Reducing Arsenic Uptake and Increasing Green Bean Yield by Lime Combined with Coconut Fiber on Arsenic Pollution Farmland

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Abstract

A field research was performed with four treatments and four replications, which had the objective of ascertaining the Coconut Fiber (CF) impacts associated with lime addition on soil traits and arsenic uptake in green bean (GB) stems and seeds and yield and yield composition. The results showed that the lime, combined with CF, increased the pH level and farmland arsenic content of the soil. Arsenic content in stems and in GB seeds of the lime associated with CF treatment was lower than that of the control up to 32.0% and 50.0%, respectively. The lime combined with CF treatment raised pH and EC in the soil. The Arsenic accumulation of GB stems and seeds was lower than those of the control treatment up to 11% and 50.0%, respectively. The lime and CF amendment reduced the GB arsenic accumulation and increased the yield and yield traits. The maximum soil traits were obtained from using the lime combined with CF treatment of all measured treatments, and significantly different. The highest GB yield reached 2.45 t ha^{-1} in amendment of lime combined with CF and the lowest yield (1.9 t ha^{-1}) at chemical fertilizer treatment alone, which was 22.5% higher than that of chemical fertilizer application only.

Key words: Arsenic, lime, green bean, coconut fiber, uptake

INTRODUCTION

Green beans contain twice as much nitrogen as other grains contain (Laekemariam and Worku, 2013). Mickelbart *et al.* (2015) proved that mung beans help fight a number of diseases such as anemia and ailments related to old age, including heart disease, cancer, diabetes and obesity. Green beans contain highly nutritious elements that render these beans a valuable food source for humans. Green beans are legumes and have nitrogen fixation capabilities, which are beneficial to the soil and positively affect soil fertility and yield in the following rice crops (Khan *et al*., 2018). Many recommendations advocate for the use of organic fertilizers in place of inorganic fertilizers to improve soil fertility (Khan *et al.*, 2018). Food shortages constitute one prominent cause of malnutrition in the world (Hunger Notes, 2016), and people depend on the availability and quality of food (Keatinge *et al.,* 2011; Popkin *et al.,* 2012). Plant growth is restricted and stressed by very high arsenic contamination in the soil that reduces food quality and leads to deterioration in food quality and crop yield. Arsenic pollution levels in soil have recently become increasingly serious and have reduced the yield and quality of many different plants (Bailey-Serres *et al.*, 2012). Arsenic is an element that is toxic to humans and plants and is present in soil, water and air environments around the world (Alam *et al.,* 2011). Human and nature are the two main causes of arsenic contamination of soil (Steffan *et al.,* 2018). Arsenic is highly toxic and harmful to humans and plants (Agency for Toxic Substances and Disease Registry [ATSDR], 2011) because it inhibits plant root growth and promotes lipid oxygenation (Abbas *et al.,* 2018). Many recent studies have recognized that farmers have used contaminated groundwater to irrigate their crops, thus creating a health hazard for those who eat this contaminated food (Gillispie *et al.*, 2015). The arsenic accumulating in the soil from arsenic contaminated water poses a serious threat to sustainable agricultural systems (Gillispie *et al.*, 2015). An Phu is predominantly an agricultural district, and its people use arsenic-contaminated groundwater to irrigate their crops. About 69.,6% of the total groundwater withdrawn is utilized in the agricultural areas (Chuong, 2023).

Vietnam is, due to intensive farming, known as a heavy consumer of chemical fertilizer. Previous studies have reported that the use of well water contaminated with arsenic caused serious contamination of soil and crops. Chuong and Chinh, 2018 showed that application of lime combined with CF ash reduces the absorption of arsenic and increases the plant yield. The lime associated with rice husk ash combination increased pH and EC in the soil and the lowest arsenic contents of soybean in stems and seeds were 81.0; 27.0 µg/kg, respectively (Chuong and Chinh, 2018). Application of lime combined with rice husk ash resulted in the highest yield (7.59 tons/ha), in comparison to the lowest yield (4.63 tons/ha) in the control treatment.

Biosorption technology that includes metal removal performance for industrial wastewater, is a highly economical and conventional treatment for metal remediation (Lee *et al.*, 2009). The sawdust is a biological absorbent derived from plants that is capable of removing toxic metals from contaminated water (Lee *et al.*, 2009). The mechanism of CF absorption is mainly related to ion exchange reactions: arsenate and arsenide ions are trapped on the surface by the positively charged ions present in the sawdust. 90.2% of arsenic content was mainly removed by relating to ion exchange of three algal biomasses (Christobel and Lipton, 2015).

The nitrogen-fixing bacteria in legume roots are particularly stimulated by lime. Lime plays a role in promoting organic matter decomposition of beneficial microorganisms in soil and helping to improve soil fertility, and this substance is responsible for providing calcium to the soil and is essential for most of the beneficial microorganisms that live in soil. Plants cannot grow in acidic soil; therefore, lime fertilization is an indispensable tool that reduces the soil acidity, maintains high yields and improves soil quality to meet the requirements of crops (Kamaruzzaman *et al*., 2014). To illustrate, the growth and yield of peanuts dramatically improved from 9.1% to 30.4% productivity when 5 tons of lime and coconut fiber per hectare were applied lime 5 tons of lime and coconut fiber per ha had a significant effect on the growth and. Productivity of the peanut that increased from 9.10% to 30.4%, compared without liming and coconut fiber. (Chuong, 2018). Some efforts have been made to remove arsenate by bio-sorption (Mohamed, 2016).

MATERIALS AND METHODS

Description of the study site

The study features an experiment conducted in the town of Quoc Thai, An Phu district, An Giang province. The experiment was carried out the field area inside the dike with four treatments: T1 (without lime and CF), T2 (4.0 t $CaCO_3$ ha^{-1} and without CF); T3 (4.0 t CF ha^{-1} and without lime) and T4 (4.0 t $CaCO_3$ ha^{-1} combined with 4.0 t CF ha^{-1}) and four replications. The kind of irrigation water (deep well water) × two doses of lime and CF (8.0 t per ha), with an area of each replicate equivalent to 24 m^2 (6 m × 4 m), planted in a single row with a distance of 50 cm × 30 cm (three seeds were planted per hole); the distance between plants was 30 cm and between rows was 50 cm.

Experimental Procedures

The field experiment was conducted on four different treatments of lime and sawdust fertilization. The inorganic fertilizer was applied (N, P and K at 40, 60 and 50 kg ha^{-1}, respectively) for the entirety of all four treatments. Three germinated mung bean seeds were sown per hole. The water of Mekong Delta river was used to irrigate crops for all treatments. Soil samples were taken before and after the experiment on each treatment, agronomic parameters were monitored by the time of growth. The yield and yield components of the mung beans were taken after harvest, and arsenic concentration was determined via the atomic absorption method. The soil was air-dried, mixed well and passed through a 2-mm sieve after the harvest of the samples. The characteristics of the plants and the soil were analyzed in the laboratory at An Giang University.

Statistical analysis

Data were statistically analyzed and means were compared by least significant differences (LSD) tests at the 5% level of significance according to procedures outlined by Steel and Torrie using the MSTAT-C computer program.

RESULTS

Table 1. Soil particle size distribution and chemical characteristics at the first of the experiment (n=10)

Soil Analysis		**Soil depth (cm)**		**Soil analysis**		**Soil depth (cm)**	
		0 -20	**20-40**			**0-20**	**20-40**
Mechanical analysis	Sand (%)	5.20	3.10	Available nutrients	Total N (%)	0.130	0.140
	Clay (%)	54.0	65,0		Available P (mg kg^{-1})	50.1	49,3
	Silt (%)	49.8	31,9		Available K (mg kg^{-1})	534	612
	C (%)	1.73	1.13		Total Ca (%)	19.0	20.0
	OM (%)	2.46	2.26		As in soil (mg kg^{-1})	48.2	36.1
	C/N	13.3	16.0		As in deep well water (mg kg^{-1})		579

Soil properties

The soil pH at the end of the experiment ranged from 6.2 (control treatment) to 6.53 (T4) and exhibited significant differences among the four treatments. The treatment that involved combining lime and CF (T4) yielded the highest pH result (6.53). The interaction of lime and total soluble salts (EC**)** (Table 2) resulted in significant differences among treatments. The EC value ranged from 210 µS cm^{-1} to 230 µS cm^{-1}, the latter of which occurred in the group that received the CF and lime treatment. This result confirmed that application of CF and lime increases the EC of soil EC. The different levels of lime and CF application resulted in a range of total nitrogen percent, from 0.136% to 0.183% (Table 2). Maximum total nitrogen was observed under the treatment containing 4.0 t$CaCO_3$ ha^{-1} combined 4.0 t CF ha^{-1} (T4), and the minimum concentration appeared in the control group (T1).

Table 2. Results of Soil chemical analysis at the end of the experiment*

Traits	**Treatments**				
	Control (T1)	**Lime (T2)**	**CF(T3)**	**CF and lime (T4)**	***P value*** **=0.05**
pH	6.20±0.169b	6.49±0.008a	6.40±0.082a	6.53±0.025a	0.001
EC (mS cm-1)	210±0.816d	213±0.816c	220±0.816b	230±0.816a	0.000
Total N (%)	0.136±0.000d	0.157±0.001c	0.166±0.001b	0.183±0.001a	0.000
Available P (mg kg^{-1})	44.9±0.629d	60.0±0.408c	78.1±0.081b	90.1±0.081a	0.000
Exchangeable K (mg kg^{-1})	611±0.816d	623±0.816c	657±0.816b	780±0.816a	0.000
Soil total organic matter (%)	1.20±0.081c	1.24±0.033c	1.45±0.041b	1.57±0.016a	0.000
Total Calcium (%)	18.4±0.163d	20.3±0.245c	18.7±0.163b	21.5±0.048a	0.000

* Values are the mean of four replicates. Means within each row having different letters, are significantly different according to $P_{value} \leq 0.05$ and ≤ 0.01. Sign (±) indicates the mean standard deviation of four replications

The available phosphorus was maximized (90.1 mg kg^{-1}) in the three experimental groups (Table 2). The minimum available phosphorus remained steady at 44.9 mg kg^{-1} in the control. The results in Table 2 showed that co-application of lime and sawdust increased the soil's potassium concentration as a result of the carbonate and cation content in the soil. The highest exchangeable potassium (780 mg kg^{-1}) was obtained in the T4, the lowest exchangeable potassium (611 mg kg^{-1}) was found in the control. The soil's organic matter (OM) content ranged from 1.20% to 1.57%, with significant differences among the treatments. The highest value (1.57%) was obtained by the co-application treatment of lime and CF (T4). In contrast, the SOM content in the control treatment (1.20%) resulted in the lowest value.

Growth traits

The mean value of plant height varied from 31.5 to 37.6 cm at 20 DAS (Table 3). Among treatments, from 20 DAS to harvest, the greatest plant height was obtained in the treatment T4, and the second-greatest appeared in treatment T2. However, there were significant differences due to treatment influence. The lowest plant height was recorded for the treatment T1 in all DAS. The highest plant height obtained under T4 and T2 was at 45 DAS, 60 DAS and harvest.

Table 3. Effects of liming and CF addition on the GB plant height

Treatment	Plant height (cm)			
	20 DAS*	**45 DAS**	**60 DAS**	**Harvest**
Control (T1)	31.5±0.408d	55.7±0.163d	58.4±0.327d	57.6±0.245d
Lime (T2)	35.1±0.082b	64.0±0.081b	66.5±0.408b	66.4±0.163b
CF(T3)	33.7±0.163c	61.4±0.163c	63.5±0.408c	64.3±0.245c
CF and lime (T4)	37.6±0.244a	67.3±0.2445c	69.7±0.163a	70.2±0.163a
P_{value}	0.000	0.000	0.000	0.000

* DAS: days after sowing; Values are the mean of four replicates. Means within each row having different letters, are significantly different according to $P_{value} \leq 0.05$ and ≤ 0.01. Sign (±) indicates the mean standard deviation of four replications

Table 4's results demonstrates that there were significant effects of lime and CF treatments on all studied traits of yield and yield components. All studied yield characteristics increased gradually, in ascending order, in the control, lime, CF, and lime combined with CF. The differences among levels were significant for all traits: lime combined with CF at (2 tons $CaCO_3$ ha^{-1} + 10 t CF ha^{-1}) produced the maximum number of pods plant^{-1} (23.3), seeds per pod (9.0), seed weight per ha (2.45 t ha^{-1}) and 16.8 g of 100 seeds. The GB yield ranged from 1.9 (T1) to 2.45 t ha^{-1} (T4); it is also worth noting that T3 resulted in a yield of 1.97 t ha^{-1}, only slightly higher than that of T1.

Table 4. Effects of lime and CF addition on GB yield and yield components

Treatment	**Yield component and productivity**			
	Weight of 100 seeds (g)	**Pod number (pod plant^{-1})**	**Seed number (seed plant^{-1})**	**Fresh seed yield (t ha^{-1})**
Control (T1)	15.3±0.245c	19.3±0.245d	6.00±0.817c	1.90±0.082c
Lime (T2)	16.5±0.408ab	21.3±0.245b	8.00±0.817ab	2.15±0.041b
CF (T3)	16.3±0.245b	20.4±0.326c	7.20±0.163b	1.97±0.016c
CF and lime (T4)	16.8±0.163a	23.3±0.245a	9.00±0.817a	2.45±0.041a
P_{value}	0.0000	0.0000	0.0000	0.0000

* Values are the mean of four replicates. Means within each row having different letters, are significantly different according to $P_{value} \leq 0.05$ and ≤ 0.01. Sign (±) indicates the mean standard deviation of four replications

Arsenic accumulation

The Table 5's results presented that there were significant differences, at 5%, among treatments of Arsenic concentrations in the soil prior to and following the experiment. The highest Arsenic concentration in soils before the experiment was 33.6 mg/kg, and the lowest was 31.6 mg kg^{-1}. These values underscore the alarming overabundance of Arsenic in the cultivated farmland in the An Phu district. In addition, the Arsenic content in the soil after the experiment had a statistically significant difference at 5%; the highest concentration of Arsenic (46.6 mg kg^{-1}) occurred in group T4, the lowest occurred in treatment T1 (34.7 mg kg^{-1}), and the concentrations for T2 and T3 were 44.5 mg $kg^{-1}$and 37.1 mg kg^{-1}, respectively.

Table 5. Effects of lime and CF addition on Arsenic concentrations of the experimental soil and green bean (GB)

Treatment	**Arsenic concentration**			
	Experimental soil (mg kg^{-1})		Stems, leaves and seeds (µg kg^{-1})	
	Before	After	GB Stems	GB Seeds
Control (T1)	31.6±0.163d	34.7±0.163d	140±1.63a	12.5±0.048a
Lime (T2)	33.5±0.408b	44.5±0.408b	107±1.63c	8.40±0.163c
CF (T3)	32.9±0.082c	37.1±0.081c	114±1.63b	11.0±0.048b
CF and lime (T4)	33.6±0.163c	46.6±0.163a	95.3±0.245d	6.33±0.024d
P_{value}	0.000			

* Values are the mean of four replicates. Means within each row having different letters, are significantly different according to $P_{value} \leq 0.05$ and ≤ 0.01. Sign (±) indicates the mean standard deviation of four replications

The results in Table 5 indicate that Arsenic concentration in the GB stems and seeds to which the lime and CF treatments were applied is lower than that of the control treatment. In T4, Arsenic accumulation in GB stems and seeds was (95.3 and 6.33 mg kg^{-1}) was lower than 0.5 in stems and 2.0 times in seeds than in non-lime treatments. Arsenic concentration of lime or CF treatments decreased on average from 0.5 to 1.5 times from the control treatment values. The highest Arsenic concentration in GB stems and seeds (140 and 12.5 mg kg^{-1}) appeared in T1.

DISCUSSION

This result showed that application of lime increased the soil pH due to the lime's carbonate content, echoing the results of Mkhonza *et al.* (2020), who also demonstrated that application of lime to the soil resulted in higher soil pH compared to both control treatments and treatments without lime at a soil depth of 0-20 cm. According to Yuli *et al.* (2016), the soil EC after the application of lime and chicken manure (6 t ha^{-1}) increased by 0.78 µS cm^{-1}, from 0.99 µS/cm to 1.77 µS cm^{-1}. This outcome further demonstrated that application of lime and organic matter increases the total nitrogen concentration because of the large supply of carbon and nitrogen present in the sawdust. This change in nitrogen concentration reproduces the findings in Lekhika *el al.*'s *(*2019) study, namely, that application of lime and organic amendment spurs a rise in the N-mineralization rate. . Application of lime and chicken manure increased microbial activity and available phosphorous in highly acidic soils (Simonsson *et al.,* 2018; Lekhika *el al.,* 2019). Chuong (2023) likewise observed that the highest available potassium (0.170 meq 100 g^{-1}) was present in soil that had received 3.5 tons of $CaCO_3$ $ha^{-1}$and 10 t of cow manure per ha. The above results proved that co-application of lime and sawdust can both increase available K and reduce K leaching in soil. The organic matter content in the soil after the experiment increased the most when the fertilizer contained cow manure, lime and NPK (Chuong, 2019). Furthermore, different kinds of organic manure and different levels of lime also affect the levels of organic matter in the soil. The application of lime and organic manure in the soil could increase soil organic carbon content because organic manure may contain The soil calcium concentration in the lime treatments was always higher than in the group without lime treatments. The calcium content ranged from 18.4% (T1) to 21.5% (T4), and the significant differences were 1% among different treatments. When lime was applied to the soil, the Ca^{2+} and Mg^{2+} concentrations in the soil increased and produced higher yields of alfalfa (Adônis and Nand, 2010).

The average arsenic concentration in the soil was 48.2 mg kg^{-1} in deep soil from 0–20 cm and 36.1 mg kg^{-1} in soil depth from 20–40 taken in surveyed areas. Moreover, arsenic concentrations of the deep well water used in crop irrigation was 579 µg kg^{-1}. Chuong and Chinh (2018) found that the Arsenic concentration of 60 deep well water samples exceeded both Vietnamese and WHO standards (50 µg L^{-1} and 10 µg L^{-1}, respectively). Farmers of six communes in the An Phu district had used the arsenic polluted water of this deep wells to irrigate their fields (69.6% of six communes). The different yields of mung beans in the present study depended on the production system. Dinesh et al. (2017) recommended that application of 200 kg lime ha^{-1} and organic fertilizer reduced soil acidity and increased yield of green beans in the Vindhyan region of India.

Many previous studies have shown that the application of lime and organic fertilizers, which has long-term positive effects on soil physics, increased soil fertility and plant nutrients such as total N, available P and available K (Haynes and Naidu, 1998). Lime and organic matter were responsible for reducing EC in acidic soils. Soil EC and pH levels were increased by the presence of mineral salts and CaCO3 when lime and manure were applied (Agus et al., 2008). In the present study, the value of lime and sawdust treatments of soil pH, total nitrogen, available phosphorous, available potassium, total organic matter and total calcium increased without lime and sawdust. In contrast, the soil and the deep well water were polluted by arsenic; the Arsenic concentration in both sources exceeded the maximum allowed standard by one to two times. The Arsenic contaminated deep well water was mainly to irrigate crops in Quoc Thai, where a high rate of farmers (90%) used the contaminated water. The average Arsenic concentration of deep well water was 297 µg L^{-1} (Chuong, 2022).

Lime and sawdust fertilizer are important factors in achieving better growth and development of the reproductive organs of mung beans, and these components result in increases of photosynthesis rate, photosynthetic matter production, yield components and seed yield. Lime and sawdust treatments significantly affected all studied characteristics in this study (Table 4). Application of lime and sawdust treatments reduced the uptake of Arsenic in the stems and seeds of mung bean plants, so Arsenic was retained more in the soil than in the control treatments. Therefore, Arsenic in the soil in the control treatments was absorbed by stems and seeds of mung beans. This study shows that the soil in this area is seriously contaminated due to the As-heavy deep well water used in irrigating the land for cultivation. The soil Arsenic concentration exceeds the allowed concentration in agricultural soil of 12 mg/kg. According to Chuong and Chinh (2020), the protective dyke against floods in An Phu has resulted in a lack of river water for irrigating crops. Farmers in 69.6 % of six communes had to use the As-contaminated deep well water instead of river water for the past five years (Chuong and Chinh, 2018). Long-term use of polluted water for irrigation of crops increased arsenic concentrations in the agricultural soil (Meharg and Rahman, 2003).

Lime combined with sawdust effectively reduces the Arsenic that has accumulated in plants. All growth parameters were improved when mung bean plants received the advantageous effects of lime and CF. Moreover, additional GB growth stemmed from a combination of lime and CF. Continued application of lime and other organics enhanced growth and reduced the need to resort to chemical fertilizers and pesticides; the reduced arsenic absorption in GB stems and seeds is an example of proper conservation and sustainability. Prior studies further showed that reduce arsenic absorption in up to 98.8% of GB is possible through surface ion adsorption of CF and precipitation of lime (Sandip *et al*., 2017; Chuong and Chinh, 2018, 2020).

CONCLUSION

Application of lime combined with CF improved soil fertility and reduced up to 11% arsenic absorption in the stems and 50% in the GB seeds. The GB yield increased by 22.5% over the yield of the seeds planted in soil with no added lime and CF. Additional in-depth studies are needed to identify with greater clarity the mechanism of reducing Arsenic uptake into plants and removing Arsenic from agricultural soils.

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