbers were shown above.

The experimental data were statistically analyzed for significant differences at *P<0.05* and *P<0.01*. The analysis of variance was performed using Statgraphics Centurion XV software.

3. Results and Discussion

3.1 The impact of *E. asburiae*, VC, and irrigation water on farmland chemical traits

The results in Table 3 of this study showed that applying 10 tons of VC per ha had a highly significant effect (P <0.01) on soil pH, cation exchange capacity (CEC), soil organic matter (SOM), total N and available P. The chemical values of the soil for the 10 t VC/ha treatments were all higher than the control treatments. Similarly, *E. asburiae* inoculant increased in all soil nutrient attributes at harvest compared to non-bacterial inoculation (except for total N) and the differences were significant (P<0.01). When considering the type of irrigation water, the usage of As-contaminated deep well water for peanuts resulted in lower nutrient levels in the soil than river water irrigation, and the results were statistically significant (P<0.01). Meanwhile, factors such as VC application, *E. asburiae* inoculant and type of irrigation water had a very large interaction between them (except for factor B, there is no interaction between the inoculation and the non-inoculation of *E. asburiae* species in the % total N). Furthermore, the amount of total nitrogen was insignificantly different between the VC application and *E. asburiae* inoculation (Table 3).

Table 3. Farmland traits at harvest

Factors	pH	CEC (cmol$^+$/kg)	SOM (%)	Total N (%)	P (mg/100g)
Vermicompost (A)					
0.0 t/ha	5.14^b	6.09^b	1.18^b	0.09^b	20.8^b
10 t/ha	5.90^a	6.61^a	2.10^a	0.14^a	32.9^a
E. *asburiae* (B)					
Inoculation	5.24^b	7.56^a	1.59^a	0.11	29.60^a
Non inoculation	6.00^a	5.05^b	1.50^b	0.10	25.90^b
Irrigation water (C)					
Deep well water	5.34^b	5.23^c	1.99^b	0.08^b	30.50^b
River water	6.10^a	7.98^a	2.21^a	0.18^a	35.20^a
F (A)	**	**	**	**	**
F (B)	**	**	**	ns	**
F (C)	**	**	**	**	**
F (AxB)	**	**	**	ns	**
F (AxC)	**	**	**	**	**
F (BxC)	**	**	**	**	**
F(AxBxC)	**	**	**	**	**
CV (%)	11.80	11.10	12.50	23.0	11.60

ns: insignificant difference; **: significant difference at *LSD* ≤ 0.01

The results of Table 3 show that soil pH values ranged from 5.14 to 6.10 over the three factors (VC, *E. asburiae*, and irrigation water) after the experiment. The pH values in the experiments with 10 t of VC, *E. asburiae* inoculation, and river water irrigation were all higher than others. Similarly, the values of the CEC, SOM, total nitrogen, and available phosphorus in the experiments with 10 t VC/ha, *E. asburiae* inoculation, and river water irrigation were all higher than the treatments without VC application, without *E. asburiae* inoculation, and with As-contaminated deep well water irrigation. However, the value of total nitrogen was not statistically different between no *E. asburiae* inoculation and *E. asburiae* inoculation. In this study, the VC application (factor A), *E. asburiae* inoculation (factor B), and irrigation water type (factor C) had a highly remarkable impact ($P < 0.01$) on the farmland components, and the interaction among factors also had a significant impact ($P < 0.01$).

Previous research showed that pH, chemical attributes, and nutrients of soil could increase after application of organic fertilizer and lime. However, irrigating with arsenic-contaminated water decreased soil pH after the experiment, due to the number of H^+ ions added to the agricultural soil from arsenic-contaminated water, which released H^+ in the soil from soil acids into a free form (Cuong & Chuong, 2022). A previous study by Islam et al. (2021) showed an increase in soil pH when applying organic manures combined with chemical fertilizers compared to control.

3.2 Peanut agronomy traits

Plant height at 20, 45, and 65 DAS is an important indicator for evaluating peanut plant development. Plant height is also an indicator of the efficient usage of soil nutrients, and exploitation of environmental resources. The individual effects of VC application, *E. asburiae* inoculation, and irrigation water type on plant height at the three-time stages were significantly different at the 1% level, while their interactions were not statistically significant for this trait (except for the interaction between VC (A) and irrigation water (C) at the 45 and 65 DAS stages at the 1% level). The plant height values of three-time stages (20, 45 and 65 DAS) in the experiments with 10 t VC/ha, *E. asburiae* inoculation, and river water irrigation were all higher than other treatments (Table 4). This suggests that the combination of VC application with *E. asburiae* inoculation and water irrigation with non-As-contaminated water helped plants grow taller than those without VC application, without *E. asburiae* inoculation, and As-contaminated water irrigation (Nguyen, 2023; Nguyen & Tri, 2024).

The numbers of branches at the 20, 45 and 65 DAS stages ($P<0.01$) were statistically different between treatments for factor A (VC: Vermicompost) and factor B (*E. asburiae*). However, at the 45 and 65 DAS stages, there was no significant difference at the 1% level for irrigation water type (except 20 DAS). Irrigation with non-As-contaminated water, VC application and *E. asburiae* inoculation resulted in more branches than the control treatment of non VC application, non *E. asburiae* strains, and irrigation with As-contaminated water. As per the results in Table 5, there was significant interaction between three factors (VC, *E. asburiae* and irrigation water) during 20, 45, and 65 DAS at the 1% level (except for the interaction between VC and irrigation water (AxC)). Organic manure, nitrogen-fixing bacteria, and non-contaminated irrigation water helped peanut plants produce more buds, which created leaves and flowers. The buds grow into the ground to form pods, so if a plant has many branches, it will produce more pods and flowers (Craufurd et al., 2006).

Table 4. Impact of VC, *E. asburiae* and irrigation water on peanut plant height at harvest

Factor	Height of Peanut Plant (cm)		
	20 DAS	45 DAS	65 DAS
Vermicompost (A)			
0.0 t/ha	11.10^{b}	20.40^{b}	49.30^{b}
10 t/ha	12.70^{a}	22.80^{a}	53.20^{a}
***E. asburiae* (B)**			
Inoculation	13.0^{a}	23.10^{a}	53.70^{a}
Non inoculation	10.60^{b}	19.60^{b}	48.40^{b}
Irrigation water (C)			
Deep well water	9.90^{b}	18.60^{b}	46.70^{b}
River water	12.40^{a}	22.10^{a}	51.90^{a}
F (A)	**	**	**
F (B)	**	**	**
F(C)	**	**	**
F (AxB)	ns	ns	ns
F (AxC)	ns	**	**
F (BxC)	ns	ns	ns
F (AxBxC)	ns	ns	ns
CV (%)	16.70	14.70	12.20

DAS: days after sowing; **: significant difference at *LSD* ≤ 0.01

Table 5. Effects of VC, *E. asburiae* and irrigation water on groundnut branches at harvest

Factors	Branches per Plant		
	20 DAS	45 DAS	65 DAS
Vermicompost (A)			
0.0 t/ha	3.75^{b}	4.50^{b}	5.12^{b}
10 t/ha	3.86^{a}	5.75^{a}	6.25^{a}
E. *asburiae* (B)			
Inoculation	3.67^{a}	5.50^{a}	6.50^{a}
Non inoculation	3.50^{b}	4.75^{b}	5.50^{b}
Irrigation water (C)			
Deep well water	3.50^{b}	5.13	5.88
River water	3.80^{a}	5.13	5.88
F (A)	**	**	**
F (B)	**	**	**
F(C)	**	ns	ns
F (AxB)	**	**	**
F (AxC)	ns	ns	ns
F (BxC)	**	**	**
F (AxBxC)	**	**	**
CV (%)	16.70	14.70	12.20

ns: no significant difference **: significant differences at $p < 0.01$

3.3 Peanut yield components

Peanut biomass was affected by the application of VC and *E. asburiae* at the 1% level (except irrigation water) (Table 6). All treatments of VC application combined with *E. asburiae* inoculant had higher peanut biomass than the control treatments (except for the river water and well water treatments). The interaction of the experimental factors on peanut biomass was significantly different at the 1% level (except for *E. asburiae* and irrigation water). The *E. asburiae* inoculation had the highest biomass (296 g plant^{-1}) and the treatment with only applied NPK and the treatment with As-contaminated irrigation had the lowest biomass value (244 g plant^{-1}) (Table 6). These results in Table 5 may be attributed to the positive relationship between VC application, *E. asburiae* inoculation and river irrigation with farmland nutrient addition (Mathenge et al., 2019). The groundnut biomass increased remarkably when applying organic fertilizers associated with N_2 fixing bacterial inoculation (Jain et al., 2017).

The number and weight of full beans and nodules across the three factors, which consisted of A: Vermicompost; B: *E. asburiae* and C: irrigation water, were significantly different among treatments at the 1% level. The interaction among the three factors were also significant different at 1%, (excepted the interaction between VC application and irrigation water at number and weight of peanut nodules). However, for weight of 1,000 seeds, there was significant difference at the 1% level for VC application, bacterium and irrigation water type. Irrigation with non-As-contaminated water, VC application and *E. asburiae* inoculation resulted in higher weight of 1,000 seeds than the control treatment of non VC application, non *E. asburiae* bacterium and irrigation with As-contaminated water. For the results in Table 6, there was significant interaction between the three factors (VC, *E. asburiae* and irrigation water) at harvest at the 1% level. In prior research, Vadthe & Umesha (2022) presented that applying a lot of organic manure combined with bio-fertilizer increased the yield components and yield of peanut. In our research, the results indicated that all traits of peanut yield components were higher than those without VC and *E. asburiae* application. The application of VC and/or *E. asburiae* inoculation had higher weight of 1,000 peanut seeds than the control (Gomoung et al., 2017).

3.4 Quality and yield components of peanut

The results showed that different VC rates had a significant effect on the moisture percentage of peanut seeds (Table 7). The treatment with VC application (32%) gave a higher moisture than that without VC application (30%), and the *E. asburiae* inoculation (32.8 %) provided higher moisture than non *E. asburiae* inoculation (29.2%). Similarly, the seed moisture percentage of treatment with deep well irrigation water (30%) was lower than treatment with river water irrigation (32.1%). There were significant differences among treatments at the 1% level for the three factors, and their interactions were not significant different.

The VC application impact of 10 t/ha recorded the higher lipid concentration of 25.9% compared to the lipid content of non VC application, which was 25.3% and the significant difference at the 1% level. The average lipid content of peanut was not significantly different between uninoculated and inoculated *E. asburiae* treatments. However, the peanut lipid content that was obtained with treatment of river irrigation was higher than the lipid values of deep well water irrigated peanut. The interactions of A×B, AxC, BxC and AxBxC were insignificantly different for peanut seed lipids (Table 7). The

Table 6. Effect of VC, *E. asburiae* and irrigation water on the yield attributes at harvest

Factors	Biomass (g plant-1)	No. of Fill Beans (plant)	Wt. of Fill Beans (g plant-1)	No. of Nodules	Wt. of Nodules (g plant^{-1})	Wt. of 1,000 seeds (g)
Vermicompost (A)						
0.0 t/ha	244^{b}	63.80^{b}	158^{b}	235^{a}	0.96^{b}	860^{b}
10 t/ha	282^{a}	78.30^{a}	176^{a}	175^{b}	1.27^{a}	1,050^{a}
***E. asburiae* (B)**						
Inoculation	296^{a}	80.80^{a}	175^{a}	257^{a}	1.39^{a}	1,050^{a}
Non inoculation	228^{b}	64.90^{b}	135^{b}	155^{b}	1.22^{b}	840^{b}
Irrigation water (C)						
Deep well water	244	78.3	131^{b}	181^{b}	0.90^{b}	870^{b}
River water	260	76.5	171^{a}	307^{a}	1.70^{a}	925^{a}
F (A)	**	**	**	**	**	**
F (B)	**	**	**	**	**	**
F(C)	ns	ns	**	**	**	**
F (AxB)	**	**	**	**	**	**
F (AxC)	**	**	**	ns	ns	**
F (BxC)	ns	**	**	**	**	**
F (AxBxC)	**	**	**	**	**	**
CV (%)	12.50	20.60	21.90	11.60	18.60	21.90

ns: no significant difference (p>0.05) **: P< 0.01

interactions among the three factors were not significant different (except for F(BxC), which was different at the 1% level). The different impacts were not significantly different for percent of groundnut seed protein for two factors (except factor C). The protein content of peanut seeds grown with deep well water irrigation (15.2%) was statistically lower compared to river water irrigation (19.1%) at 1% level (Table 7).

Legumes such as peanut (*Arachis hypogaea* L.) can meet almost all of their N_2 demand through a symbiotic relationship with N_2-fixing microorganisms. The availability of nutrients is largely determined by the diversity of microbial sources and their activities in the peanut roots that impact plant development, quality, and plant output, all of which affect farmland nutrient and fertility. Peanuts could meet most of their nitrogen requirements through symbiosis with N-fixing bacteria and endophytic bacteria. The nutritional value is mainly determined by the diversity and activity of microorganisms in the rhizosphere, affecting the health, nutrition, and yield of peanuts, as well as soil quality and fertility. However, in-depth research concerning the effects of the yield of different peanut varieties in integrated farming systems, combined with organic fertilizer, in comparison to conventional farming systems is still needed (Gresshoff & Ferguson, 2017; Fess & Benedito, 2018; Paudel et al., 2023). There is a significant two-way interaction between farming type and factors such as earthworm fertilizer, nitrogen-fixing bacteria strains, and water for irrigation that was not contaminated with heavy metals, which had beneficial effects on the quality and yield of peanut plants (Paudel et al., 2023).

Table 7. Effect of VC, *E. asburiae* and irrigation water on the yield and quality at harvest

Factor	Seed Moisture Contents (%)	Lipid Contents (%)	Protein (%)	Seed Yield (t ha^{-1})	As Contents (µg kg-1)	
					Stems	Seeds
Vermicompost (A)						
0.0 t/ha	30.0[b]	25.30[b]	17.30	6.53[b]	1,064[a]	116[a]
10 t/ha	32.0[a]	25.90[a]	17.30	7.34[a]	958[b]	101[b]
***E. asburiae* (B)**						
Inoculation	32.80[a]	25.80	17.30	7.47[a]	944[b]	99.5[b]
Non inoculation	29.20[b]	25.40	17.40	6.40[b]	1,077[a]	118[a]
Irrigation water (C)						
Deep well water	30.00[b]	23.50[b]	15.20[b]	6.03[b]	1,260[a]	128[a]
River water	32.10[a]	27.70[a]	19.10[a]	7.87[a]	766[b]	89.3[b]
F (A)	**	**	ns	**	**	**
F (B)	**	ns	ns	**	**	**
F(C)	**	**	**	**	**	**
F (AxB)	ns	ns	ns	ns	ns	**
F (AxC)	ns	ns	ns	ns	ns	**
F (BxC)	ns	ns	**	ns	ns	**
F (AxBxC)	ns	ns	ns	ns	ns	**
CV (%)	12.50	20.60	21.90	11.60	18.60	21.90

ns: no significant statistical difference (p>0.05); ***: P < 0.01*

Peanut fresh seed yields across the three factors ranged from 6.03 to 7.87 t ha^{-1}. The highest productivity of fresh peanut seeds was 7.87 t/ha for the treatments with river water irrigation, and the lowest fresh yield of peanut seeds (6.03 t ha^{-1}) was seen for the treatment with deep well water. The fresh seed yields of the 10 t VC/ha application, *E. asburiae* inoculation and river water irrigation were higher than treatments of non VC application, non *E. asburiae* inoculation and deep well water irrigation, and the differences were significant at 1%. However, the interaction of the experimental factors on peanut yield was insignificant at the 5% level (Table 7). There were significant negative correlations between the number of shoots, root biomass, and nodule number with some other parameters, especially without organic fertilizers, non-nitrogen-fixing bacterial strains, and irrigation water contaminated with heavy metals. These negative relationships led to decrease peanut biomass in conventionally cultivated fields. However, inorganic fertilizer application and organic fertilizer amendment associated with N_2-fixing bacteria, and non-contaminated water irrigation, raised biomass of peanuts, possibly due to the application of inorganic fertilizers, which raised the level of readily available nutrition to the plants. Studies on other crops have shown that the use of chemical fertilizers combined with organic fertilizers contributed significantly to increase crop yield and quality (Howieson & Dilworth, 2016; Chuong, 2024b).

The results in Table 7 showed that application of 10 t VC per ha had a remarkable impact (p <0.01) on As uptake of peanut stems and seeds. The stem and seed As concentration of peanut in treatment of 10 t VC ha^{-1} application was lower than the control treatments (without VC application). Similarly, the use of *E. asburiae* inoculant significantly decreased peanut stems and seeds at harvest compared to the non-bacterial inoculation ($P<0.01$). When considering the type of irrigation water, the usage of As-contaminated deep well water for peanuts resulted in higher As accumulation in peanut stems and seeds than those of irrigation with river water, and the results were significantly different ($P<0.01$). Meanwhile, the interaction of all factors such VC application, *E. asburiae* inoculant and type of irrigation water did not have a significant effect on As accumulation in peanut stems. However, the interactions of A×B, AxC, BxC and AxBxC were significantly different in the As content of peanut seeds (Table 7).

The total As content in soil decreased significantly when using animal manures, mainly thanks to the lower As concentration in these manures than in the soil. Long term usage of clean organic fertilizer may reduce the risk of As pollution of farmland-crop systems (Wang et al., 2021). The role of *E. asburiae* in the uptake and accumulation of As in plants has not been well studied. Therefore, recent research on the ABA synthesis pathway and comparative analysis of the physiological and molecular mechanisms involved in the uptake, translocation, and detoxification of As in plants at different ABA concentrations or between different species have been carried out. These results have led to the development of methods for controlling the uptake and accumulation of As in plant tissues by the use of *E. asburiae* inoculation in peanut cultivation (Chuong & Tri, 2024).

4. Conclusions

The results in this study proved that the application of 10 t VC/ha in combination with *E. asburiae* inoculant, and river water irrigation (not polluted with As) had a very positive impact on the soil fertility, agronomic attributes, yield components, quality, and As accumulation in peanut stems and seeds. The application of VC, *E. asburiae* inoculant, and river water irrigation increased peanut yields by 11.0, 14.3, and 23.4%, respectively, compared with the control. In particular, As accumulation in the stems and seeds decreased by 11.0, 12.9, 23.4%, and 12.9, 15.7, and 30.2%, respectively, compared to no VC application, no *E. asburiae* inoculant, and As-contaminated water irrigation. From the above results, the application of VC, and *E. asburiae* inoculant, combined with non-As-contaminated irrigation, could lead to higher yields and lower As uptake in peanuts

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6. Conflicts of Interest

The author declares that there are no conflicts of interest regarding the publication of this paper.

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