

Reducing Arsenic Absorption of Corn (*Zea mays* L.) and Its Content in Soil by Lime and Ferns (*Pteris vittata*)

Nguyen Van Chuong^{1*}, Le Tan Trung²

¹Department of Crop Science, Faculty of Agricultural, An Giang University, Vietnam

²Loc Troi Group Joint - Stock Company, Vietnam

^{1*}Corresponding author: Nguyen Van Chuong; nvchuong@agu.edu.vn

ABSTRACT

The aim. This study aimed to find out effects of liming and fern on reducing the absorption of arsenic (As) on maize and As content in the soil. Materials and methods. The single-factor experiment was designed in a completely random block (4 treatments and 4 replicates). Treatments were followed: treatment 1 (NT1) liming (3 tons CaO ha⁻¹); NT2: Plant ferns alternately with maize (Without liming); NT3: Plant ferns alternately with maize and liming (3 tons CaO.ha⁻¹); NT4-Control (no liming and ferns). Results. The co-application of liming and ferns had positive influences on chemical properties of soil and yield of corns tested in this study. The yield difference between the application of lime and intercropped ferns was increased from 5.4 to 22.3 %. Moreover, arsenic concentrations of soil, trunks, and grains were 25.7, 32.0, and 50 % lower than that of the control, respectively. Conclusions. Ferns absorbed As content from soil to stems and roots, which decreased a large amount of As content in soils. Therefore, to reduce production cost, increase soil and maize quality, application of lime (3 ton ha⁻¹) and intercropped ferns is recommended.

Keywords:

Arsenic, chemical properties of soil, fern, liming, maize

1. Introduction

Corn (*Zea mays* L.), which has widely planted in Asian countries are the main food for humans (Rosas et al., 2014). According to Liu et al., (2018); Zhao et al., (2018) showed that As uptake of stems and seeds of maize when grown in As contaminated soil. Former studies also reported that corn option of As-resistant varieties, which will reduce As uptake of stems and seeds of maize (Fu et al., 2016). The maize, which is a plant that accumulates high As toxicity planted on As contaminated soil (Ruíz-Huerta et al., 2017). The As content of corn seeds that exceeds safe limits could be the danger to human health. (Ali et al., 2013). The lime combined with Ferns are the best way to reduce As content of soil and its uptake by maize (Requejo & Tena, 2012). The fern (*Pteris vittata*), which grows on As-contaminated soils absorbs the high As content on its roots and stems (Zeng et al., 2019). Growing ferns to treat As contaminated soils has been a good way to reduce As concentration of soils and plants (Zeng et al., 2019; Sun et al., 2015).

Application of lime combined with fertilizers, which increased soil pH and As precipitation is a good method in agricultural production (Xiao et al., 2009; Bolan & Duraisamy, 2015). The immovement and decrease of As element in soil was applied by lime and ferns, which increased yield of crops and reduced As contents of stems and grains of soybean (Moon et al., 2014, Cu et al., 2014; Chuong & Chinh, 2018; Chuong, N.V. and Hung, N.N., 2015). **The main aim.** This experiment aimed to investigate the effects of lime fertilization combined to plant ferns on arsenic and improve the quality of crop soil.

2. Materials and methods

Study area and study species: The field experiment was conducted at An Phu district, An Giang province. During December 2018 to April 2019. Treatments was applied with NPK fertilizer of (40kg N- 60kg P₂O₅- 350kg K₂O ha⁻¹). Maize (NK 4300) were used in field experiment.

Study design and data collection: The field study was carried out in the field at areas inside the dike with 4 treatments (NT): NT1: lime (3 tons CaO ha⁻¹); NT2: Plant ferns alternately with maize (Without lime); NT3: Plant ferns alternately with maize and lime (3 tons CaO ha⁻¹); NT4-Control (no lime and ferns). The fields were ploughed and split into sixteen plots. The deep well water was irrigated for crops x 2 doses of lime (5 tons.ha⁻¹) and ferns, with an area of each replicate of being equivalent to 24 m² (6m x 4m), planted in a single row with a distance of 50 cm x 30 cm (three seeds.hole⁻¹). Ferns are planted between maize plants in NT2 and NT3. The distance between plants is 30 cm and the row is 50 cm. The biomass of the maize plants was harvested after 10 weeks.

Data and statistical analysis: All soil and plant samples, which were were digested by nitric and perchloric acids were dried at room temperature. The digests were analyzed for As with plasma atomic emission spectrometer. Chemical and physical properties of Soil samples was analyzed by procedure of Walkley and Black (1934) at the center laboratory of An Giang University. Data was analyzed in variance and tested DUNCAN at the 5% significance level to compare the differences between the treatments using the program SPSS Statistics 22. Using Excel software to process the average data and draw the graph.

Results and discussion

Total Arsenic: The As content of inside the dike (32.4 mg kg⁻¹) was higher than outside the dike (13.8mg.kg⁻¹). Arsenic contents of soils in outside and inside the dike that was very high exceeded As concentration in agricultural of 12 mg.kg⁻¹. Especially, the deep well water contained the high As concentration (540 µg L⁻¹), which exceeded the allowed standard of Vietnam (50 µg L⁻¹) and world (10 µg.L⁻¹). Farms inside the dike were irrigated by deep well water because because their fields are so far from the river that has used deep well water to to irrigate.

Table 1.soil characteristics before the experiment (0-20 cm)

Soil analysis	Characteristics	Results
Mechanical analysis (%)	Clay	36.5
	Silt	60.7
	Sand	2.84
	Total P (%)	0.11
Available nutrients	Available P (mg kg ⁻¹)	16.0
	Total N(%)	0.150
	Available K(mg kg ⁻¹)	650
As (mg kg ⁻¹)	Inside the dike	32.4
	Outside the dike	13.8
As (µg L ⁻¹)	Deep well water to irrigate	540

Soil pH:the results of soil pH was insignificant difference before the experiment (Table 2). However, there were significant differences at 1% ($P_{value} = .01$) among treatments. The highest pH value had at NT1 and NT3. This could be due to the fact that the soil of the experimental site had a relatively high buffering capacity based on its high carbonate content (3 tons CaO ha⁻¹) and

intercropped ferns. Some studies were found that As accumulation by *Pityrogramma calomelanos* was optimum in the soil of pH 3.6 (Anh et al., 2013). Nevertheless, the results of this study demonstrate that remediation of As-contaminated mining soils, by this fern, can be improved by changing the soil pH from 4.6 to 6.8 (Zeng et al., 2019).

Total Soluble Salts (EC): Effects of conventional intercropped practices of ferns and maizes and lime incorporation on EC of soil at depths 0-20 cm is shown in Table 2. The EC of soil pre-treatments was from 210 to 230 $\mu\text{S}\cdot\text{cm}^{-1}$ at treatments. However, insignificant differences of treatments used before the experiment. On the contrary, results of all treatments in the end of crop were significant differences ($P=.001$). Furthermore, maximum EC of soil was obtained towards NT3 (287 $\mu\text{S}\cdot\text{cm}^{-1}$), while minimum towards NT4 (188 $\mu\text{S}\cdot\text{cm}^{-1}$) as compared with other treatments. However, EC of soil was significantly affected by intercropped practices between ferns and maizes with applied incorporation with lime.

Table 2. pH, EC and OM in Soil depth (0-20 cm)

Treatment	pH		EC ($\mu\text{S}\cdot\text{cm}^{-1}$)		OM (%)	
	first	end	first	end	first	end
NT1 (3 tons CaO ha ⁻¹)	6.30	6.90 ^c	210	228 ^b	0.856	1.20 ^b
NT2 (fern alternately with maize)	6.31	6.40 ^b	213	242 ^c	0.855	1.34 ^c
NT3 (3 tons CaO ha ⁻¹ + fern)	6.28	7.02 ^c	220	287 ^d	0.857	1.45 ^d
NT4 (Control)	6.33	6.05 ^a	230	188 ^a	0.854	1.17 ^a
F	ns	**	ns	**	ns	**
CV%	0.60	6.51	7.8	15.7	0.97	12.0

** Significant at $P = 0.01$; * at $P = 0.05$ and ns = insignificant

Total Organic Matter (O.M.): OM values of soil, which were shown in Table 2 were insignificant differences before the experiment. On the contrary, results of OM were significantly different at the end of the experiment ($P= .01$). The maximum content of soil organic matter (1.45%) was reached by NT3 and NT1 treatment had the minimum content (1.17%) (Table 2). The soil organic matter of the end of the experiment increased from 27.0% to 40.9% compared to the treatments of the first of the experiment. Ferns is an important role on humus in the soil. They not only increase soil fertility but also improve properties of soil humus (Cu et al., 2014).

The results presented in Fig. 1 showed that As concentrations of all treatments in the soil before the experiment were significantly different ($P= .05$). the highest As concentration in soils before the experiment was 32.9 $\text{mg}\cdot\text{kg}^{-1}$ and the lowest is 32.5 $\text{mg}\cdot\text{kg}^{-1}$. Thereby, the source of cultivated land in An Phu district is seriously infected by As. In addition, the As content in the soil after the experiment had a statistically significant difference at 1%, the highest value of 46.4 $\text{mg}\cdot\text{kg}^{-1}$ in treatment 1 and the lowest was the treatment 2 (27.1 $\text{mg}\cdot\text{kg}^{-1}$), the treatment 4 achieved 36.5 $\text{mg}\cdot\text{kg}^{-1}$, the treatment of ferns combined liming achieved 28.2 $\text{mg}\cdot\text{kg}^{-1}$. This is explained by the fact that in the lime treatments, it reduced the uptake of As in the stems and seeds of maize plants, so As was retained more in the soil than in the control treatments. Therefore As in soils in the control treatments are absorbed by stems and seeds of mungbeans (Chuong & Chinh, 2018). On the other hand, treatments that intercropped ferns with maize, contained lower As concentration than others because ferns absorbed As by its shoots, stems and leaves (Cu et al., 2014). This shows that the soil here is seriously contaminated with As because local farmers used deep well water to irrigate for their crops. The As content of the soil exceeds allowed levels in agricultural

soil of 12 mg kg⁻¹. From there, liming combined with planing ferns effectively reduces As content in soil and accumulated in the plant.

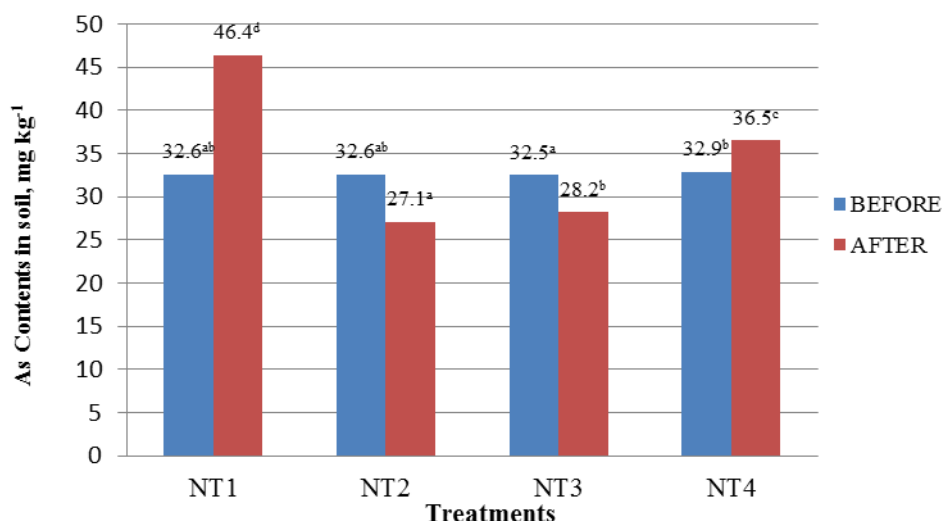


Fig.1 Arsenic contents in soil before and after the experiment

Plant height of maize: Plant height after 20, 45, and 65 DAS were no significant differences among treatments, but the harvesting crop under treatments were significant differences at 1% (Table 4). The plant height (269 cm), which was reached at NT3 was the maximum value. Opposite, the lowest plant height (237 cm) was observed towards NT4 (Control treatment). The following values were NT1 (251 cm) and NT2 (247 cm). the plant height is a genetic trait that is altered by factors such as moisture and nutrient availability at active growth stages. Effects of lime and ferns co-application showed that plant height was affected significantly ($P < 0.01$).

Table 3. Effect of liming and ferns on plant height of maize

Treatments	Plant height (cm)			
	20 DAS	45 DAS	65 DAS	Harvest
NT1 (3 tons CaO ha ⁻¹)	66.3	186	217	251 ^c
NT2 (fern alternately with maize)	66.8	185	219	247 ^b
NT3 (3 tons CaO ha ⁻¹ + fern)	66.6	191	222	269 ^d
NT4 (Control)	66.3	185	219	237 ^a
F	ns	ns	ns	**
CV%	1.63	2.28	0,94	4.78

*DAS: days after seewig; ** Significant at $P = 0.01$; ns = insignificant

Plant biomass of maize: Results of plant biomass after the harvesting crop were reached the maximum weight of maize plant (17.7 ton ha⁻¹) was reached towards NT3, while the lowest weight (15.0 ton ha⁻¹) was NT4. The following values were NT1 (17.1 ton ha⁻¹) and NT2 (16.7 ton ha⁻¹). Plant biomass is essentially a genetic trait that is altered by factors such as moisture and nutrient availability at active growth stages. Results related to plant biomass at harvest affected by lime and fertilizer of the fern showed that plant biomass was significantly affected ($P < 0.01$).

Weight of thousand grains:Weight of thousand grains ranged from 320g to 258g per plant .The highest weight of thousandgrains (320g) was reached at the 3 tons CaO ha⁻¹ + fern treatment (NT3), and the lowest value of thousand grains (258 g) at the control treatment (Table 4). The following high weights were at the 3 tons CaO ha⁻¹ treatment (NT2-313 g) and fern alternately with maize treatment (NT2-301g). The yield of a crop depends on the total grain weight per the plant. So that, thousand-grain weight of a plant is an important role for increasing or reducing the yield of crops. The amended application of 3 tons CaO ha⁻¹ and fern had the good result of the thousand grain weight, whereas the lowest weight per the plant was at the control treatment. Impacts on thousand grain weight were found significantly. Application of lime combined with ferns reduced the soil As toxic for plant growth, healthy root, and increaing yield.

Grains per plant. The highest number of grains (487 and 482) that was observed towards NT3 and NT1, respectively, was insignificant differences while the minimum (350) were observed towards NT4. However, treatments NT2 was observed as 367. The results showed that the conventional lime application with intercropped fern at As contents of contaminated soil significantly different from the grains per plant. The interactive effects of lime and fern on grains per plant were found significant at 1%(Table 4) .

Table 4. yield and its components of maize after the harverst

Treatments	Plant biomass (ton ha ⁻¹)	Weight thousand grains (g)	of Grains plant ⁻¹ (g)	Total yield (ton ha ⁻¹)	grain
NT1 (3 tons CaO ha ⁻¹)	17.1 ^c	313 ^{ab}	482 ^c	10.8 ^c	
NT2 (fern alternately with maize)	16.7 ^b	301 ^b	367 ^b	9.20 ^b	
NT3 (3 tons CaO ha ⁻¹ + fern)	17.7 ^d	320 ^c	487 ^c	11.2 ^d	
NT4 (Control)	15.0 ^a	258 ^a	350 ^a	8.70 ^a	
F	**	**	**	**	
CV(%)	6.26	8.76	15.5	11.0	

** Significant at P = 0.01

Total grain yield: The enhancement of the As contaminated soil environment by lime application with intercropped fern in significantly higher grain yields compared with the other treatments. The results of Table 4 were showed the total grain yield of NT3 treatment that reached (11.2 ton per ha) was obtained, the lowest value (8.7 ton ha⁻¹) was towards NT4. From the above results, application of lime (3ton ha⁻¹) combined with ferns. According to Chuong & Hung, (2015) was proved that application of lime amendment combined inorganic fertilizer, which increased the yield and its growth of maize.

Arsenic contents:The amendedapplication of lime and intercropped ferns, which contained the lower percentage of As contents in stems and grains of maize were significantly than the control treatment (Table 5). The maximum As conten of maize was 180 µg kg⁻¹ in grains and 385 µg kg⁻¹ in stems in the control treatment. Contrary to the result of the control treament, the minimum As concentration (90.1 µg kg⁻¹ in seeds and 262 µg kg⁻¹ in stems) was observed towards NT3. However, the treatment NT1 and NT2 were observed as 108 µg kg⁻¹, 120 µg kg⁻¹ in seeds and 288 µg kg⁻¹ 355 µg kg⁻¹ in stems, respectively (Table 5). Growing ferns on As contaminated soil has really been a treatable method of heavy metal pollution in soil with plants (Ding et al., 2011; Jankong, and Khokiattiwong, 2007). The fern is a tree that As super-accumulations in the polluted environment, harvesting biomass and dewatering is a biological safe treatment (Zeng et

al., 2019, Binessi et al., 2019). The As concentration of stems, roots (237 and 65.9 mg kg⁻¹), and (221 and 65.9 mg kg⁻¹) was had towards NT3 and NT2, respectively. The prior study of Zeng et al., (2019) show that it would take eight years of using ferns (*P. vittata*) for reducing As contents of soils to a safe level.

Table 5. Effect of lime and ferns on Arsenic concentrations of maize and ferns

Treatments	Arsenic concentrations in plants			
	Fern (mg kg ⁻¹)		Maize (µg kg ⁻¹)	
	Stems	Roots	Stems	seeds
NT1 (3 tons CaO ha ⁻¹)	-	-	288 ^a	108 ^b
NT2 (fern alternately with maize)	237	65.9	355 ^b	120 ^c
NT3 (3 tons CaO ha ⁻¹ + fern)	221	44.1	262 ^a	90.1 ^a
NT4 (Control)	-	-	385 ^c	180 ^d
F			**	**
CV(%)			15.4	25.3

** Significant at P = 0.01

3. Conclusions

Application of lime and ferns, which had positive influences on chemical properties of the soil increased yield and yield components of the maize. The yield difference between the application of lime and intercropped ferns was marginal. Moreover, the arsenic contents in soil, stems, and seeds were lower than that of the control. Ferns that absorbed As from soil to stems and root, decreased a large amount of As content in soils. Therefore, to reduce production cost, increase soil and maize quality, application of lime (3 ton ha⁻¹) and intercropped ferns is recommended

References

- [1] Ali, H., Khan, E., and Sajad, M.A., 2013. Phytoremediation of heavy metals - Concepts. SciVerse ScienceDirect, Chemosphere, 91:869-881.
- [2] Anh, B.T., Kim, D.D., Kuschik, P., Tua, T.V., Hue, N.T., and Minh, N.M., 2013. Effect of soil pH on as hyperaccumulation capacity in fern species, *Pityrogramma calomelanos*. J Environ Biol., 34(2):237-42.
- [3] Binessi, E.I., Alexis, C.F.T., Lyde, A.S.T., Fidèle, S., and Arouna, Y., 2019. Metal-Contaminated Soil Remediation: Phytoremediation, Chemical Leaching and Electrochemical Remediation. Intechopen. DOI: 10.5772/81223.
- [4] Bolan, N.S. and Duraisamy, V.P., 2015. Role of inorganic and organic soil amendments on immobilization and phytoavailability of heavy metals: a review involving specific case studies. Aust. J. Soil Res., 41:533-555.
- [5] Chuong, N.V. and Chinh, N.T., 2018. Effects of lime and rice husk ash on total arsenic content in soybean grown inside the dike at An Phu district, An Giang province. Journal of Vietnam agriculture, science and technology, 7(92):26-30.

- [6] Chuong, N.V. and Hung, N.N., 2015. Research on mitigating of rice, maize, and mung beans uptake of cadmium in An Phu district, An Giang province. *Science and Technology Journal of Agriculture & Rural Development*, 1(12):73-77.
- [7] Cu, N.X. and Thu, T.T.T., 2014. The Effects of Fern (*Gleichenia linearis*) Mulching on Soil Properties, Humus Substance and Microbial Fauna in Soils Growing Tea in Phu Tho Province, Vietnam. *International Journal of Science and Research (IJSR)*, 3(8):18-23.
- [8] Ding, D., Li, W.H., Song, G.L., Qi, H.Y., Liu, J.B., and Tang, J.H., 2011. Identification of QTLs for Arsenic Accumulation in Maize (*Zea mays* L.) using a RIL population. *PLoS ONE*, 6(10), e25646. <https://doi.org/10.1371/journal.pone.0025646>.
- [9] Fu, Z.J., Li, W.H., Xing, X.L., Xu, M.M., Liu, X.Y., Li, H.C., Xue, Y.D., Liu, Z.H., Tang, and J.H., 2016. Genetic analysis of arsenic accumulation in maize using QTL mapping. *Scientific Reports*, 6, 21292.
- [10] Jankong, V.P. and Khokiattiwong, S., 2007. Enhanced phytoremediation of arsenic-contaminated land. *Chemosphere*, 68:1906-1912.
- [11] Liu, X., Feng, H.Y., Fu, J.W., Chen, Y., Liu, Y., and Ma, L.Q., 2018. Arsenic-induced nutrient uptake in As-hyperaccumulator *Pteris vittata* and their potential role to enhance plant growth. *Chemosphere*, 198:425-431.
- [12] Moon DH, Dermatas D, Menounou N. 2014. Arsenic immobilization by calcium-arsenic precipitates in lime treated soils. *Sci Total Environ*. 330(1-3), 171-85.
- [13] Requejo, R. and Tena, M., 2012. Influence of glutathione chemical effectors in the response of maize to arsenic exposure. *Journal of Plant Physiology*, 169:649-656.
- [14] Rosas, C.J.M., Guzmán-Mar, J.L., Hernández-Ramírez, A. Z., Garza-González, M.T., and Hinojosa-Reyes, L., 2014. Arsenic accumulation in maize crop (*Zea mays*): A review. *Science of The Total Environment*, 176-187.
- [15] Ruíz-Huerta, E.A., Garza Varela, A., Gómez-Bernal, J.M., Castillo, F., Avalos-Borja, M., SenGupta, B., and Martínez-Villegas, N., 2017. Arsenic contamination in irrigation water, agricultural soil and maize crop from an abandoned smelter site in Matehuala, Mexico. *Journal of Hazardous Materials*, 339:330-339.
- [16] Sun, Y.Y., Liu R.L., Zeng, X.B., Lin, Q.M., Bai, L.Y., Li, L.F., Su, S.M., and Wang, Y.N., 2015. Reduction of arsenic bioavailability by amending seven inorganic materials in arsenic-contaminated soil. *Journal of Integrative Agriculture*, 14:1414-1422.
- [17] Walkley, A. and Black, I. A., 1934. An examination of the Degtjareff method for determining soil organic matter and proposed modification of the titration method. *Soil Science*, 37: 29–38.
- [18] Xiao, X.Y., Chen, T.B., Liao, X.Y., Yan, X.L., Xie, H., Wu, B., and Wang, L.X., 2009. Comparison of concentrations and bioconcentration factors of arsenic in vegetables, grain

and oil crops in China. *Acta Scientiae Circumstantial*,29:291-296.

- [19] Zeng, P., Guo, Z., Xiao, X., Peng, C., Feng, W., Xin, L. and Xu, Z., 2019. Phytoextraction potential of *Pteris vittata* L. co-planted with woody species for As, Cd, Pb and Zn in contaminated soil. *Sci Total Environ*, 650:594-603.
- [20] Zhao, Z., Zhang, H., Fu, Z., Chen, H., Lin, Y., Yan, P., Li, W., Xie, H., Guo, Z., Zhang, X., and Tang, J., 2018. Genetic-based dissection of arsenic accumulation in maize using a genome-wide association analysis method. *Plant Biotechnology Journal*. 16:1085-1093