# ประสิทธิภาพของบอน *Colocasia esculenta* (L.) Schott (บอนจีนดำและบอนเขียว) ในการกำจัดสารหนูที่ปนเปื้อนในดิน

นางสาว จิราวรรณ จำปานิล

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

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ลิขสิทธิ์ของจุฬาลงกรณ์มหาวิทยาลัย

# EFFICIENCY OF ARSENIC REMOVAL FROM SOIL BY *Colocasia esculenta* (L.) Schott (DARK VIOLET AND GREEN)

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science in Environmental Science
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| | |
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| Thesis Title | Efficiency of arsenic removal from soil by *Colocasia esculenta* (L.) Schott (dark violet and green) |
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จิราวรรณ จำปานิล : ประสิทธิภาพของบอน *Colocasia esculenta* (L.) Schott (บอนจีนดำและบอนเขียว) ในการกำจัดสารหนูจากดิน (EFFICIENCY OF ARSENIC REMOVAL FROM SOIL BY *Colocasia esculenta* (L.) Schott (DARK VIOLET AND GREEN)) ที่ปรึกษา : รศ.ดร.ธเรศ ศรีสถิตย์ ที่ปรึกษาร่วม : ผศ. เตือนใจ โก้สกุล 99 หน้า. ISBN 974-13-0223-1

การวิจัยนี้เพื่อศึกษาความสามารถในการเจริญเติบโตของ *Colocasia esculenta* (L.) Schott (บอนจีนดำและบอนเขียว) ในดินที่มีการปนเปื้อนสารหนู ศึกษาระดับการสะสมสารหนูในส่วนต่างๆ ของต้นบอน และศึกษาประสิทธิภาพการดูดดึงสารหนูของบอนทั้งสองพันธุ์ในดินทดลอง ผสม $Na_2HAsO_4.7H_2O$ ให้มีความเข้มข้นเป็น 0 50 75 100 125 และ 150 มิลลิกรัม/กิโลกรัม ระยะเวลาการศึกษา 90 วัน โดยจะ บันทึกผล 6 ครั้ง ทุกๆ 15 วัน

การศึกษาพบว่า บอนจีนดำสามารถเจริญเติบโตได้ในทุกระดับความเข้มข้นของสารหนูและมีการอยู่รอดทั้งหมด นอกจากนี้ยังพบว่ามีการสะสมสารหนูในส่วนของรากมากกว่าลำต้นใต้ดิน ใบ และก้านใบ ประสิทธิภาพการดูดดึงสารหนูมีค่าสูงขึ้นตามระยะเวลาและค่าประสิทธิภาพที่มากที่สุด คือ ร้อยละ 0.07 ของปริมาณสารหนูที่ปนเปื้อนในดิน 100 มิลลิกรัม/กิโลกรัม ส่วนบอนเขียวนั้นก็สามารถเจริญเติบโตได้ดีในทุกสภาวะการปนเปื้อนและมีการอยู่รอดทั้งหมดเช่นเดียวกัน ประสิทธิภาพมีค่าสูงขึ้นตามระยะเวลาการทดลอง และพบว่ามีการสะสมเพิ่มขึ้นตามลำดับ คือ ก้านใบ ใบ ลำต้นใต้ดิน และราก ค่าประสิทธิภาพมากที่สุดเท่ากับร้อยละ 0.06 ของปริมาณสารหนูที่ปนเปื้อนในดิน 125 มิลลิกรัม/กิโลกรัม และมีค่าเพิ่มตามระยะเวลาอีกด้วย

จากผลที่ได้แสดงว่าบอนทั้งสองพันธุ์มีประสิทธิภาพในการดูดดึงสารหนูได้ใกล้เคียงกันและมีอัตราการอยู่รอดทั้งหมดที่ปลูกในดินที่มีการปนเปื้อนสารหนู 0-150 มิลลิกรัม/กิโลกรัม ดังนั้น ควรจะมีการนำบอนทั้งสองพันธุ์มาใช้ประโยชน์มากขึ้นในประเทศไทยและในพื้นที่ที่มีปัญหาการปนเปื้อนของสารหนู

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KEYWORD: PHYTOTREATMENT / BIOREMEDIATION / ARSENIC REMOVAL

JIRAWAN JAMPANIL: EFFICIENCY OF ARSENIC REMOVAL FROM SOIL BY *Colocasia esculenta* (L.) Schott (DARK VIOLET AND GREEN) THESIS ADVISOR: ASSOC. PROF. THARES SRISATIT, Ph.D., THESIS CO-ADVISOR: ASSIST. PROF. TUENCHAI KOSAKUL, M.Sc., 99 pp. ISBN 974-13-0223-1

The purposes of this study were to investigate growth rate of *Colocasia esculenta* (L.) Schott (dark violet and green) in arsenic contaminated soils, to find the level of arsenic accumulation in parts of *Colocasia esculenta* (L.) Schott, and to compare arsenic removal efficiency from soil by both *Colocasia esculenta* (L.) Schott. Experimental soil was contaminated with $Na_2HAsO_4.7H_2O$ at concentrations of 0, 50, 75, 100, 125, and 150 mg As/kg soil dry weight. All data were recorded every 15 days, on 6 consecutive occasions over a 90-day trial period.

From the results, of *Colocasia esculenta* (L.) Schott (dark violet) could grow well under all concentration of arsenic, with 100% survival. In addition, amount of arsenic accumulated in root was more than that in corm, lamina, and petiole. Maximum arsenic removal rate was 0.07% in 100 mg As/kg soil dry weight and its efficiency increased throughout the experiment.
Another test for *Colocasia esculenta* (L.) Schott (green), the result showed similar to *Colocasia esculenta* (L.) Schott (dark violet), *Colocasia esculenta* (L.) Schott (green) could grow well in all tested conditions. Amount of arsenic was increased in petiole, lamina, corm, and root, respectively. Maximum efficiency of arsenic removal was 0.06% in 125 mg As/kg soil dry weight and its efficiency increased by time of growth as well.

In conclusion, the efficiency of both *Colocasia esculenta* (L.) Schott was not different; in addition, all plants of the experiment can survive under arsenic concentration ranged from 0-150 mg As/kg. Consequently, *Colocasia esculenta* (L.) Schott is more appropriate for Thailand and should be recommended for soil improvement in case of arsenic contamination.

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# CHAPTER I

# INTRODUCTION

## 1.1 Cause of the problem and development

Arsenic contaminated soil is the problem over years, especially in the tin mining site, such as Ron Phibun District, Nakorn Sri Thammarat Province, which is located in southern of Thailand. This area has an extensive history of bedrock and alluvial mining, the waste from which is typically rich in arsenopyrite (FeAsS) and related alteration products (Williams, 1996). In mining procedure, the floatation results in arsenic contamination to environment directly, thus arsenic sediment is able to transform to other arsenic compounds in phases of soil, water, and sediment. Arsenic can enter into human body via plant uptake from soil, by drinking arsenic contaminated water and by biomagnification as one move up the food chain. The occurrence of human health problems resulting from arsenic contamination of domestic water supplies was first recognized in 1987. As a result, the people in 12 villages and vicinity areas of tin mines have been suffering from chronic arsenic poisoning and skin cancer because of drinking arsenic contaminated water (Intrasuta, 1991).

There are many ways to clean up the arsenic polluted environment. This includes detoxification, transformation of the mobile form into the non-mobile form, immobilization or stabilization, and removal of arsenic from the polluted area by physical, chemical or biological treatment. **Bioremediation** is a method that used the living things such as microorganism and plants, **phytoremediation**, for clean up the contaminated areas. Thailand is the tropical country with high biodiversity, result in the benefit and enhancement of bioremediation of arsenic contaminated land potentially. Phytoremediation is the use of vegetation for *in situ* treatment of contaminants such as heavy metals and pesticide in soil and water. It is a form of ecological engineering that

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has proven effective and relatively inexpensive (Raskin, 1997). The arsenic level in soil could be reduced, so that the level of arsenic in surface water would thus be reduced.

This study was aimed to select *Colocasia esculenta* (L.) Schott for phytoremediation of arsenic contaminated land. This plant is feasible to study because of its characteristics; perennial herb, succulent stem, tolerance to and insect disease (Surrency, 1993) and widely found in Thailand.

### 1.2 Objectives

1.2.1 To study growth rate of *Colocasia esculenta* (L.) Schott in the arsenic contaminated soils.

1.2.2 To study on the level of arsenic contamination in various parts *of Colocasia esculenta* (L.) Schott (dark violet and green).

1.2.3 To compare of arsenic removal efficiency from soil by both types of *Colocasia esculenta* (L.) Schott.

### 1.3 Hypothesis

Efficiency of arsenic removal from soil by *Colocasia esculenta* (L.) Schott (dark violet) and *Colocasia esculenta* (L.) Schott (green) differ in various arsenic concentrations and harvest times.

### 1.4 Scope of study

1.4.1 Study on arsenic accumulated in parts of *Colocasia esculenta* (L.) Schott, which are *Colocasia sp.* (dark violet) and *Colocasia sp.* (green), growing in soil contaminated with arsenic into concentrations of 50, 75, 100, 125, and 150 mg As/kg soil.

1.4.2 Study on the growth rates of *Colocasia esculenta* (L.) Schott into their cumulative length and weight.

1.4.3 Study on arsenic accumulations in lamina, petiole, corn, and root every 15 days during the experimental run, 90 days.

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1.4.4 Compare efficiency of arsenic removal between *Colocasia esculenta* (L.) Schott (dark violet) and *Colocasia esculenta* (L.) Schott (green) by using totally arsenic accumulated in plants.

## 1.5 Anticipated benefits

1.5.1 Efficiency of arsenic removal by both types of *Colocasia esculenta* (L.) Schott will be determined.

1.5.2 Appropriate kind of plants will be actually used as phytoremediation to reduce the arsenic contamination in contaminated areas.

1.5.3 Environmental amendment to biologically local resources will be available.

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# CHAPTER II

# LITERATURE REVIEWS

## 2.1 Arsenic

Arsenic is classified as a metalloid element, with symbol As. It is the third member of nitrogen family with atomic number 33. Its properties are similar to phosphorus and antimony, with oxidation state of +3, +5, 0 and –3. Its atomic weight is 74.92158, melting point is 817 ° C, and boiling point is 616 ° C. (McGraw-Hill, 1992) The physical characteristics of arsenic are shown in Table 2-1

Table 2-1 Some properties of arsenic

| Property | Value |
|---|---|
| Nuclear charge number | 33 |
| Atomic weight | 74.92158 |
| Crystal structure | Rhombohedral |
| Color | Grey |
| Specific gravity | 5.727 (crystalline)<br>2.026 (yellow cubic)<br>4.7 (black amorphous) |
| Melting point | 817 °C (28 atm) |
| Boiling point | 616 °C |

Source: McGraw-Hill, 1992.

Arsenic usually occurs in combination with one or more elements such as oxygen, chlorine, and sulfur and is referred to as inorganic arsenic. When arsenic occurs in combination with carbon and hydrogen, it is know as organic arsenic. It is important to maintain a distinction between inorganic and organic acid, since the

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inorganic form is usually more toxic than the organic form. Moreover, the inorganic form is more mobile than the organic form (Intarakarunvetch, 1989).

### 2.1.1 Occurrence of arsenic in the environment

Arsenic is naturally occurring element in the earth's crust. It is found widely distributed in nature approximately $5x10^{-4}$% of the earth's crust (McGraw-Hill, 1992). The most common of the As minerals is arsenopyrite, FeAsS, and As is found associated with many types of mineral deposits especially those including sulphide mineralisation. The concentration of associated As can range from a few parts per million up to percentage quantities (O'Neill, 1990).

Table 2-2 Arsenic in crustal materials

| Type | Range (mg/kg) |
|---|---|
| Igneous rocks | |
| Ultrabasic | 0.3-16 |
| Basalts | 0.06-113 |
| Andesites | 0.5-5.8 |
| Granitic | 0.2-13.8 |
| Sedimentary rocks | |
| Limestones | 0.1-20 |
| Sandstones | 0.6-120 |
| Shales and clay | 0.3-490 |
| Phosphorites | 0.4-188 |

Source: WHO, 1981.

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Arsenic is widely distributed in a large number of minerals. The highest mineral concentrations generally occur as arsenides of copper, lead, silver, or gold or as the sulfide. Major arsenic containing minerals are arsenopyrite (FeAsS), realgar ($As_4S_4$), and orpiment ($As_2S_3$). Oxidized forms of arsenic are usually found in sedimentary deposits.

The elemental oxidation state, though stable in reducing environments, is rarely found (WHO, 1981). Table 2-2 gives some ranges of the arsenic contents of crustal materials.

Although the values shown are generally low, mineralized zones of sulfidic ores may contain much higher concentrations of arsenic.

In the atmosphere, trace amounts of arsenic contain both inorganic and organic arsenic compounds (WHO, 1981). Table 2-3 presents the total arsenic in some areas.

Table 2-3 Arsenic in the atmosphere

| Areas | Quantity ($ng/m^3$) |
|---|---|
| South pole | 0.007 |
| Europe | 1.5-53 |
| Near volcano | < 850 |

Source: Alloway, 1997.

Arsenic not only occurs in earth's crust and atmosphere, but it also presents in water. In aquatic system, arsenic occurs in both inorganic and organic forms. The main organic species, methylarsonic acid and dimethylarsinic acid, are generally present in smaller amounts than the inorganic forms, arsenite and arsenate (WHO, 1981).

Bowen (1979) referred by Alloway (1997) reported that fresh water contains arsenic concentrations ranging from 0.2-230 µg/l, in addition, arsenic in seawater is 0.5-3.7 µg/l.

### 2.1.2 Speciation of arsenic

Arsenic is a ubliquitous element with metalloid properties. Its chemistry is complex and there are many difference compounds of both inorganic and organic arsenic (WHO, 1981). The most important forms for the evaluation of health effects are shown in Table 2-4

Table 2-4 Some common inorganic and organic arsenic compounds

| *Name* | *Synonyms* | *Formula* |
|---|---|---|
| *Inorganic arsenic,trivalent* | | |
| Arsenic(III) oxide | Arsenic trioxide<br>Arsenous oxide<br>White arsenic | $As_2O_3$ (or $As_4O_6$) |
| Arsenous acid | | $H_3AsO_3$ |
| Arsenenous acid | Arsenious acid | $HAsO_2$ |
| Arsenites, salts of arsenous acid | | $H_2AsO_3^-$ , $HAsO_3^{2-}$ or $AsO_3^{3-}$ |
| Arsenic (III) chloride | Arsenic trichloride<br>Arsenous trichloride | $AsCl_3$ |
| Arsenic (III) sulfide | Arsenic trisulfide<br>Orpigment, auripigment | $As_2S_3$ |
| *Inorganic arsenic, pentavalent* | | |
| Arsenic (V) oxide | Arsenic pentoxide | $As_2O_5$ |
| Arsenic acid | Orthoarsenic acid | $H_3AsO_4$ |
| Arsenenic acid | Metaarsenic acid | $HAsO_3$ |
| Arsenates, salts of arsenic acid (ortho) | | $H_2AsO_4^-$ , $HAsO_4^{2-}$ or $AsO_4^{3-}$ |
| *Organic arsenic* | | |
| Methylarsonic acid | Methanearsonic | $CH_3AsO(OH)_2$ |
| Dimethylarsinic acid | Cacodylic acid | $(CH_3)_2AsO(OH)$ |
| Trimethylarsine oxide | | $(CH_3)_3AsO$ |
| Methylarsine | | $CH_3AsH_2$ |
| Dimethylarsine | | $(CH_3)_2AsH$ |
| Trimethylarsine | | $(CH_3)_3As$ |

Source: WHO, 1981.

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### 1) Inorganic arsenic

Arsenite and arsenate are the most common inorganic compounds in the environment. Arsenic, which is a component of sulfidic ores, is weathering to form arsenate although arsenite may be formed under anaerobic conditions. Arsenate is the predominant form of arsenic in water.

Arsine or arsenic trihydride is colorless, extremely poisonous, natural gas. Its melting point and boiling points are –117 °C and –55 °C, respectively. Arsine is a powerful reducing agent, even for fairly weak oxidizing agents. Its is produced accidentally as a result of generation of nascent hydrogen in the presence of arsenic. Arsine and its methyl derivatives may be formed from other arsenic compounds by microbial action or inadvertent chemical reaction that generate strong reducing conditions.

### 2) Organic arsenic

A very large number of arsenic compounds that contain one or more arsenic-carbon bonds have been synthesized. The large variety of compounds is made possible by property of arsenic atom to bond from one to five organic groups, aromatic or aliphatic. The valences not used in bonding organic group can be linked to other atoms and groups. Such compounds may contain trivalent or pentavalent arsenic atoms or be onium derivatives of arsenic. The most important general types of organic arsenic compounds are shown in Table 2-5

Methylated arsenic such as methylarsonic acid (MAA),dimethylarsenic acid (DMAA), trimethylarsine oxide (TMAO), and tatramethylarsonium ion are methyl derivatives. Small amounts of methylarsenic (MMA) and dimethylarsenic (DMA) are found in water, MMA generally present at higher concentrations than DMA. Furthermore, the methyl derivatives are found to be present in aquatic organisms and may concern with arsenic detoxification process.

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Table 2-5 Important Classes of Organic Arsenic Compounds

| | |
|---|---|
| $RAsX_2$ | X = H, halogen, $NR_2$, OR, SR, SeR, Alkaline metal, pseudohalogen |
| $R_2AsX$ | |
| $R_3As$ | Triorganylarsine |
| $[R_4As]^+X^-$ | Tetraorganylarsunium salt (X = Uninegative anion) |
| $R_5As$ | Pentaorganyl arsenic |
| $(RAsY)_n$ | Y = O, S, NH, NR |
| $R_2As\text{-}X\text{-}AsR_2$ | X = O, S, Se, NR |
| $R_3AsY$ | Y = O, S, Se, Te, NR |
| $R_3AsX_2$ | X = halogen |
| $RAsO(OH)_2$ | Arsonic acid |
| $R_2AsO(OH)$ | Diorganylarsinic acid |

Source: National Academy of Sciences, 1977.

### 2.1.3 Uses of arsenic compounds

Arsenic compounds are mainly used in agriculture and forestry. Much smaller amounts are used in the glass and ceramics industry and as feed additives and drugs. In agriculture, compounds such as lead arsenate, calcium arsenate, and organic arsenic compounds are used as pesticides. Substantial amount of methylarsonic acid and dimethylarsinic acid are used as selective herbicides. In addition to dimethylarsinic, it is used as silvicide in forest control (WHO, 1981).

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Chromated copper arsenate, sodium aresenate, and zinc arsenate are used as wood preservatives so that the preserved timber is resistant to both fungal and insect attack (WHO, 1981).

Small amount of arsenic compounds such as dihydrogen arsenate is used in medicine. In addition, most of the medical uses of arsenic compounds depend on their toxic nature (McGraw-Hill, 1992).

### 2.1.4 Effects of arsenic on human

Acute and subacute effects of arsenic may involve many organ systems including the respiratory, gastrointestinal, cardiovascular, nervous, and haematopoietic systems. Many studies indicate that trivalent inorganic is more toxic than pentavalent. It is also evident that arsenic in solution is more toxic than undissolved arsenic, probably because of better absorption. Besides, long-term exposure to inorganic arsenic has been found to give rise to effects in large number of organs.

Inorganic arsenic in the trivalent state can give rise to skin lesions in man, especially palmo-plantar hyperkeratosis that has a characteristic appearance. Furthermore, it can exert chronic effects on the peripheral nervous system in man (WHO, 1981).

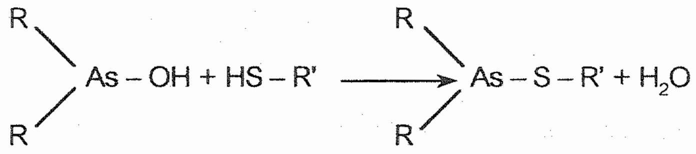
However, the toxicity of arsenic depends on factors such as species of compounds, route, dose of exposure, time in addition to age, sex, and forms of arsenic.

Arsenic exposed into body is mostly accumulated in such skin, nail, and hair because of keratin. Arsenic reacts with sulhydryl group, SH, of keratin in either protein or enzyme so that energy synthesis is not available, in addition, disturbing DNA polymerase by arsenic could interfere DNA formation. As a result, it may be a cause of cancer.

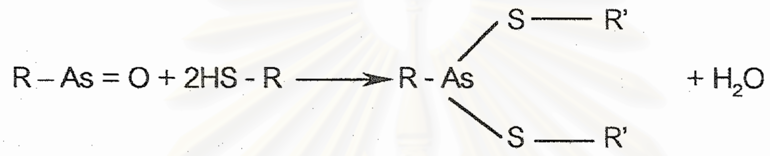
In living organisms, As (III) is more highly reactive than As (V), furthermore, As (V) could be usually reduced to As (III) by mechanisms in complicated organisms. Consequently, As (III) is more toxic than As (V).

Toxicity of As (III) results from reactivity with sulhydryl group, which is a major chemoreceptors, in tissues. Sulhydryl group is a constituent in enzymes, resulting in different mechanisms, such as lactase dehydrogenase, cytochrome oxidase, and glucose oxidase. It may be reactive with either substrate or intermediate substance of enzyme as follow:

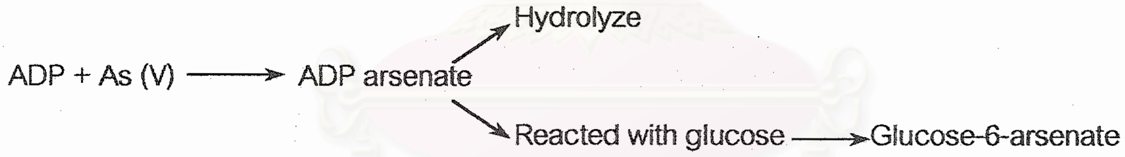
Monosubstituted arsenical reaction



Disubstituted arsenical reaction



Not only be As (V) reduced to As(III), it is also toxic to human health. Most of As (V) could substitute phosphate in enzyme catalyzed reaction such ATP process as this reaction.



### 2.1.5 Limiting concentration

1) Drinking water

In guideline of World Health Organization (WHO), arsenic concentration in drinking water should not exceed 0.05 mg/l. Besides, Environmental Protection Agency has also established a Maximum Contaminant Level of 0.05 mg/l.

Arsenic in drinking water set by countries and other organizations has shown in Table 2-6. In respect to harmful of arsenic, many governmental organizations in Thailand have also allowed arsenic contaminated in drinking water should not more than 0.05 mg/l, shown in Table 2-7.

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2) Food

Arsenic contamination not only is determined in drinking water standard, but it also is set for food. In Thailand, Ministry of Public Health has established arsenic contaminant level of 2 mg/l in food (Jutithepharak, 1988).

Table 2-6 Drinking water standards set by countries and other organizations

| Countries or organizations | Acceptable arsenic concentration in drinking water (mg/l) |
|---|---|
| United State of America | 0.05 |
| Union of Soviet Socialist Republic | 0.05 |
| European Union | 0.05 |
| World Health Organization | 0.05 |

Source: Department of Environmental Standard Quality, 1987.

Table 2-7 Drinking water standards set by governmental organizations in Thailand

| Organizations | Acceptable arsenic concentration in drinking water (mg/l) |
|---|---|
| Ministry of Public Health | 0.05 |
| Department of Mineral Resources | 0.05 |
| Metropolitan Waterworks Authority | 0.01-0.05 |
| Department of Public Works | 0.05 |
| Thai Industrial standards Institute | 0.05 |

Source: Department of Environmental Standard Quality, 1987.

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### 2.2 Arsenic environmental transportation and distribution

Most environmental transformations for arsenic appear to occur in the soil, in sediments, in plants and animals and in zones of biological activity in the oceans.

Biomethylation and bioreduction are probably the most important environmental transformations of the element, since they can produce organometallic species that are sufficiently stable to be mobile in air and water.

The proposed mechanism indicates that As(V) has to be reduced to As(III) before being methylated (WHO, 1981).

$$As^{V}O_{4}3- \xrightarrow[-O^{2-}]{2e} As^{III}O^{3-} \xrightarrow{CH_3+} CH_3AsO_3^{2-} \xrightarrow[-O^{2-}]{2e} CH_3As^{III}O_2^{2-} \xrightarrow{CH_3+}$$

$$(CH_3)_2As^{V}O_2^{-} \xrightarrow[-O^{2-}]{2e} (CH_3)_2As^{III}O^{-} \xrightarrow{CH_3+} (CH_3)_3As^{V}O \xrightarrow[-O^{2-}]{2e} (CH_3)_3As^{III}$$

### 2.2.1 Aquatic system

There are many studies on the molecular forms of arsenic compounds in seawater have been reported into the concentration ratio As(III)/As(V) which is variable. The presence of arsenic (III) compounds is the result of some reductive activity, which could be either biological or non-biological effect of dissolved organic matter on arsenic (V). The finding of methylarsenic acids in seawater and fresh natural water is evidence that arsenic goes through reactions other than simple oxidation or reduction. In both sea and fresh water, the occurrence of methylarsenic compounds is associated with phytoplankton activity. In fresh water, the levels of methylarsenic compounds were especially high in locations where nutrients from fertilizers (presumably, also containing arsenic) had built up in lakes and ponds (WHO, 1981). Nevertheless, Sediment samples from two natural water environments did not contain unusually large amounts of methylarsenic compounds (WHO, 1981).

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### 2.2.2 Air-soil systems

Arsenic distributed in the environment is converted to arsenates except under highly reducing conditions. Arsenic ions are readily sorbed by hydrous oxides of iron and aluminium and leaching of arsenate is slow. Absorption appears to be a major factor in retention of arsenic in soils (WHO, 1981).

High arsenic levels can cause a depression in plant growth but the amounts required to produce this effect depend on the plant species. Bioaccumulation of arsenic in food crops is not particularly high. A proposed model of an air-soil arsenic system is shown in Figure 2-1. The system has little chance of being in apparent equilibrium, since air transport of transpiral volatile arsenic is rapid, compound with evolution rates.

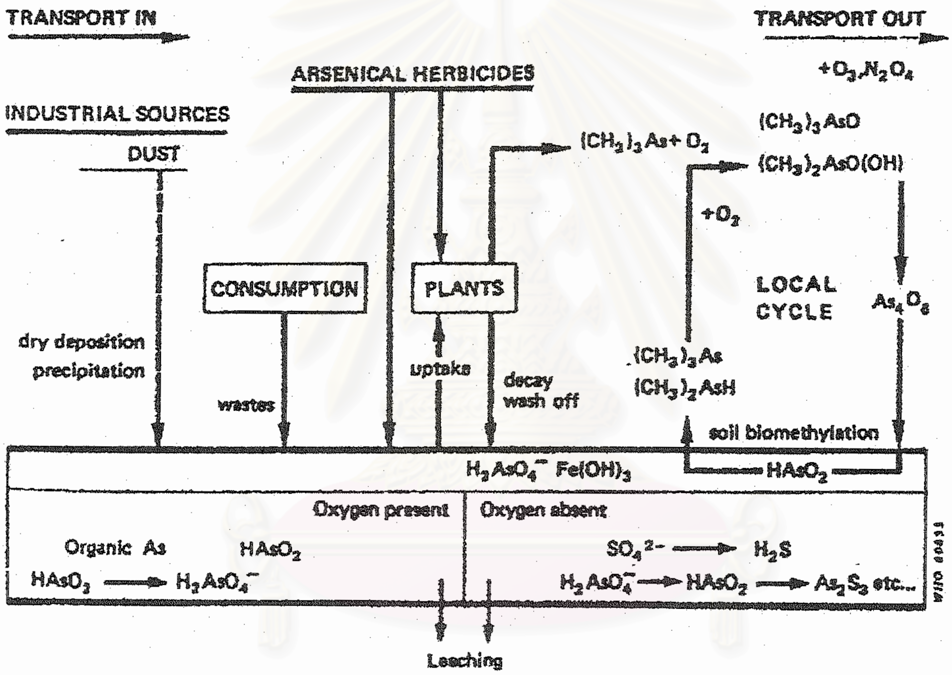

Figure 2-1 Soil-air cycle for arsenic.

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The most important translocation factors were absorption by soil and oxidation, uptake by vegetation, and volatilization after biomethylation (WHO, 1981).

### 2.2.3 Chemical behavior in soil

Arsenic is often described as a metalloid element, but for the chemical behavior in soil it can be thought of as a non-metal forming covalent compounds or being found in anionic species. The chemistry of arsenic in similar to phosphorus, commonly form oxyanion in the +5 oxidation state in soils, it is also found in +3 oxidation state (O'Neill, 1993).

The natural sources of arsenic in soils are mainly oxysalts and S containing minerals. The normal oxidizing conditions ate Earth's surface under which weathering takes place lead to formation of oxyanions based on the +5 oxidation state. The range of Eh and pH in soils can lead to either As(V) or As (III) with microbial activity causing methylation, demethylation and/or change in oxidation state and the presence of S species may, if the redox potential is low enough, favour the formation of arsenic sulphide minerals. A further complicating factor may be the presence of clay minerals, Fe and Al oxides and organic matter that can influence solubility and rate of oxidation.

The equilibria for arsenous acid, As(III), and arsenic acid, As(V), in aqueous solutions are given below. The $pK_a$ values indicate that the species that should be thermodynamically most stable over the normal soil pH ranges of 4-8 will be: (a) $H_3AsO_3$ (up to about pH 9); (b) $H_2AsO_4^-$ (approximately pH 2-7); (c) $HAsO_4^{2-}$ (above pH 7);

Arsenic acid

$$H_3AsO_4 + H_2O \rightleftharpoons H_2AsO_4^- + H_3O^+ \qquad pK_a\ 2.20$$

$$H_2AsO_4^- + H_2O \rightleftharpoons HAsO_4^{2-} + H_3O^+ \qquad pK_a\ 6.97$$

$$HAsO_4^{2-} + H_2O \rightleftharpoons AsO_4^{3-} + H_3O^+ \qquad pK_a\ 11.53$$

Arsenous acid

$$H_3AsO_3 + H_2O \rightleftharpoons H_2AsO_3^- + H_3O^+ \qquad pK_a\ 9.22$$

$$H_2AsO_3^- + H_2O \rightleftharpoons HAsO_3^{2-} + H_3O^+ \qquad pK_a\ 12.13$$

$$HAsO_3^{2-} + H_2O \rightleftharpoons AsO_3^{3-} + H_3O^+ \qquad pK_a\ 13.4$$

A change in ratio of As(V) to As(III) can be brought about purely be inorganic mechanism with Eh/pH changes, but the presence of microorganisms can also influence the reaction pathway (O'Neill, 1993).

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## 2.3 Phytoremediation

Phytoremediation is the use of certain plants and trees to clean up soil and water contaminated with metal and/or organic contaminants such as solvents, crude oil, and polyaromatic hydrocarbons (PAHs). Phytoremediation of metals is a cost-effective green technology based on the use of specially selected metal-accumulating plants to remove toxic metals, including radionuclides, from soils and water. Phytoremediation takes advantage of the fact; that a living plant can be compared to a solar driven pump, which can extract and concentrate particular elements from the environment. The metals targeted for phytoremediation include lead, cadmium, arsenic and various radionucildes. The harvest plant tissue, rich in accumulated contaminant, is easily and safety processed by drying, ashing or composting (Raskin, 1994).

### 2.3.1 The advantages of phytoremediation

The advantages of using metal accumulating plants to remove arsenic from contaminated soil as follows (Raskin, 1994)

1) Plants can transform toxic arsenic forms to less or non-toxic forms
2) Low cost to work and maintenance
3) Ability to treat contaminated areas in situ
4) Ability to apply with other treatment technologies

The suitable plants for remediation of heavy metals should have the following characteristics:

1) High metal accumulated in their shoot
2) High biomass especially in shoot
3) Widely distribution and can grow in high metal contaminated land
4) Short life span and life cycle
5) High propagation

### 2.3.2 Uptake of arsenic by plants

The uptake of arsenic by plants was studied in various plant s. In common with most trace elements, the degree of uptake varies widely from species to species. The degree of uptake and concentration of arsenic species absorbed by bean roots was arsenate > arsenite > monomethylarsonate > demethylarsinate, with toxicity being directly proportional to the root concentration (O'Neill, 1993). Besides, the uptake of arsenic and other heavy metals by chosen crops was studied by Tlustos, et al. (1997) that showed the difficulties to get positive effect of remediation treatment application in soil neutral in pH, high clay and organic matter content.

In addition , there is data indicates that when each soil type contains similar As concentrations, lower level are found in plants grown on clays and silts with their higher clay mineral and Fe/Al oxide content, than in plants growing on lighter soils such as sands or sandy loam (O'Neill, 1993).

### 2.3.3 Translocation and transformation of arsenic in plants

Entering the root, arsenic can be translocated to different part s of plant. Most studies are more concerned with accumulation of arsenic in agricultural products. In general roots contain higher level than stem, leaves or fruit (O'Neill, 1990).

Tlustos, et al. (1998) also indicated that root were the dominant part in arsenic uptake.

Pongratz, 1998 showed that the transformations from arsenate to arsenite resulted in monomethylarsonic acid and dimethylarsinic acid being present due to microbial activity, in addition, the transformations indicated by microorganism in the highly contaminated soil lead to detoxifacation.

After the transformation of arsenic occurs in the plant body, from root to shoot, phytotoxicity will take place. In general, arsenates are less toxic than arsenites (O'Neill, P., 1993). Arsenate is known to uncouple phosphorylation. It decouples the conversion of D-glyceraldehyde-3-P into 1,3-diphosphoglycerate by substituting the phosphate in position 1. The subsequent hydrolysis delivers no ATP. In addition, the toxicity of arsenic, particular 5+, may be explained by the formation of ADP-As so that the energy

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of adenosine triphosphate (ATP) is not available and the plant must slowly succumb (National Academy of Sciences, 1977).

### 2.4 *Colocasia esculenta* (L.) Schott

This plant, commonly known as Elephant-ear, grows well at either high or low altitude, in swamp, marshes, and other muddy shallow water areas. Optimum growth occurs in hot, humid areas. This large shore plant grows in riprap areas of reservoirs (Aquatic Plant Research and Control Florida Department of Natural Resources, 1979).

This herb with tuberous rhizomes has succulent stems usually from 0.5-1.2 m tall, but occasionally reaches a height of over 2-m under ideal conditions. Its large stiff leaves, 40-90 cm long, are thick in texture, ovate with a cordate base, and always peltate (Sripen, 1992 and International Cooperation of Agriculture and Forestry for Association, 1997). The inflorescence is much shorter than the petioles with the staminate flowers occupying the upper three-quarters and pistillate flowers the lower quarter section of a short cylindric crowded spedix (Figure 2-2). The pale yellow spathe is ovatelanceolate shaped usually with enrolling margins. The fruit of elephant-ear is an oblong berry containing numerous viable seeds. Reproduction also occurs by the production of stolons (Aquatic Plant Research and Control Florida Department of Natural Resources, 1979).

For this study, two types of *C. esculenta* were identified with petiole color, dark violet and green, as shown in Figure 2-3. In other characteristics, there was no difference between types.

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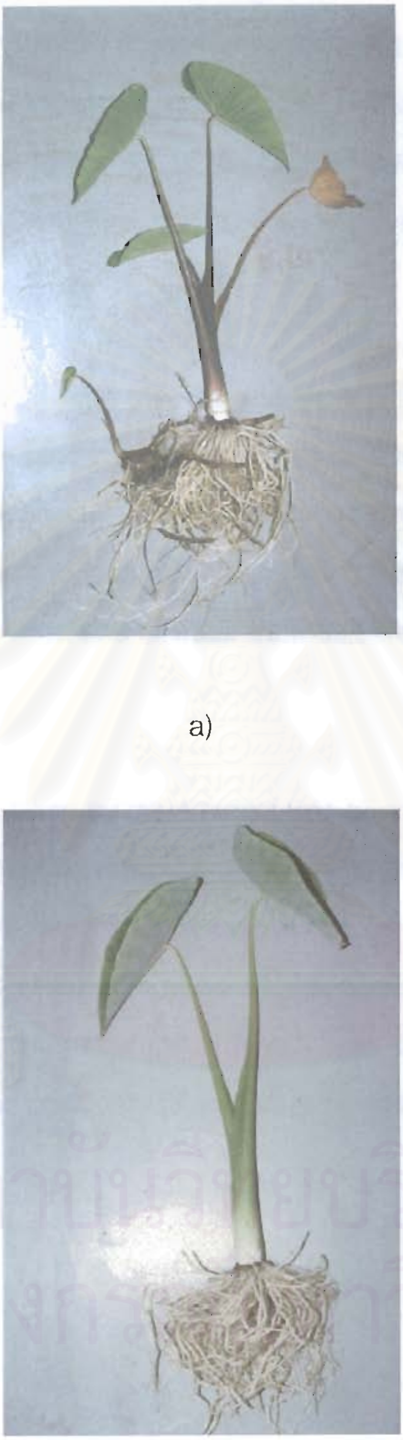
Figure 2-2 *Colocasia esculenta* (L.) Schott : a) habit b) inflorescence c) fruit



a)

b)

Figure 2-3 *Colocasia esculenta* (L.) Schott; a) dark violet b) green

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## 2.5 Case of arsenic contamination in Thailand

Towards late 1987, a news broke out that people in some villages of Amphoe Ron Phibum, Nakhon Sri Thammarat Province were suffering from Bowen's disease or basal cell cerinoma or simply known as skin cancer. Drinking arsenic contaminated water causes this disease. The symptoms of the disease are recognized as spots on skin, palm and sole which are prevalent among the people in 12 villages and vicinity areas of tin mines.

Results of investigation showed that the arsenic in water came from dissolution of arsenopyrite accumulated in placer deposits and water from ore dressing plants by floatation process. Arsenic contamination covered a broad area, more or less following the pathways of both surface and groundwater flows. Thus, high concentrations of arsenic can be found in soil, plants, and in water from dug wells. However, the disease is not contagious and providing clean water can do protection.

The remedial measure taken by government was to drill deep wells and extract clean water from limestone and shale at 50 m deep. Also, the people were trained to make cement jars and cement tanks to store rain water. In addition to providing the people with clean, arsenic-free water from deep aquifer, and arsenic removal, the team of hydrologists, environmental scientists and chemists from the Department of Mineral Resources also investigated the possibility of arsenic removal from soil and groundwater (Intrasuta, 1991).

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# CHAPTER III

# METHODOLOGY

This study was conducted at Bangpoo Industrial Estate, Samutprakarn Province. Experimental Scale was set near the officer residences.

## 3.1 Preparation

### 3.1.1 Soil

The top soil sample was collected from Pathumthani Province. Its chemical and physical properties are shown in Table 3-1. The soil texture is silt loam, both of conductivity and pH are common as organic matter. Not only available phosphorus but also potassium is high concentrated. In the other hand, nitrogen is humbly concentrated.

Table 3-1 Some chemical and physical properties in experimental soil.

| PROPERTIES | QUANTITY | METHODS |
|---|---|---|
| sand : silt : clay | 16.83 : 58.17 : 25.00 | Hydrometer Method |
| pH | 6.44 | pH Meter Method |
| CEC | 13.7518 me/100 g | Ammonium acetate |
| organic matter | 0.94 % | Walkey-Black Method |
| phosphorus | 575 mg/kg | Perchloric acid Digestion |
| nitrogen | 0.05 % | Kjeldahl Method |
| potassium | 369.3 mg/kg | Flame photometer |
| moisture | 20.2 % | Gravimetric Method |
| arsenic | non-detectable | Nitric acid and Sulfuric acid Digestion, Atomic Absorption Spectrophotometer with Hydride Generator |

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### 3.1.2 Preparation of *Colocasia esculenta* (L.) Schott

1) *Colocasia esculenta* (L.) Schott for this study are *Colocasia esculenta* (L.) Schott (dark violet) and *Colocasia esculenta* (L.) Schott (green), which those petiole are dark violet and green, respectively. Figure 3-1 illustrated the source of plant samples collected from Suphanburi Province. The circumference of *Colocasia esculenta* (L.) Schott (dark violet) petiole was determined in the range of 7.80-11.50 cm, whereas which of *Colocasia esculenta* (L.) Schott (green) was 10.20-15.60 cm.

Figure 3-1 *Colocasia esculenta (L.)* Schott were collected from natural area.

2) All clean plants were cut to obtain the corms which is conform to length is 20 cm as shown in Figure 3-2.

Figure 3-2 The performance of corm with petiole of *Colocasia esculenta* (L.) Schott was prepared for this experiment

### 3.1.3 Chemicals

1) Chemicals for this experiment is disodium hydrogen arsenate ($Na_2HAsO_4.7H_2O$) for soil treatments which provide to various concentrations of 0, 50, 75, 100, 125 and, 150 mg As/kg of soil.

2) Chemicals for soil and plant analysis are sulfuric acid, nitric acid, hydrochloric acid, potassium iodide, sodium hydroxide, and sodiumborohydride.

## 3.2 Procedure

### 3.2.1 Period for time

This study was set for three months, from January to April 2000. For all harvest time were shown in Table 3-2.

Table 3-2 Date for each harvest

| Harvest | Date |
|---|---|
| Start | 27 January 2000 |
| First harvest | 11 February 2000 |
| Second harvest | 26 February 2000 |
| Third harvest | 13 March 2000 |
| Forth harvest | 28 March 2000 |
| Fifth harvest | 12 April 200 |
| Sixth harvest | 27 April 2000 |

### 3.2.2 Plant samples

1) Arsenic non-detectable, a prepared plant sample was grown in a pot with 6 kilograms of soil and nursed for a month (Figure 3-3). Arsenic ($Na_2HAsO_4.7H_2O$) was added to these pots with the concentrations of 0, 50, 75, 100, 125, and 150 mg As/kg, respectively,

2) After already contaminated with arsenic, all plants would be arranged according to complete randomized design at approximately 0.75-m intervals.

### 3.2.3 Growth rate

1) Cumulative length of petiole was recorded from beginning to end, on 6 consecutive occasions over a 90-day trial period.

2) As same as cumulative length, which was recorded every 15 days, total dry weight was the total weight of all parts such as lamina, petiole, corm, and root.

### 3.2.4 Harvest

1) Harvests had been taken every 15 days for all 6 times. Each plant would be cleaned and separated into four parts such as root, corm, petiole and lamina.

2) All parts of plant samples are weighed for wet weight and then dried in the oven. The feasible temperature, for stable dry weight, was taken in 60 °C for 3 days.

3) All dry parts of plants are ground and then digested by acids.

a)

b)

Figure 3-3 Prepared plant samples; a) *Colocasia sp.* had been nursed in pots for a month, b) *Colocasia sp.* were ready to be contaminated with arsenic

### 3.2.5 Arsenic digestion

All parts of plant samples are provided to grind and then weigh each sample in 2.0 grams approximately. All samples are digested by nitric acid, sulfuric acid, and hydrogen peroxide (US EPA-3030, 1982) for non-color solution. After making volume up to 50 ml, arsenic sample solution would be detected by Atomic Absorption Spectrophotometer with Hydride Generator.

### 3.2.6 Arsenic accumulation in various parts of plants

Arsenic accumulation/concentration was calculated from amount of arsenic in which tissue of plant per dry weight as followed equation.

$$\text{As accumulation in tissues of plant (mg/kg)} = \frac{\text{amount of arsenic in tissues (mg)}}{\text{dry weight (kg)}}$$

### 3.2.7 Efficiency of arsenic removal

Efficiency of arsenic removal was calculated from total arsenic accumulated in plant per amount of arsenic in pot as followed equation.

$$\text{Efficiency of arsenic removal (\%)} = \frac{\text{[As in lamina +As in petiole+As in corm+As in root] (mg) X100}}{\text{Total As in pot (mg)}}$$

## 3.3 Data analysis

### 3.3.1 The growth rate of *Colocasia eaculenta* (L.) Schott.

The effect of arsenic on both plants was observed by the growth rate. In each harvest, the length of petiole was analyzed by analysis of variance (one-way ANOVA) with confidential level of 95%.

### 3.3.2 Arsenic accumulation in parts of *Colocasia sp.*

Arsenic accumulated in parts of *Colocasia sp.*, which are lamina, petiole, corm, and root, were tested by analysis of variance (two-way ANOVA) with confidential level of 95%.

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### 3.3.3 Compare of arsenic removal efficiency from soil by both plants

Three factors effect on the efficiency of arsenic removal are level of arsenic in soil, growing time, and types of plant was analyzed by two-way ANOVA. DMRT (Duncan Multiple Range Test) has proposed for composing any and all possible contrasts between factor means. This method could explain the difference between

1) Efficiency of arsenic removal with different plants.

2) Effect of variously arsenic concentrations in soil on efficiency of arsenic removal.

3) Effect of growth time on arsenic removal efficiency.

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# CHAPTER IV

# RESULTS AND DISCUSSION

## 4.1 General observation of *Colocasia esculenta* (L.) Schott

During experimental period, growth of *Colocasia esculenta* (L.) Schott was recorded into cumulative length and dry weight. In spathe production, the petiole of *C. esculenta* (dark violet) could be developed and spouted out from its corm more than *C. esculenta* (green). In contrast, petiole and lamina of *C. esculenta* (green) were larger than *C. esculenta* (dark violet) because of its natural characteristics. Moreover, all *C. esculenta* could survive under all conditions of arsenic concentration in soil and could grow as well as the controls (Figure 4-1).

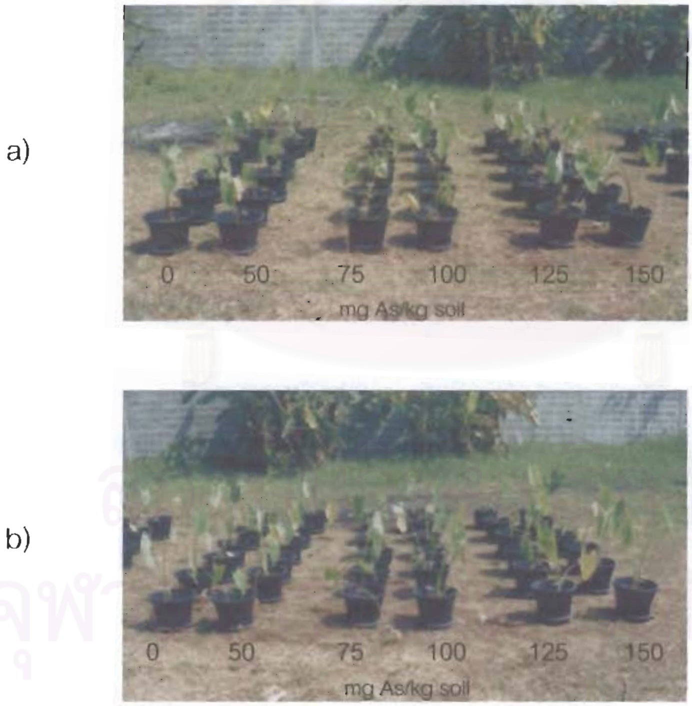

Figure 4-1 Growth of *Colocasia esculenta* (L.) Schott at day 30

a) *C.esculenta* (dark violet) b) *C. esculenta* (green)

## 4.2 Analysis in growth of *Colocasia esculenta* (L.) Schott

Concerning on the growth rate of *Colocasia esculenta* (L.) Shott (dark violet and green), weight and cumulative length were measured under condition of various arsenic concentrations of 0, 50, 75, 100, 125, and 150 mg As/kg. In addition, the data of weight and cumulative length in each pot were measured in the period of 15 days for all 90 days.

### 4.2.1 Cumulative length

The cumulative length of each plant was the sum of all petiole lengths and also compared with the controls, which is non-arsenic contamination.

Consider to *Colocasia esculenta* (L.) Schott (dark violet), the cumulative length had been consistently increasing throughout the experimental period of 90 days as shown in Figure 4-2. During the early phase of growth of experimental period, the length of *Colocasia esculenta* (L.) Schott (dark violet) were 117.20, 78.90, 104.93, 137.15, 143.38, and 142.80 cm with the concentrations of 0, 50, 75, 100, 125, and 150 mg As/kg, respectively. Besides, the maximum length of all contaminated plants occurring in the latest trials were 275.23, 245.78, 297.75, 314.58, 286.33, and 300.90 cm, respectively (Table 4-1). From statistical analysis, it was found that there was no significant difference between the treatment group and the controls (p. >0.05).

Consider to *Colocasia esculenta* (L.) Schott (green), the cumulative length had been consistently increasing throughout the experimental period of 90 days as shown in Figure 4-3. In the early trials, the cumulative length of *Colocasia esculenta* (L.) Schott (green) were 96.95, 98.88, 120.83, 121.18, 105.38, and 111.73 cm with the concentrations of 0, 50, 75, 100, 125, and 150 mg As/kg, respectively. Besides, the maximum length of all treated plants occurring in the latest trials were 305.43, 337.45, 336.30, 311.63, 267.38, and 312.83 cm, respectively (Table 4-2). As same as *Colocasia esculenta* (L.) Schott (dark violet), the statistical analysis showed that there was no significant difference between the treatment group and the controls (p. >0.05).

By comparing the growth between *C. esculenta*, it was found that average cumulative length of *Colocasia esculenta* (L.) Schott (dark violet) was higher than *Colocasia esculenta* (L.) Schott (green) in the early trials. On the contrary, the average length of *Colocasia esculenta* (L.) Schott (green) was higher than *Colocasia esculenta* (L.) Schott (dark violet) under all tested conditions during the latter part of experimental period. However, growth of both *C. esculenta* was related to harvest time.

Table 4-1 Cumulative length of *Colocasia esculenta* (L.) Schott (dark violet)

| Level of As concentration in soil (mg As/kg) | Cumulative length of *C. esculenta* (dark violet ) at harvest time (cm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | day 0 | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 0 mg/kg | 117.20$^{a}$ | 139.53$^{a}$ | 187.78$^{a}$ | 197.20$^{a}$ | 217.30$^{a}$ | 242.85$^{a}$ | 275.23$^{a}$ |
| 50 mg/kg | 78.90$^{a}$ | 111.48$^{a}$ | 167.23$^{a}$ | 174.28$^{a}$ | 195.70$^{a}$ | 219.73$^{a}$ | 245.78$^{a}$ |
| 75 mg/kg | 104.93$^{a}$ | 122.30$^{a}$ | 181.48$^{a}$ | 211.85$^{a}$ | 238.33$^{a}$ | 268.18$^{a}$ | 297.75$^{a}$ |
| 100 mg/kg | 137.15$^{a}$ | 154.48$^{a}$ | 222.45$^{a}$ | 237.18$^{a}$ | 255.30$^{a}$ | 290.78$^{a}$ | 314.58$^{a}$ |
| 125 mg/kg | 143.38$^{a}$ | 158.78$^{a}$ | 205.85$^{a}$ | 220.50$^{a}$ | 231.20$^{a}$ | 268.65$^{a}$ | 286.33$^{a}$ |
| 150 mg/kg | 142.80$^{a}$ | 160.28$^{a}$ | 200.95$^{a}$ | 214.38$^{a}$ | 243.90$^{a}$ | 283.73$^{a}$ | 300.90$^{a}$ |

Note: The alphabet on the right corner means there is no significant difference at 95% confidence.

Table 4-2 Cumulative length of *Colocasia esculenta* (L.) Schott (green)

| Level of As Concentration in soil (mg As/kg) | Cumulative length of *C. esculenta* (green) at harvest time (cm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | day 0 | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 0 mg/kg | 96.95$^{a}$ | 118.05$^{a}$ | 183.43$^{a}$ | 203.20$^{a}$ | 223.78$^{a}$ | 259.95$^{a}$ | 305.43$^{a}$ |
| 50 mg/kg | 98.88$^{a}$ | 146.33$^{a}$ | 194.25$^{a}$ | 211.83$^{a}$ | 263.78$^{a}$ | 288.48$^{a}$ | 337.45$^{a}$ |
| 75 mg/kg | 120.83$^{a}$ | 136.95$^{a}$ | 185.30$^{a}$ | 211.60$^{a}$ | 250.00$^{a}$ | 276.78$^{a}$ | 336.30$^{a}$ |
| 100 mg/kg | 121.18$^{a}$ | 157.88$^{a}$ | 190.30$^{a}$ | 211.85$^{a}$ | 264.88$^{a}$ | 293.28$^{a}$ | 311.63$^{a}$ |
| 125 mg/kg | 105.38$^{a}$ | 133.28$^{a}$ | 169.55$^{a}$ | 177.13$^{a}$ | 202.88$^{a}$ | 249.55$^{a}$ | 303.43$^{a}$ |
| 150 mg/kg | 111.73$^{a}$ | 141.83$^{a}$ | 181.73$^{a}$ | 191.45$^{a}$ | 227.88$^{a}$ | 273.93$^{a}$ | 312.83$^{a}$ |

Note: The alphabet on the right corner means there is no significant difference at 95% confidence.

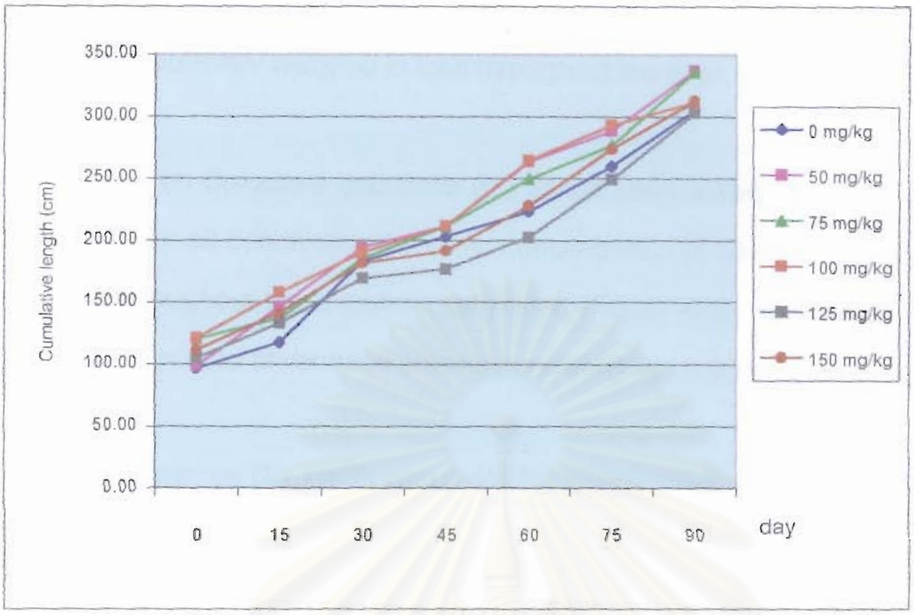

Figure 4-2 Trend of cumulative length of *Colocasia esculenta* (L.) Schott (dark violet)

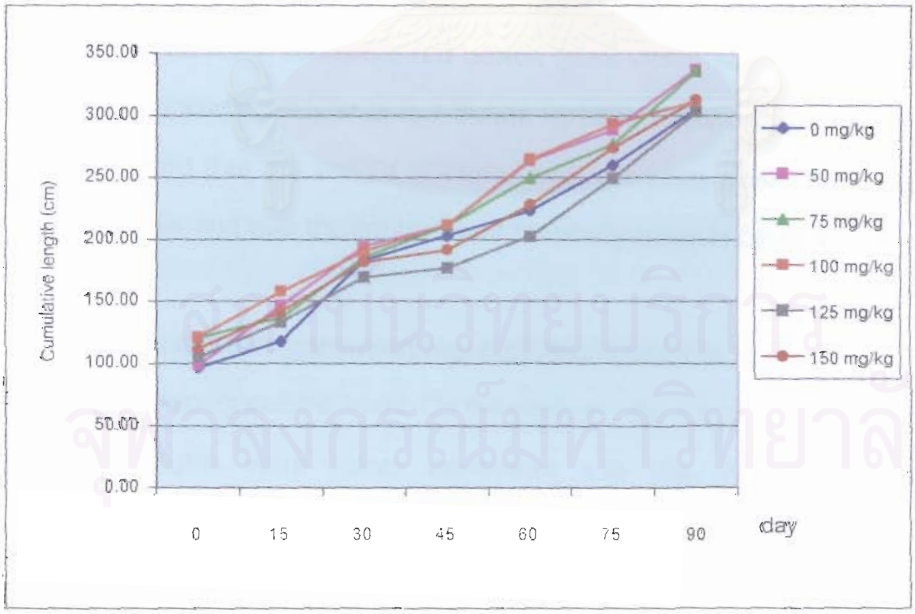

Figure 4-3 Trend of cumulative length of *Colocasia esculenta* (L.) Schott (green)

### 4.2.2 Dry weight

For weight of plants, all parts of *C. esculenta* consisting of lamina, petiole, corm, and root were consecutively weighed in total throughout the trials.

Concerning on *Colocasia esculenta* (L.) Schott (dark violet), total dry weight of plants growing under all conditions of arsenic concentration of 50-150 mg As/kg seem to be increased throughout the experimental period (Figure 4-4). However, there were fluctuations in some record of variance arsenic conditions as shown in Table 4-3.

In the same way as *Colocasia esculenta* (L.) Schott (dark violet), total dry weight of *Colocasia esculenta* (L.) Schott (green) growing under all conditions of various arsenic concentrations of 50-150 mg As/kg tended to increase throughout the experimental period (Figure 4-5). Nevertheless, there were fluctuations in some arsenic conditions as shown in Table 4-4.

In this experiment, the total weight of *Colocasia esculenta* (L.) Schott (green) is comparable with *Colocasia esculenta* (L.) Schott (dark violet). It was illustrated that the total weight of with *Colocasia esculenta* (L.) Schott (dark violet) was slightly lower than the weight of with *Colocasia esculenta* (L.) Schott (green). Comparing of weight of the four parts, it was found that the weight of corm, and root were close to the weight of petiole. Accordingly, lamina was the lightest over the study period (Table 4-5 and 4-6).

In order to being rather generated regularly, those weights of lamina and petiole had been increasing throughout the trials. On the contrary, the corm and root was slowly grown, so their weights were rather consistent with this experimental period. Consequently, the weight of lamina and petiole of both *C. esculenta* may be occasionally higher than the weight of corm and root.

From Figure 4-6 to 4-13, it illustrated dry weight of each parts of both *C. esculenta* over study period.

Table 4-3 Total dry weight of *Colocasia esculenta* (L.) Schott (dark violet)

| Level of As Concentration in soil (mg As/kg) | Total dry weight at harvest time (g) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 0 | 11.6435 | 14.9068 | 10.5191 | 17.8756 | 9.3689 | 25.7674 |
| 50 | 12.2695 | 13.0390 | 16.3532 | 16.0467 | 15.4819 | 23.0177 |
| 75 | 7.9943 | 10.4990 | 13.1960 | 13.8990 | 15.4087 | 21.2580 |
| 100 | 9.6974 | 11.9310 | 18.5931 | 17.9101 | 18.1589 | 17.4026 |
| 125 | 10.2605 | 9.6789 | 13.4672 | 14.5098 | 18.0225 | 12.3824 |
| 150 | 7.1660 | 12.8562 | 15.2964 | 16.2590 | 16.4094 | 21.1379 |

Table 4-4 Total dry weight of *Colocasia esculenta* (L.) Schott (green)

| Level of As Concentration in soil (mg As/kg) | Total dry weight at harvest time (g) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 0 | 13.8021 | 13.3097 | 17.3553 | 18.7176 | 20.2033 | 15.8535 |
| 50 | 13.6071 | 13.9937 | 14.3430 | 19.1377 | 20.6877 | 20.9398 |
| 75 | 12.0616 | 15.2853 | 16.0030 | 15.3464 | 14.6771 | 23.7989 |
| 100 | 13.3326 | 17.7868 | 13.1969 | 15.2013 | 22.9862 | 23.0970 |
| 125 | 10.9264 | 11.0678 | 11.3792 | 13.8779 | 16.2698 | 20.7533 |
| 150 | 11.3573 | 14.9472 | 14.9997 | 15.3668 | 18.7293 | 21.9687 |

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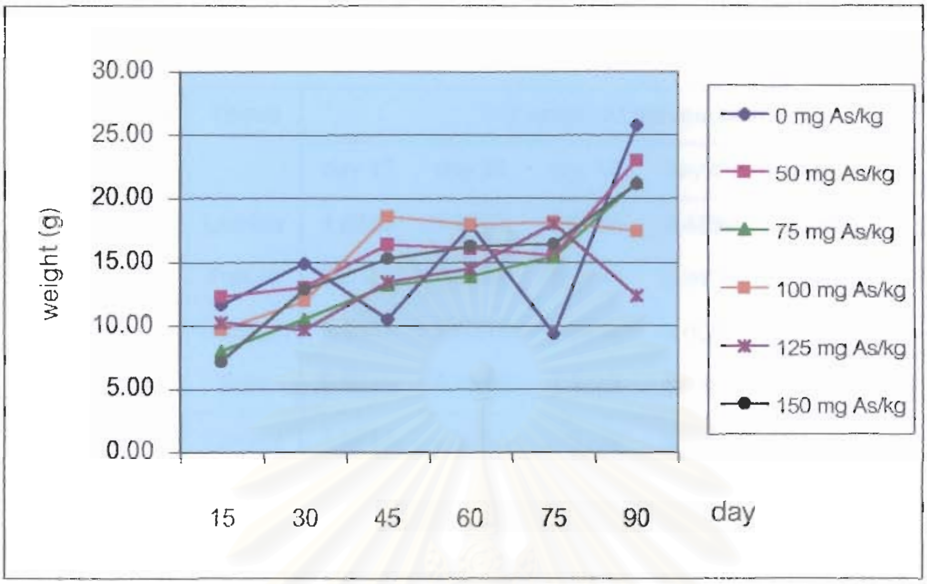

Figure 4-4 Total dry weight of *Colocasia esculenta* (L.) Schott (dark violet)

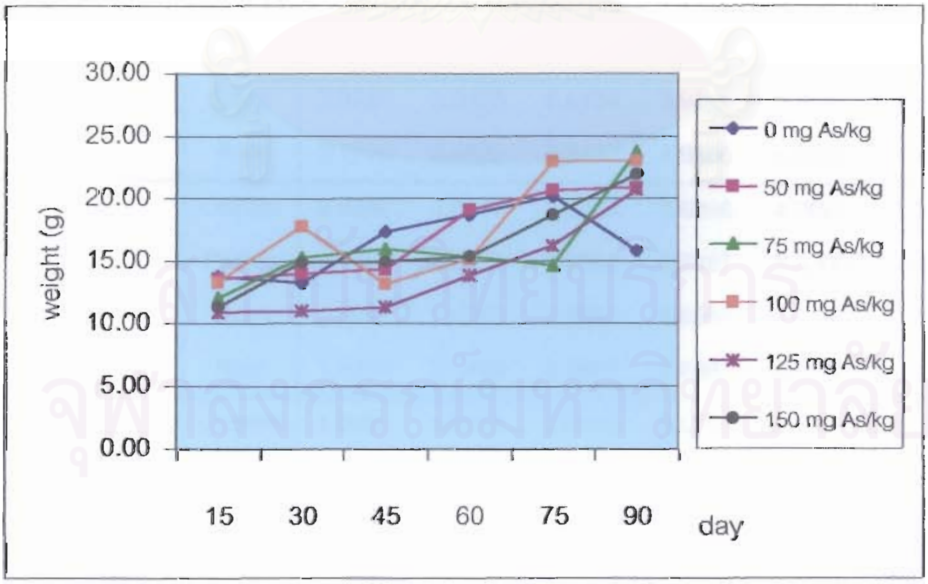

Figure 4-5 Total dry weight of *Colocasia esculenta* (L.) Schott (green)

Table 4-5 Dry weight of various parts of *Colocasia esculenta* (L.) Schott (dark violet)

| Level of As Concentration in soil (mg As/kg) | Tissue | Dry weight at harvest time (g) | | | | | |
|---|---|---|---|---|---|---|---|
| | | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 0 | Lamina | 1.8752 | 1.9883 | 1.9608 | 3.4559 | 2.7286 | 5.8928 |
| | Petiole | 2.8087 | 3.4176 | 3.1797 | 5.8809 | 3.1856 | 7.4040 |
| | Corm | 2.3051 | 3.0293 | 1.8404 | 3.0030 | 2.0006 | 4.1360 |
| | Root | 2.6545 | 6.4716 | 3.5382 | 5.5358 | 1.4541 | 8.3346 |
| 50 | Lamina | 1.9878 | 2.3062 | 2.6289 | 3.8995 | 2.9606 | 5.7581 |
| | Petiole | 1.9536 | 4.1243 | 3.7679 | 4.2760 | 3.2323 | 6.2489 |
| | Corm | 2.5169 | 2.5048 | 4.5347 | 3.0881 | 3.6385 | 3.0162 |
| | Root | 5.8112 | 4.1037 | 5.4217 | 4.7831 | 5.6505 | 7.9945 |
| 75 | Lamina | 1.8506 | 1.6464 | 2.3568 | 2.4020 | 3.2356 | 3.9152 |
| | Petiole | 2.0237 | 3.0129 | 4.1298 | 4.5383 | 4.8664 | 7.2144 |
| | Corm | 2.2484 | 1.8902 | 3.7771 | 2.9164 | 2.1151 | 2.7457 |
| | Root | 1.8716 | 3.8004 | 2.9323 | 4.0423 | 5.1916 | 7.3827 |
| 100 | Lamina | 1.2871 | 2.2255 | 3.0154 | 3.3697 | 3.6592 | 3.1360 |
| | Petiole | 2.8839 | 3.2117 | 4.6151 | 5.7360 | 5.9483 | 5.1820 |
| | Corm | 2.8238 | 3.0116 | 5.4134 | 3.9386 | 2.3496 | 2.5286 |
| | Root | 2.7026 | 3.4822 | 5.5492 | 4.8658 | 6.0218 | 6.5560 |
| 125 | Lamina | 2.0340 | 1.8747 | 1.6402 | 2.6396 | 4.2697 | 2.2006 |
| | Petiole | 3.1394 | 3.2499 | 3.2277 | 3.9387 | 5.9309 | 4.6137 |
| | Corm | 3.5617 | 2.4049 | 4.3043 | 4.0954 | 3.0406 | 2.6064 |
| | Root | 1.5254 | 2.1499 | 4.2950 | 3.8361 | 4.7813 | 2.9617 |
| 150 | Lamina | 1.0250 | 1.8147 | 3.0770 | 3.5269 | 3.1453 | 3.8256 |
| | Petiole | 2.0989 | 3.4699 | 4.7475 | 5.2151 | 4.4813 | 8.1908 |
| | Corm | 3.0840 | 3.6416 | 2.6101 | 3.4527 | 4.6095 | 4.5851 |
| | Root | 0.9581 | 3.9371 | 4.8618 | 4.0643 | 4.1733 | 4.5364 |

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Table 4-6 Dry weight of various parts of *Colocasia esculenta* (L.) Schott (green)

| Level of As Concentration in soil (mg As/kg) | Tissue | Dry weight at harvest time (g) | | | | | |
|---|---|---|---|---|---|---|---|
| | | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 0 | Lamina | 2.2188 | 1.7086 | 1.9578 | 4.0752 | 4.8927 | 3.2714 |
| | Petiole | 4.0984 | 4.2922 | 3.7196 | 5.1644 | 5.7789 | 4.8487 |
| | Corm | 3.2331 | 3.5850 | 5.3497 | 3.7267 | 4.0943 | 2.9247 |
| | Root | 4.2518 | 3.7239 | 6.3282 | 5.7513 | 5.4374 | 4.8087 |
| 50 | Lamina | 2.3596 | 2.5572 | 2.5303 | 3.6884 | 4.9604 | 5.4676 |
| | Petiole | 3.4157 | 3.8271 | 3.2968 | 5.0753 | 5.2990 | 7.8674 |
| | Corm | 4.1001 | 3.5008 | 3.2483 | 4.8258 | 3.8015 | 4.1620 |
| | Root | 3.7317 | 4.1086 | 5.2676 | 5.5482 | 6.6268 | 3.4428 |
| 75 | Lamina | 2.3695 | 2.6207 | 2.7657 | 2.4770 | 2.4695 | 4.5307 |
| | Petiole | 3.4530 | 4.1529 | 4.1135 | 4.8828 | 4.1563 | 6.8670 |
| | Corm | 3.7785 | 3.9974 | 3.8950 | 2.8047 | 3.4976 | 4.4230 |
| | Root | 2.4606 | 4.5143 | 5.2288 | 5.1819 | 4.5537 | 7.9782 |
| 100 | Lamina | 2.7043 | 3.2113 | 2.1217 | 3.2901 | 5.0470 | 5.0224 |
| | Petiole | 4.6415 | 5.3948 | 4.0637 | 4.5954 | 6.4066 | 7.7193 |
| | Corm | 3.1684 | 5.1733 | 3.7952 | 3.1058 | 5.8461 | 4.6602 |
| | Root | 2.8184 | 4.0074 | 3.2163 | 4.2100 | 5.6865 | 5.6951 |
| 125 | Lamina | 1.7553 | 2.1617 | 1.7971 | 2.4351 | 3.1830 | 4.6659 |
| | Petiole | 3.7130 | 3.0612 | 3.8209 | 3.5913 | 4.6772 | 6.5026 |
| | Corm | 4.0301 | 3.7796 | 2.6546 | 3.9403 | 3.9396 | 3.6165 |
| | Root | 1.4280 | 2.0653 | 3.1066 | 3.9112 | 4.4700 | 5.9683 |
| 150 | Lamina | 1.7936 | 2.3781 | 3.1423 | 3.2845 | 3.9452 | 5.1959 |
| | Petiole | 3.6078 | 4.8612 | 4.7765 | 5.2445 | 4.5808 | 7.4400 |
| | Corm | 3.9212 | 4.7994 | 3.9393 | 3.9979 | 5.5055 | 3.6457 |
| | Root | 2.0347 | 2.9085 | 3.1416 | 2.8399 | 4.6978 | 5.6871 |

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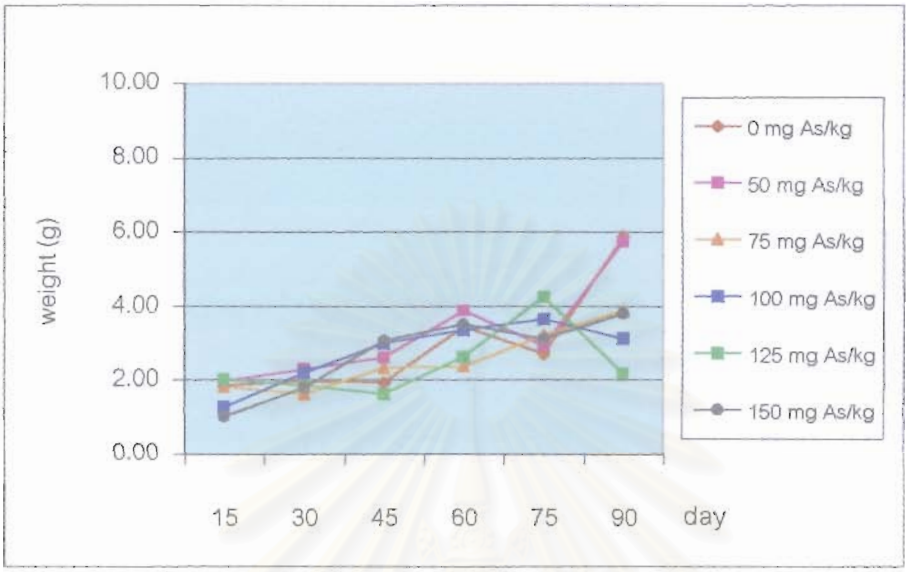

Figure 4-6 Weight of lamina of *Colocasia esculenta* (L.) Schott (dark violet)

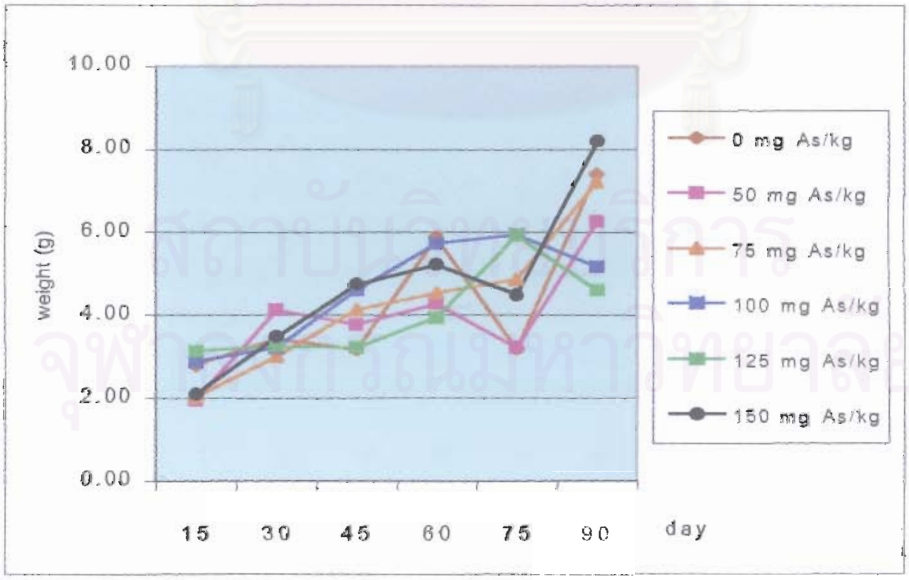

Figure 4-7 Weight of petiole of *Colocasia esculenta* (L.) Schott (dark violet)

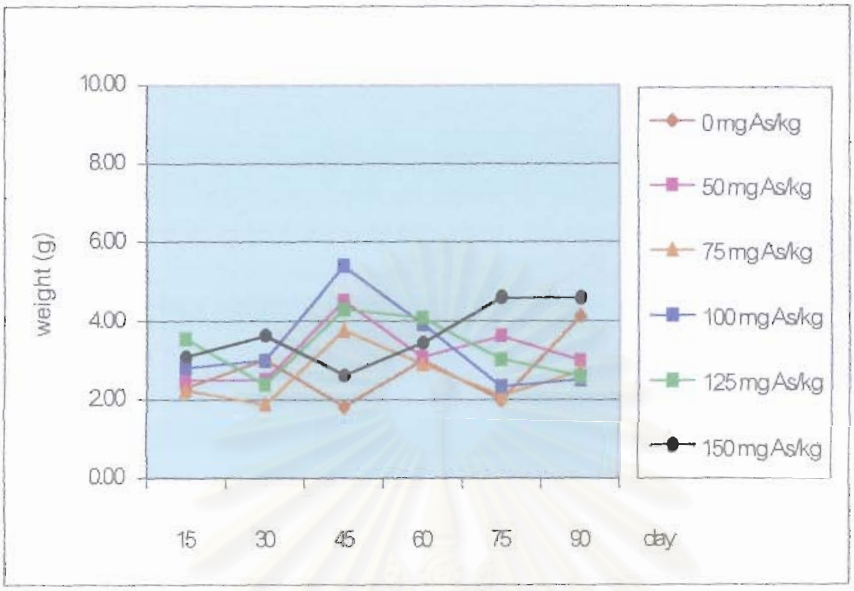

Figure 4-8 Weight of corm of *Colocasia esculenta* (L.) Schott (dark violet)

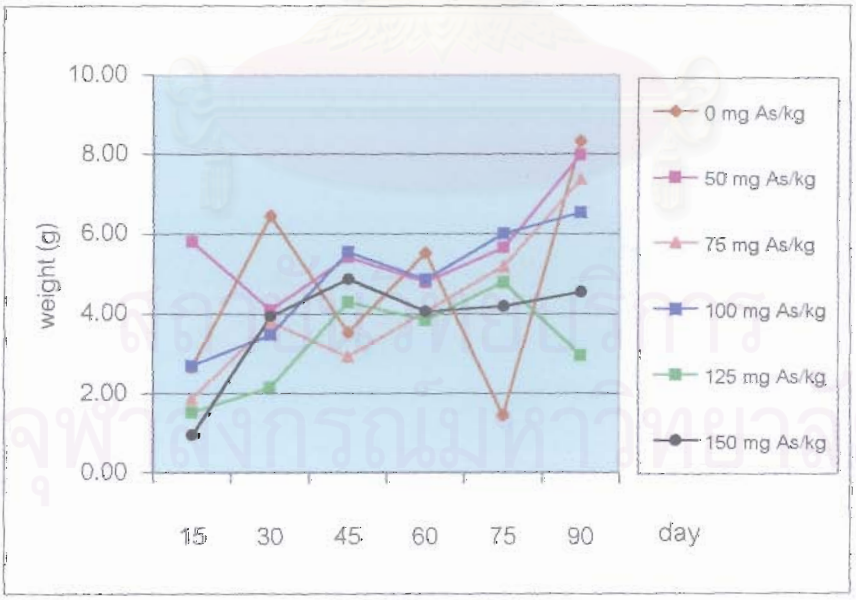

Figure 4-9 Weight of root of *Colocasia esculenta* (L.) Schott (dark violet)

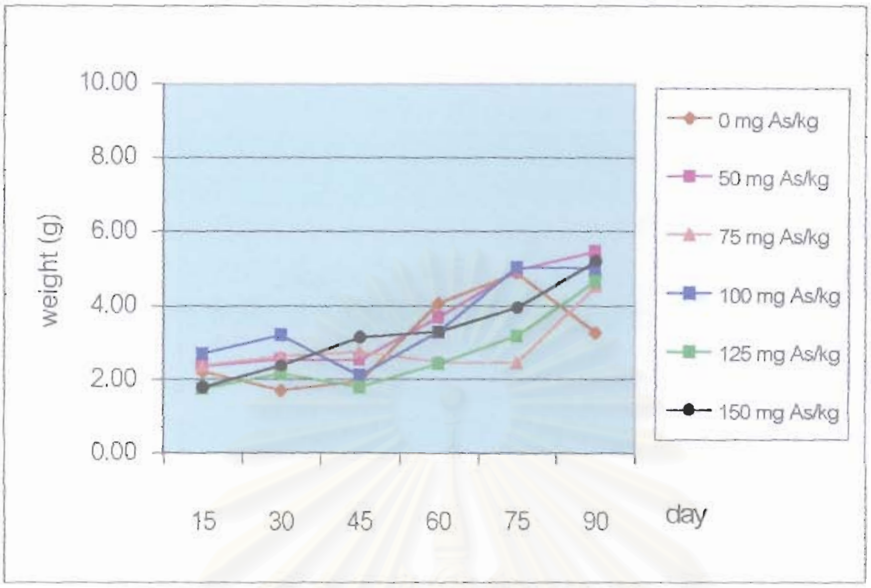

Figure 4-10 Weight of lamina of *Colocasia esculenta* (L.) Schott (green)

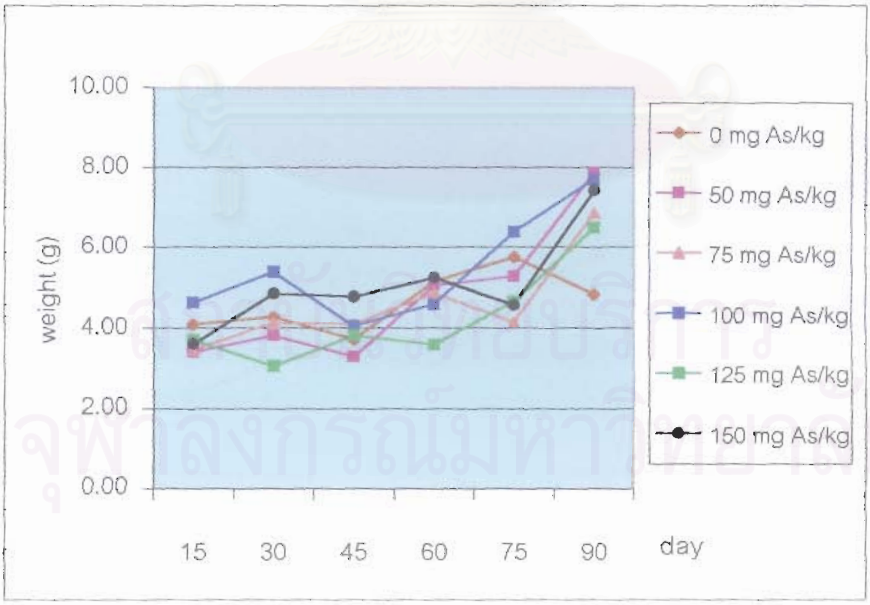

Figure 4-11 Weight of petiole of *Colocasia esculenta* (L.) Schott (green)

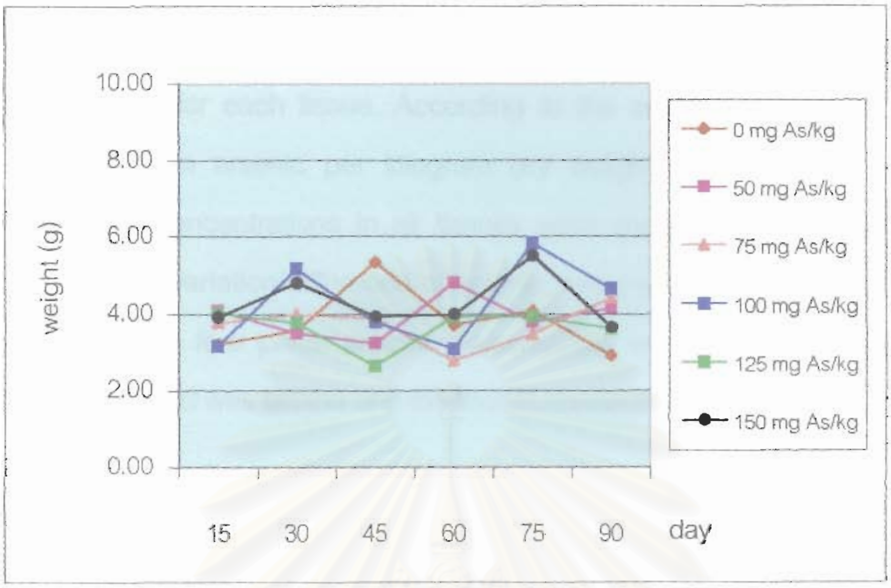

Figure 4-12 Weight of corm of *Colocasia esculenta* (L.) Schott (green)

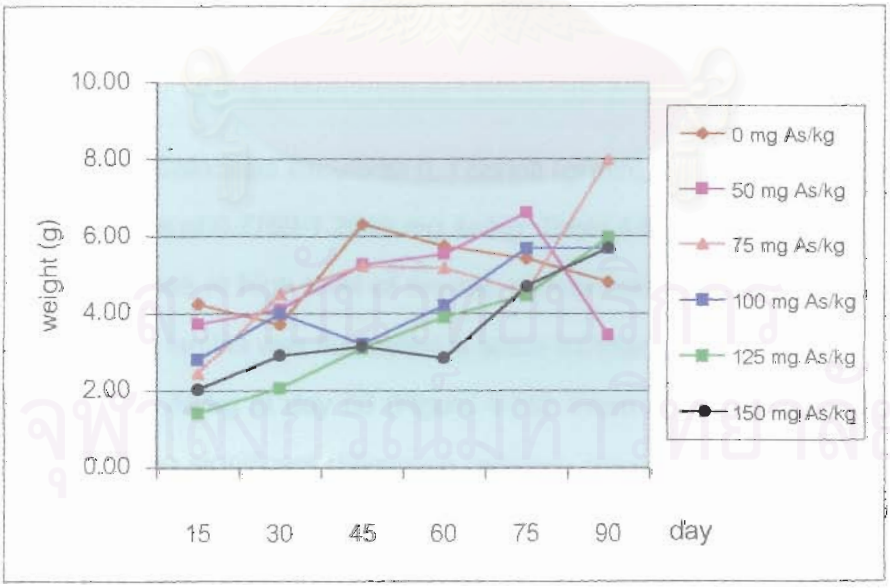

Figure 4-13 Weight of root of *Colocasia esculenta* (L.) Schott (green)

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### 4.3 Arsenic accumulation in various parts of *Colocasia esculenta* (L.) Schott.

Arsenic accumulation in both *C. esculenta* (dark violet and green), all contaminated plants were divided into four parts which are lamina, petiole, corm, and root and then analyzed for each tissue. According to the amount of arsenic, it was determined into milligram arsenic per kilogram dry weight (mg As/kg). The data indicated that arsenic concentrations in all tissues were sharply increased over the experiment. Despite the variation/difference of arsenic accumulation in various parts of *C. esculenta*, among the four parts, arsenic accumulation in root was the most, the second was corm, the third was lamina and the lowest accumulation was petiole.

#### 4.3.1 Arsenic accumulation in lamina

Arsenic accumulations in lamina of *Colocasia esculenta* (L.) Schott (dark violet) were in the range of 0.7679-1.6814 mg As/kg. Table 4-7 illustrated that arsenic in lamina was higher in the ending of the growth period and corresponding to high level of arsenic concentration in soil. However, the most of arsenic accumulation in lamina was fluctuated in some harvest time and was the highest in treatment of 100 mg As/kg at day 30 (Figure 4-14). From statistical analysis, it was shown that there was significant difference between treatments and harvest time ($p. < 0.05$) as shown in APPENDIX D.

Concerning on *Colocasia esculenta* (L.) Schott (green), arsenic accumulations in lamina were in the range of 0.7769-1.2645 mg As/kg. Table 4-8 illustrated that arsenic in lamina tended to increase at high level of arsenic concentration in soil. However, all of arsenic accumulation in lamina was fluctuated in some harvest time and was the highest in treatment of 150 mg As/kg at day 60 (Figure 4-15). From statistical analysis, it was shown that there was no significant difference between harvest time except at day 60 ($p. < 0.05$). For treatments of arsenic concentration in soil, the statistical analysis indicated that there was significant difference between treatments especially 50 mg As/kg.

Table 4-7 Arsenic accumulation in lamina of *Colocasia esculenta* (L.) Schott (dark violet)

| Level of arsenic concentration in soil (mg As/kg) | Arsenic accumulation in lamina at harvest time (mg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 0.7679 | 1.0927 | 0.8799 | 0.8076 | 0.8276 | 0.9625 |
| 75 | 0.8666 | 1.1560 | 1.1272 | 0.9678 | 0.9855 | 0.9965 |
| 100 | 1.3378 | 1.6814 | 1.2251 | 0.9894 | 1.0978 | 1.1265 |
| 125 | 1.2682 | 1.6656 | 1.4553 | 1.1183 | 1.1415 | 1.3231 |
| 150 | 1.3933 | 1.4922 | 1.4459 | 1.3541 | 1.3258 | 1.4617 |

Table 4-8 Arsenic accumulation in lamina of *Colocasia esculenta* (L.) Schott (green)

| Level of arsenic concentration in soil (mg As/kg) | Arsenic accumulation in lamina at harvest time (mg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 0.7827 | 0.7769 | 0.7911 | 0.8773 | 0.8708 | 0.8012 |
| 75 | 1.0235 | 1.0442 | 1.0788 | 1.0740 | 1.0756 | 1.0812 |
| 100 | 1.0227 | 0.9521 | 1.2380 | 1.2172 | 1.1712 | 1.0470 |
| 125 | 1.2639 | 1.1511 | 1.1505 | 1.1612 | 1.0935 | 1.1958 |
| 150 | 1.2064 | 1.2622 | 1.1608 | 1.2645 | 1.0837 | 1.1865 |

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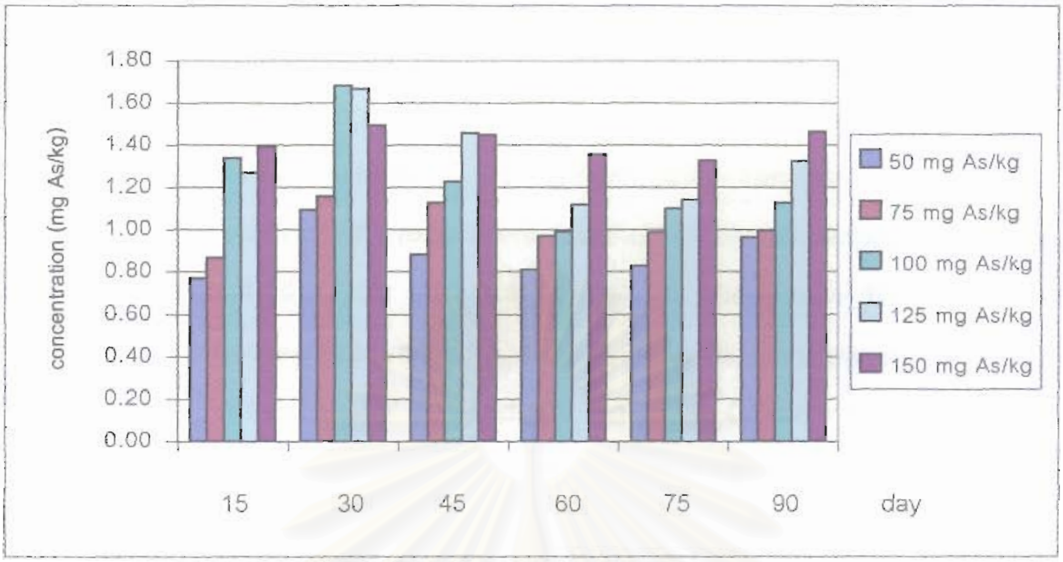

Figure 4-14 Arsenic accumulation in lamina of *Colocasia esculenta* (L.) Schott (dark violet)

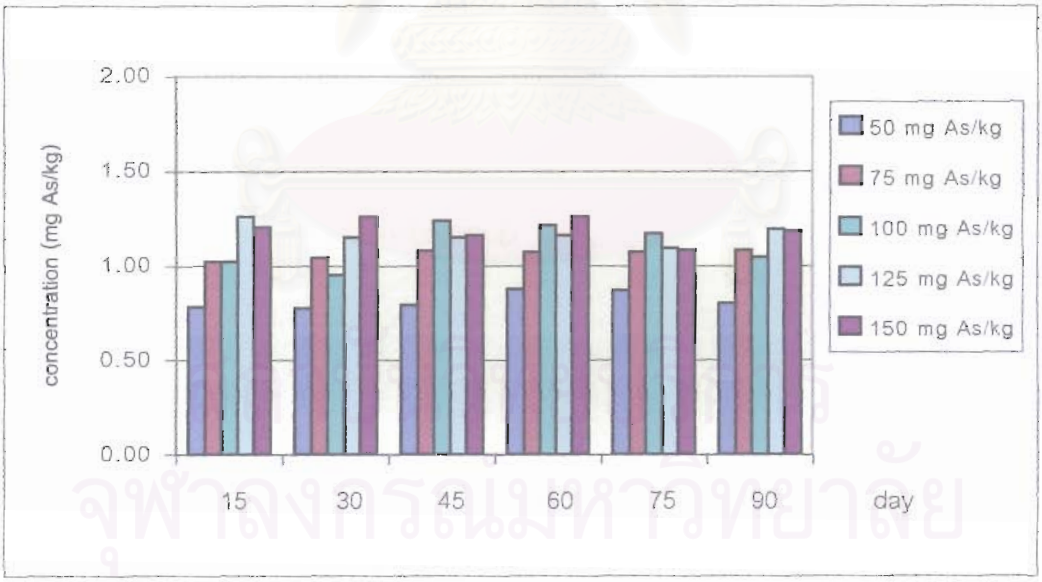

Figure 4-15 Arsenic accumulation in lamina of *Colocasia esculenta* (L.) Schott (green)

### 4.3.2 Arsenic accumulation in petiole

Arsenic accumulations in petiole of *Colocasia esculenta* (L.) Schott (dark violet) were in the range of 0.3972-0.9533 mg As/kg. Table 4-9 illustrated that the minimum arsenic in petiole was 0.3972 mg As/kg in treatment of 50 mg As/kg and the maximum was 0.9533 mg As/kg in the treatment of 125 mg As/kg soil in early trials. In addition, it mostly tended to increase over the experiment, but then it was also fluctuated in some harvest times (Figure 4-16). From statistical analysis, it was shown that there was significant difference between treatments ($p. < 0.05$), however, there was no significant difference between the treatment of 125 and 150 mg As/kg. Consider to harvest time, there was no difference between the group of day 15 and 90 and the group of day 30, 45, 60, and 75 (APPENDIX D).

Consider to *Colocasia esculenta* (L.) Schott (green), that arsenic accumulations in petiole were in range of 0.5421-1.1291 mg As/kg. In Table 4-10, arsenic accumulated in petiole was the lowest at 0.5421 mg As/kg in treatment of 50 mg As/kg at day 15 and the highest at 1.1291 mg As/kg in treatment of 150 mg As/kg at day 90. Furthermore, it mostly tended to increase throughout the experiment, nevertheless, there was fluctuation in treatment of 50 and 75mg As/kg among the study period (Figure 4-17). From statistical analysis, it was illustrated that there was significant difference between treatments ($p. < 0.05$) as shown in APPENDIX D.

Table 4-9 Arsenic accumulation in petiole of *Colocasia esculenta* (L.) Schott (dark violet)

| Level of arsenic concentration in soil (mg As/kg) | Arsenic accumulation in petiole at harvest time (mg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 0.3972 | 0.5177 | 0.5304 | 0.5457 | 0.5826 | 0.5612 |
| 75 | 0.5881 | 0.6023 | 0.6946 | 0.6315 | 0.6384 | 0.5295 |
| 100 | 0.6901 | 0.7842 | 0.8430 | 0.6979 | 0.7566 | 0.7655 |
| 125 | 0.9533 | 0.9211 | 0.8542 | 0.8298 | 0.8303 | 0.7487 |
| 150 | 0.8528 | 0.8591 | 0.8435 | 0.8925 | 0.8708 | 0.8902 |

Table 4-10 Arsenic accumulation in petiole of *Colocasia esculenta* (L.) Schott (green)

| Level of arsenic concentration in soil (mg As/kg) | Arsenic accumulation in petiole at harvest time (mg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 0.5421 | 0.6116 | 0.6558 | 0.6307 | 0.6281 | 0.6093 |
| 75 | 0.6611 | 0.6303 | 0.6430 | 0.6380 | 0.7840 | 0.7187 |
| 100 | 0.9129 | 0.9122 | 0.9143 | 0.9556 | 0.9801 | 0.9566 |
| 125 | 0.9626 | 1.0036 | 1.0045 | 1.0077 | 1.0063 | 1.0688 |
| 150 | 0.9759 | 1.0502 | 1.0857 | 1.0969 | 1.1156 | 1.1291 |

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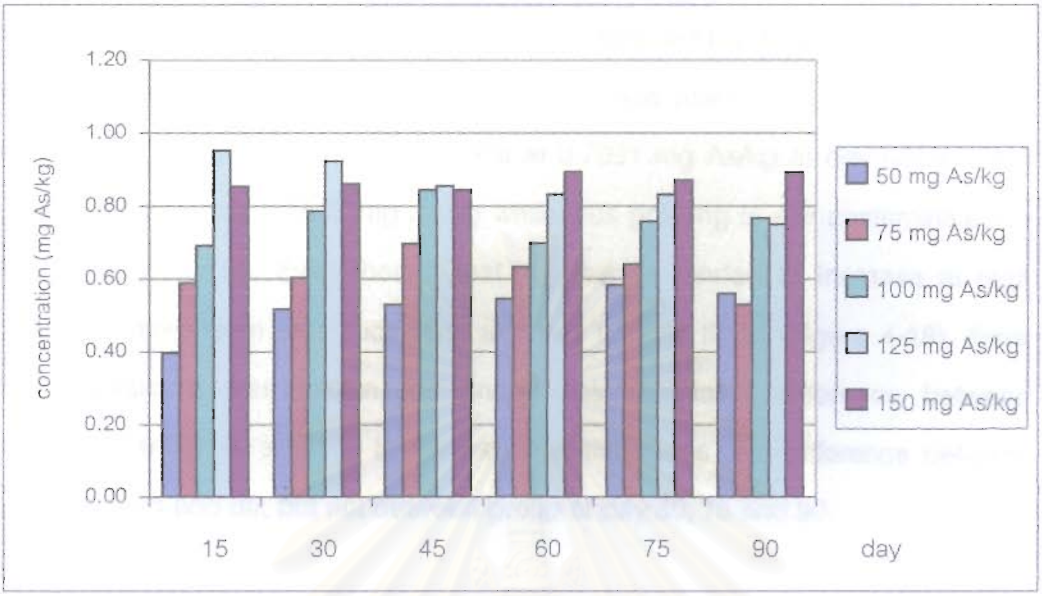

Figure 4-16 Arsenic accumulation in petiole of *Colocasia esculenta* (L.) Schott (dark violet)

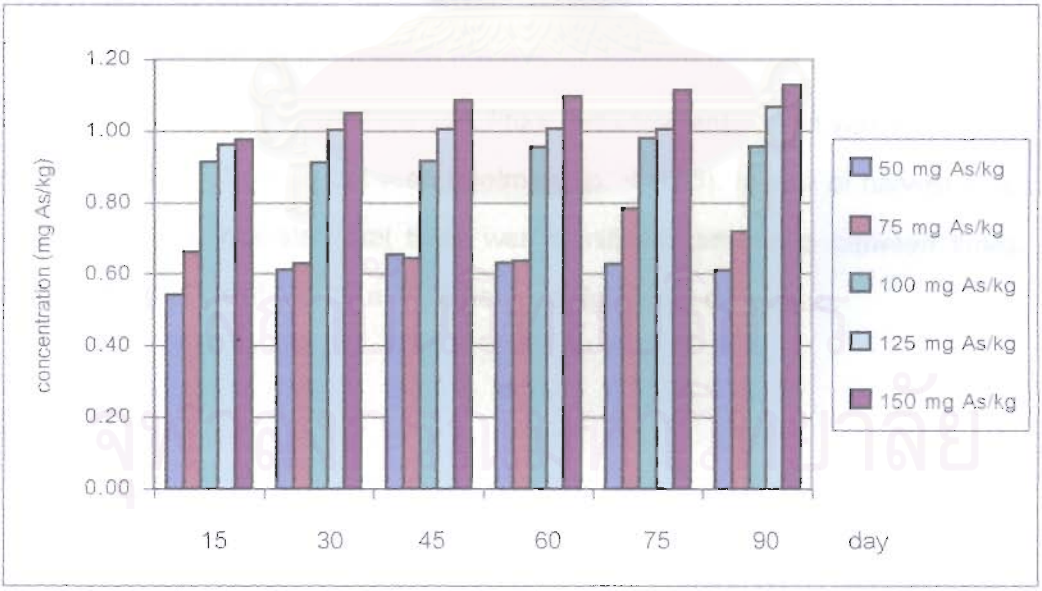

Figure 4-17 Arsenic accumulation in petiole of *Colocasia esculenta* (L.) Schott (green)

### 4.3.3 Arsenic accumulation in corm

Arsenic accumulations in corm of *Colocasia esculenta* (L.) Schott (dark violet) were in the range of 0.7091-2.0511 mg As/kg. Table 4-11 presented that arsenic accumulated in corm of *Colocasia esculenta* (L.) Schott (dark violet) growing in soil contaminated to 50 mg As/kg was the lowest at 0.7091 mg As/kg at day 60. In other words, the maximum was 0.9533 mg As/kg while was growing in soil contaminated to 150 mg As/kg at day 90. Even though that it generally tended to increase at high concentration in soil, there was fluctuation in some harvest times (Figure 4-18). From statistical analysis, it was shown that there was significant difference between treatments ($p. < 0.05$). In addition to harvest time, there was also difference between group of day 15, 45 and 60, but not between group of day 30, 75 and 90.

Consider to *Colocasia esculenta* (L.) Schott (green), that arsenic accumulations in corm were in the range of 0.7949-2.1175 mg As/kg. Table 4-12 illustrated that arsenic accumulated in corm *Colocasia esculenta* (L.) Schott (green) growing in soil contaminated to 50 mg As/kg was minimum at 0.7949 mg As/kg and the maximum was 2.1175 mg As/kg in treatment of 125 mg As/kg at day 15. Moreover, arsenic accumulation in corm tended to increase throughout the trials (Figure 4-19), there were fluctuations in some harvest times, however. From statistical analysis, it was shown that there was significant difference between treatment ($p. < 0.05$). In test of harvest time, the statistical analysis indicated that there was significant difference between times. Even so, between groups of day 15 and 45 have no significant difference.

Table 4-11 Arsenic accumulation in corm of *Colocasia esculenta* (L.) Schott (dark violet)

| Level of arsenic concentration in soil (mg As/kg) | Arsenic accumulation in corm at harvest time (mg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 mg As/kg | 1.0171 | 1.0346 | 0.7372 | 0.7091 | 0.9350 | 0.9811 |
| 75 mg As/kg | 1.0325 | 1.1016 | 1.1414 | 0.9612 | 0.7285 | 0.9817 |
| 100 mg As/kg | 1.1402 | 0.8941 | 1.3702 | 0.8763 | 1.3453 | 1.2759 |
| 125 mg As/kg | 1.3435 | 1.8673 | 1.8081 | 1.9508 | 2.0352 | 1.7682 |
| 150 mg As/kg | 1.6398 | 1.8291 | 1.9532 | 1.8913 | 1.8220 | 2.0511 |

Table 4-12 Arsenic accumulation in corm of *Colocasia esculenta* (L.) Schott (green)

| Level of arsenic concentration in soil (mg As/kg) | Arsenic accumulation in corm at harvest time (mg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 mg As/kg | 0.7949 | 1.0354 | 1.0419 | 0.9486 | 0.9425 | 0.9730 |
| 75 mg As/kg | 1.3645 | 1.3485 | 1.1138 | 1.1206 | 1.0619 | 1.6298 |
| 100 mg As/kg | 1.8923 | 1.7840 | 1.9252 | 1.8910 | 1.6207 | 1.9682 |
| 125 mg As/kg | 2.1175 | 1.6210 | 1.7034 | 1.6291 | 1.6518 | 1.7296 |
| 150 mg As/kg | 1.5061 | 1.5635 | 1.8258 | 1.6338 | 1.5061 | 2.0222 |

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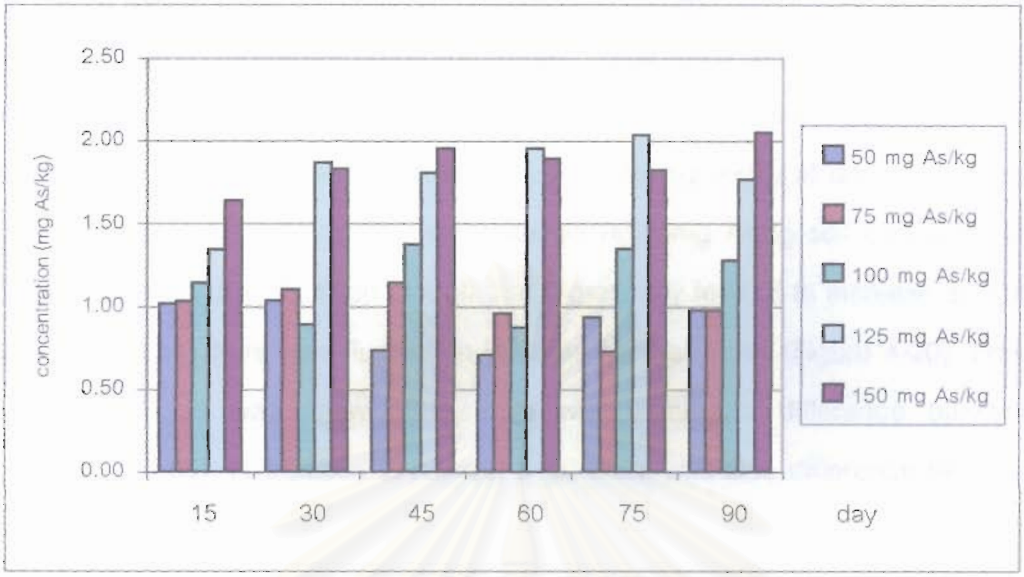

Figure 4-18 Arsenic accumulation in corm of *Colocasia esculenta* (L.) Schott (dark violet)

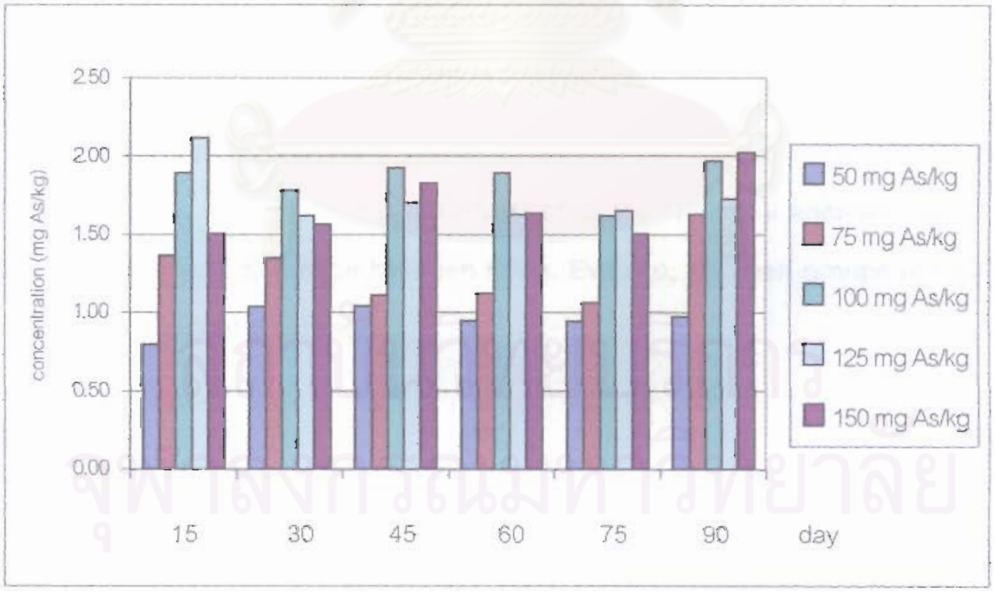

Figure 4-19 Arsenic accumulation in corm of *Colocasia esculenta* (L.) Schott (green)

### 4.3.4 Arsenic accumulation in root

Arsenic accumulations in root of *Colocasia esculenta* (L.) Schott (dark violet) were in the range of 11.1386-93.7858 mg As/kg. Table 4-13 illustrated that arsenic accumulated in root of *Colocasia esculenta* (L.) Schott (dark violet) growing in soil contaminated to 50 mg As/kg was the lowest at 11.1386 mg As/kg at day 15. In other words, the maximum arsenic accumulation was 93.7858 mg As/kg soil contaminated with 150 mg As/kg at day 15. Even though that it generally tended to increase at high concentration in soil, there was fluctuation in some harvest times (Figure 4-20). From statistical analysis, it was shown that there was significant difference between treatments ($p. < 0.05$). In addition to harvest time, there was also difference between time, except for day 30 and 45.

Consider to *Colocasia esculenta* (L.) Schott (green), arsenic accumulations in root were in the range of 8.3710-74.0477 mg As/kg. Table 4-14 illustrated that arsenic accumulated in corm of *Colocasia sp.* (green) growing in soil contaminated to 50 mg As/kg was minimum at 8.3710 mg As/kg and the maximum was 74.0477 mg As/kg in treatment of 125 mg As/kg at day 15. Moreover, arsenic accumulation in corm tended to increase throughout the trials (Figure 4-21), however, there were fluctuations in some harvest times. From statistical analysis, it was shown that there was significant difference between treatment ($p. < 0.05$). In test of harvest time, the statistical analysis indicated that there was significant difference between times. Even so, between groups of day 30 and 75 have no significant difference.

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Table 4-13 Arsenic accumulation in root of *Colocasia esculenta* (L.) Schott (dark violet)

| Level of arsenic concentration in soil (mg As/kg) | Arsenic accumulation in root at harvest time (mg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 mg As/kg | 11.1386 | 11.4593 | 10.9785 | 17.5290 | 11.2212 | 11.3746 |
| 75 mg As/kg | 14.9589 | 12.1788 | 19.1288 | 16.3684 | 14.4636 | 16.9292 |
| 100 mg As/kg | 30.6512 | 54.2902 | 59.9765 | 49.1827 | 48.3568 | 50.5703 |
| 125 mg As/kg | 72.6995 | 63.0422 | 55.2617 | 53.3675 | 62.1886 | 57.0664 |
| 150 mg As/kg | 93.7858 | 59.3747 | 55.7635 | 60.3508 | 56.5298 | 53.0059 |

Table 4-14 Arsenic accumulation in root of *Colocasia esculenta* (L.) Schott (green)

| Level of arsenic concentration in soil (mg As/kg) | Arsenic accumulation in root at harvest time (mg/kg) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 mg As/kg | 8.3710 | 10.6259 | 11.6481 | 11.3879 | 8.2302 | 12.6673 |
| 75 mg As/kg | 21.0092 | 16.9227 | 17.1880 | 18.2545 | 19.1473 | 13.6649 |
| 100 mg As/kg | 20.0080 | 16.9244 | 53.2807 | 58.8264 | 21.2674 | 21.3786 |
| 125 mg As/kg | 74.0477 | 60.7134 | 64.6233 | 58.5638 | 58.8257 | 55.8104 |
| 150 mg As/kg | 72.6799 | 61.9236 | 64.8276 | 68.5768 | 59.2338 | 60.3551 |

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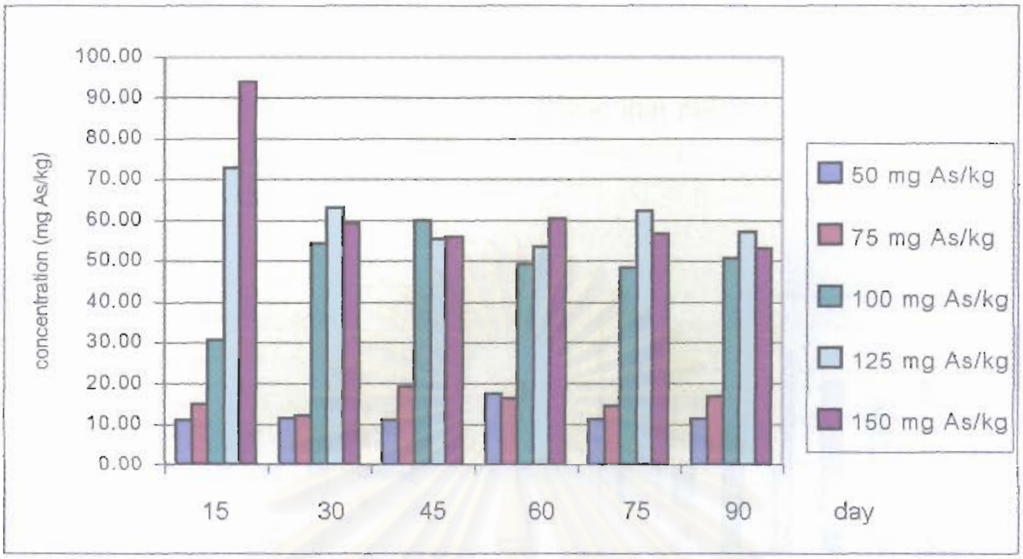

Figure 4-20 Arsenic accumulation in root of *Colocasia esculenta* (L.) Schott (dark violet)

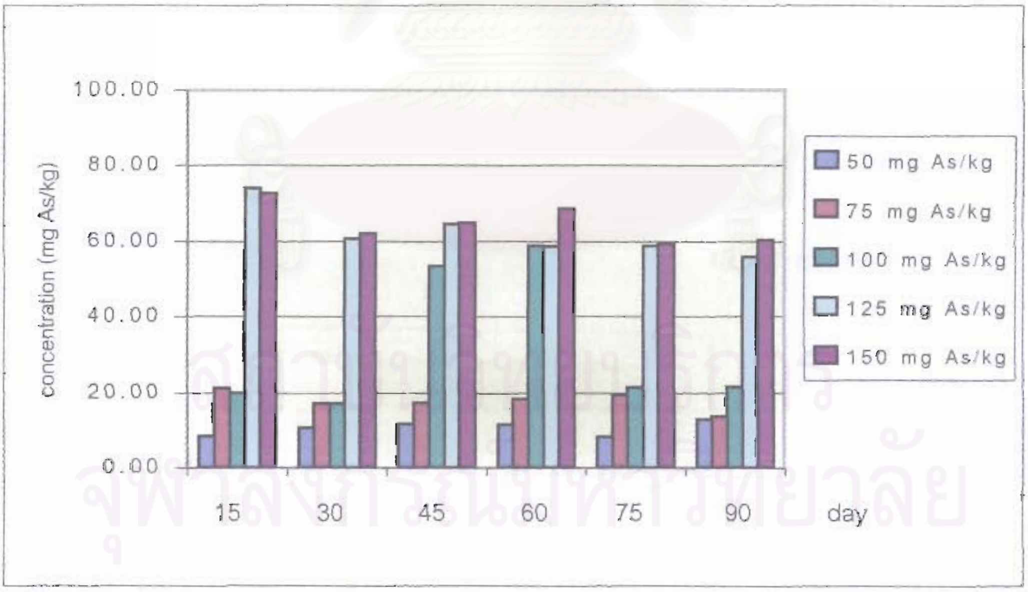

Figure 4-21 Arsenic accumulation in root of *Colocasia esculenta* (L.) Schott (green)

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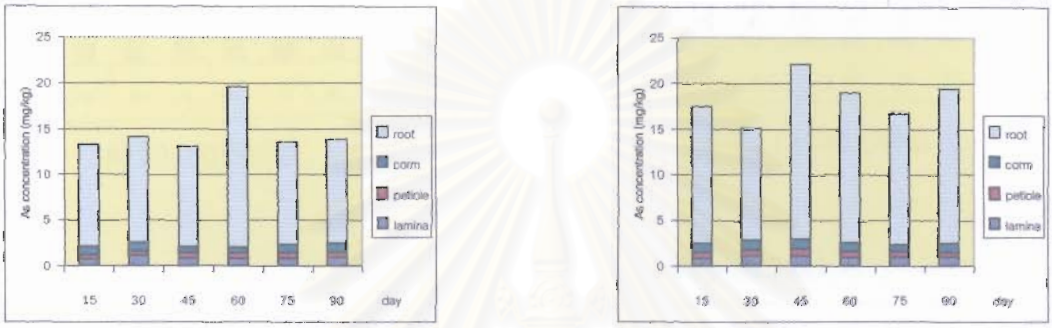
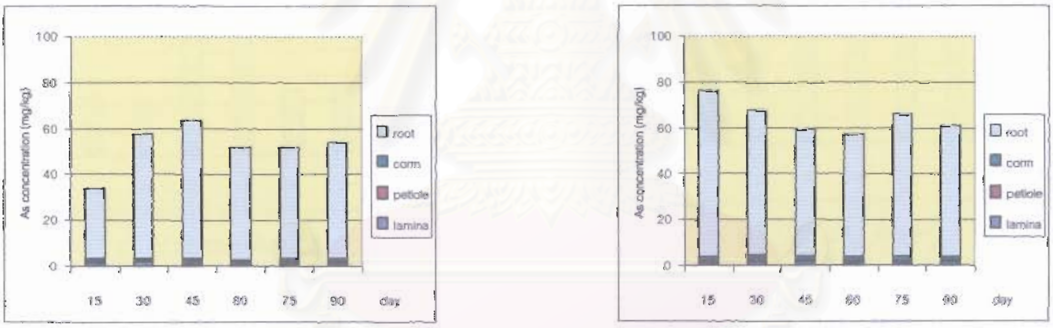
Consider to arsenic concentration of all plants under various arsenic contamination, as shown in Figure 4-22 and 4-33, it found that root was the best tissue for arsenic accumulation whereas the other parts of plant accumulated arsenic in low quantities. Consequently, root was the main tissue that result in both of total arsenic in plant and efficiency of arsenic removal.



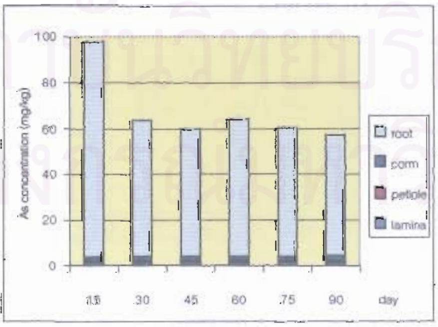
a) 50 mg As/kg

b) 75 mg As/kg



c) 100 mg As/kg

d) 125 mg As/kg



e) 150 mg As/kg

Figure 4-22 Comparison of arsenic accumulation in all parts of *C. esculenta* (dark violet)

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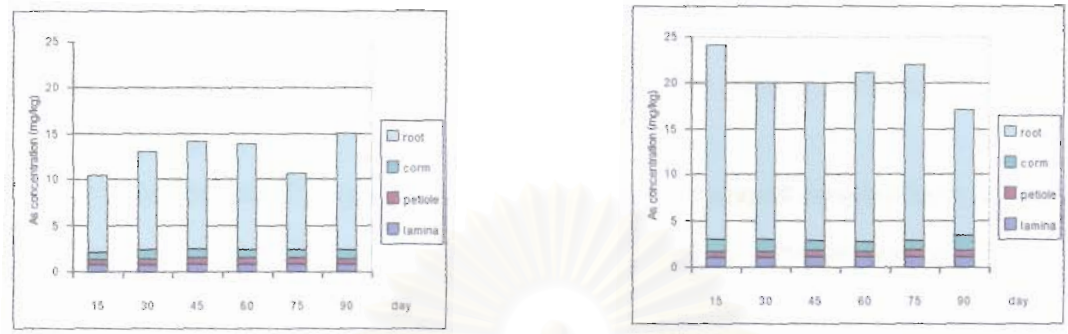
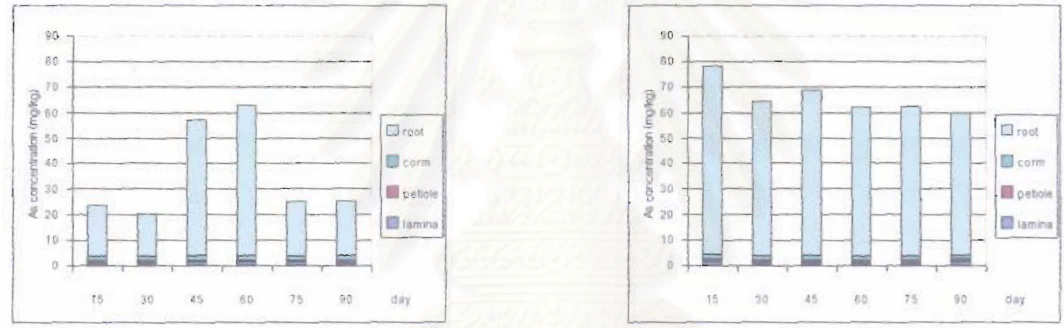


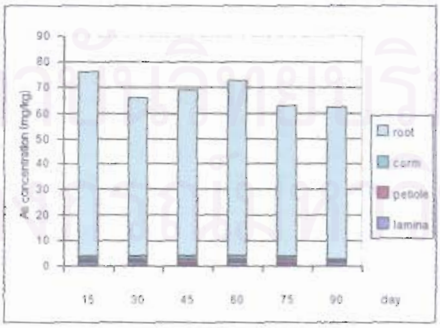
a) 50 mg As/kg

b) 75 mg As/kg



c) 100 mg As/kg

d) 125 mg As/kg



e) 150 mg As/kg

Figure 4-23 Comparison of arsenic accumulation in all parts of *C. esculenta* (green)

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## 4.4 Efficiency of arsenic removal of *Colocasia esculenta* (L.) Schott

Efficiency of arsenic removal was expressed as a percentage of total arsenic accumulated in plant per amount of arsenic in pot.

### 4.4.1 Efficiency of arsenic removal of *Colocasia esculenta* (L.) Schott (dark violet)

For treatment of 50 mg As/kg, efficiency arsenic removal ranged form 0.0217-0.0366%. In treatment of 75 mg As/kg, efficiency of arsenic removal was in range of 0.0088-0.0361 %. Both increased throughout the experimental period. Efficiency of arsenic removal efficiency of treatment of 100, 125, 150 mg As/kg, also fluctuated in some periods, were ranged from 0.0180-0.0696, 0.0194-0.0501, and 0.0131-0.0380 %, respectively (Figure 4-22). In addition, most of high efficiency occurred in treatment of 100 mg As/kg as shown in Table 4-15. From statistical analysis, it was indicated that there was difference among treatments and times, significantly at 95 % confidence (APPENDIX D). Therefore, the efficiency in treatment of 100 mg As/kg, 0.0696%, was maximum at day 45.

**Table 4-15** Efficiency of arsenic removal of *Colocasia esculenta* (L.) Schott (dark violet)

| Level of arsenic concentration in soil (mg As/kg) | Efficiency of arsenic removal at harvest time (%) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 0.0278 | 0.0217 | 0.0269 | 0.0366 | 0.0285 | 0.0412 |
| 75 | 0.0088 | 0.0139 | 0.0176 | 0.0198 | 0.0221 | 0.0361 |
| 100 | 0.0180 | 0.0396 | 0.0696 | 0.0500 | 0.0606 | 0.0685 |
| 125 | 0.0194 | 0.0234 | 0.0400 | 0.0350 | 0.0501 | 0.0288 |
| 150 | 0.0131 | 0.0328 | 0.0380 | 0.0348 | 0.0337 | 0.0350 |

From the result, the maximum arsenic removal rate of *Colocasia esculenta* (L.) Schott (dark violet) was occurred in the treatment of 100 mg As/kg instead of 150 mg As/kg. It may be suggested that the proportion of total arsenic accumulated in plant per amount of arsenic in soil was so different at high level of arsenic contaminated in soil. For this reason, the percentage of high level arsenic concentration was less than the 100 mg As/kg concentration.

### 4.4.2 Efficiency of arsenic removal of *Colocasia esculenta* (L.) Schott (green)

Concerning on the treatment of 75, 125, 150 mg As/kg, arsenic removal efficiency was in the rage of 0.0164-0.0336, 0.0192-0.0563, and 0.0213-0.0487 %, respectively (Table 4-16). Besides being fluctuated in treatment of 50 and 100 mg As/kg, in the range of 0.0153-0.0297 % and 0.0139-0.0524 %, the efficiency was mostly high in the middle period as shown in Figure 4-23. From statistical analysis, it was indicated that there was significant difference among treatments and times at confidential level of 95 % (APPENDIX D). Therefore, the maximum efficiency was 0.0563% in the treatment of 125 mg As/kg at day 90.

Table 4-16 Efficiency of arsenic removal of *Colocasia esculenta* (L.) Schott (green)

| Level of arsenic concentration in soil (mg As/kg) | Efficiency of arsenic removal at harvest time (%) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 0.0153 | 0.0206 | 0.0276 | 0.0297 | 0.0263 | 0.0227 |
| 75 | 0.0164 | 0.0232 | 0.0266 | 0.0276 | 0.0258 | 0.0336 |
| 100 | 0.0139 | 0.0170 | 0.0370 | 0.0524 | 0.0285 | 0.0287 |
| 125 | 0.0192 | 0.0219 | 0.0338 | 0.0387 | 0.0443 | 0.0563 |
| 150 | 0.0213 | 0.0261 | 0.0293 | 0.0282 | 0.0395 | 0.0487 |

In the same way as *Colocasia esculenta* (L.) Schott (dark violet), the maximum efficiency of *Colocasia esculenta* (L.) Schott (green) was occurred in the treatment of 125 mg As/kg instead of 150 mg As/kg. It may be suggested that *Colocasia esculenta* (L.) Schott (green) have the higher limit of arsenic absorption than *Colocasia esculenta* (L.) Schott (dark violet).

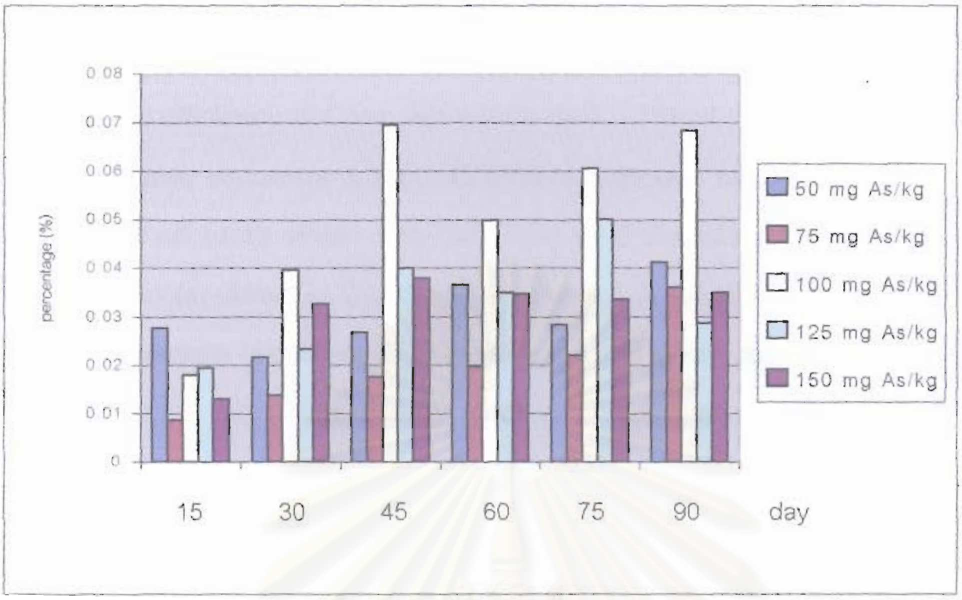

Figure 4-22 Efficiency of arsenic removal of *Colocasia esculenta* (L.) Schott (dark violet)

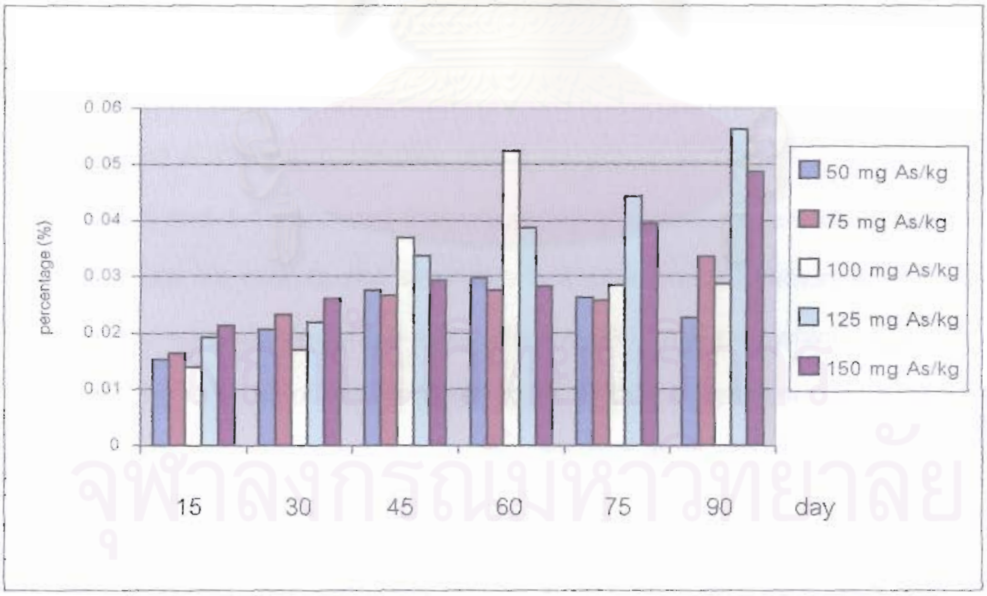

Figure 4-23 Efficiency of arsenic removal of *Colocasia esculenta* (L.) Schott (green)

### 4.4.3 Efficiency of arsenic removal between *Colocasia esculenta* (L.) Schott (dark violet) and *Colocasia esculenta* (L.) Schott (green)

In comparison of efficiency of arsenic removal between *C. esculenta*, It was found that average efficiency of *Colocasia esculenta* (L.) Schott (dark violet) was slightly higher than *Colocasia esculenta* (L.) Schott (green). Although total weight of *Colocasia esculenta* (L.) Schott (dark violet) was less than of *Colocasia esculenta* (L.) Schott (green), arsenic accumulated in *Colocasia esculenta* (L.) Schott (dark violet) was also higher than in *Colocasia esculenta* (L.) Schott (green). It could suggest that *Colocasia esculenta* (L.) Schott (dark violet) has root hairs and more surfaces for arsenic adsorption than *Colocasia esculenta* (L.) Schott (green).

The efficiency, however, was also considered to total dry weight, which is sum of dry weight of all parts, and arsenic concentration in all parts of plant, therefore, it was fluctuated by these factors. If the total dry weight and arsenic accumulation were in large quantity, the arsenic removal efficiency would be increased.

## 4.5 Comparison of efficiency of *Colocasia esculenta* (L.) Schott and vetiver grass

Compare to vetiver grass, *Vetiver zizanioides* (Linn.) Nash and *Vetiveria nemoralis* (Balansa) A. Camus (Dhitivara, 2000), as shown in Table 4-17 and 4-18, the data in Table 4-15 and 4-16 showed that efficiency of *Colocasia esculenta* (L.) Schott was higher. It could be due to the favorable soil condition. Common lateral root of *C. esculenta* could spread throughout soil in the experimental pot, which classified into the top soil, whereas the root of vetiver grass could more vertically intrude into deep soil type. For this reason, unfavorable soil condition resulted in low effectiveness of arsenic removal by vetiver grass. Consequently, *Colocasia esculenta* (L.) Schott was more appropriate for arsenic removal than vetiver grass in contaminated top soil whereas the vetiver grass could remove arsenic in the deeper soil layer.

Table 4-17 Efficiency of arsenic removal of *Vetiver zizanioides* (Linn.) Nash

| Level of arsenic concentration in soil (mg As/kg) | Efficiency of arsenic removal at harvest time (%) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 0.0157 | 0.0194 | 0.0138 | 0.0233 | 0.0365 | 0.0344 |
| 75 | 0.0154 | 0.0193 | 0.0201 | 0.0312 | 0.0391 | 0.0488 |
| 100 | 0.0122 | 0.0264 | 0.0170 | 0.0180 | 0.0281 | 0.0421 |
| 125 | 0.0132 | 0.0228 | 0.0148 | 0.0217 | 0.0326 | 0.0285 |
| 150 | 0.0100 | 0.0192 | 0.0167 | 0.0177 | 0.0322 | 0.0228 |

Source: Dhitivara, 2000.

Table 4-18 Efficiency of arsenic removal of *Vetiveria nemoralis* (Balansa) A. Camus

| Level of arsenic concentration in soil (mg As/kg) | Efficiency of arsenic removal at harvest time (%) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 0.0139 | 0.0209 | 0.0116 | 0.0384 | 0.0249 | 0.0288 |
| 75 | 0.0124 | 0.0150 | 0.0081 | 0.0198 | 0.0332 | 0.0275 |
| 100 | 0.0123 | 0.0159 | 0.0157 | 0.0238 | 0.0271 | 0.0390 |
| 125 | 0.0118 | 0.0123 | 0.0195 | 0.0251 | 0.0201 | 0.0398 |
| 150 | 0.0109 | 0.0147 | 0.0150 | 0.0200 | 0.0228 | 0.0357 |

Source: Dhitivara, 2000.

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# CHAPTER V

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

Based on the experimental results obtained, the following conclusions can be shown.

### 5.1.1 Growth rate on arsenic contaminated soil

After treating plants with arsenic, growth was recorded into cumulative length and dry weight every 15 days, on 6 consecutive occasions over a 90-day trial period.

#### 1) The cumulative length of petioles

The cumulative length of both *Colocasia esculenta* (L.) Schott was no significant difference among the controls and the treatments. Accordingly, in the range of 0-150 mg As/kg soil, it was not responsive to arsenic toxicity and also grew well under all conditions, with 100% survival.

#### 2) The dry weight of all parts of plants

Weight of *Colocasia esculenta* (L.) Schott increased by time of growth. For petiole, corm, and root, its weight was rather higher than weight of lamina. Nevertheless, lamina and petiole could put more biomass than root and corm. Therefore, its shoot could be cut for arsenic remove from soil consecutively.

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### 5.1.2 Arsenic accumulation in parts of plants

For arsenic accumulation, arsenic was measured into concentration, amount of arsenic per dry weight. As a result, it indicated that the level of arsenic accumulation was in root > corm> lamina > petiole, respectively.

#### 1) Arsenic accumulation in lamina

For lamina, both *Colocasia esculenta* (L.) Schott increasingly tended to accumulate arsenic at high arsenic condition. The maximum arsenic accumulated in lamina of *Colocasia esculenta* (L.) Schott (dark violet) was 1.6656 mg As/kg at day 30, but in *Colocasia esculenta* (L.) Schott (green) was 1.2645 mg As/kg at day 60. Therefore, arsenic was more accumulated in lamina of *Colocasia esculenta* (L.) Schott (dark violet) than *Colocasia esculenta* (L.) Schott (green).

2) Arsenic accumulation in petiole

Significantly, arsenic accumulation in petiole increased at high arsenic condition. *Colocasia esculenta* (L.) Schott (dark violet) has the best arsenic accumulation at 0.9533 mg As/kg at day 15 whereas *Colocasia esculenta* (L.) Schott (green) has the best arsenic accumulation at 1.1291 mg As/kg at day 90. So, arsenic was more accumulated in petiole of *Colocasia esculenta* (L.) Schott (green) than which of *Colocasia esculenta* (L.) Schott (dark violet) was.

3) Arsenic accumulation in corm

Arsenic accumulation in corm tended to increase at high arsenic condition, significantly. *Colocasia esculenta* (L.) Schott (dark violet) has the maximum arsenic accumulation at 2.0511 mg As/kg at day 90 whereas *Colocasia esculenta* (L.) Schott (green) has the maximum arsenic accumulation at 2.1175 mg As/kg at day 15. Therefore, arsenic was more accumulated in petiole of *Colocasia esculenta* (L.) Schott (green) than of *Colocasia esculenta* (L.) Schott (dark violet).

4) Arsenic accumulation in root

Significantly maximum concentration, root of both *Colocasia sp.* was the best tissue for arsenic accumulation. At day 15, the maximum arsenic accumulation of *Colocasia esculenta* (L.) Schott (dark violet) was 93.7858 mg As/kg whereas *Colocasia esculenta* (L.) Schott (green) was 74.0477 mg As/kg at the same time. Therefore, *Colocasia esculenta* (L.) Schott (dark violet) has higher effectiveness arsenic accumulation in root than *Colocasia esculenta* (L.) Schott (green).

### 5.1.3 Efficiency of arsenic removal of *Colocasia esculenta* (L.) Schott.

Efficiency of arsenic removal was expressed as a percentage of total arsenic accumulated in plant per amount of arsenic in pot.

1) Efficiency of arsenic removal of *Colocasia esculenta* (L.) Schott (dark violet)

Significantly at 95 % confidence, efficiency of arsenic removal tended to increase at high level arsenic condition and the maximum efficiency occurred in the treatment of 100 mg/kg. At higher condition, the proportion of arsenic accumulated in plant to amount of arsenic in system was so different, as a result, the efficiency at high condition become lower. However, the maximum efficiency of *Colocasia esculenta* (L.) Schott (dark violet) was 0.0696% at day 45.

2) Efficiency of arsenic removal of *Colocasia esculenta* (L.) Schott (green)

This is also consistent with *Colocasia esculenta* (L.) Schott (dark violet), the efficiency of *Colocasia esculenta* (L.) Schott (green) was maximum in the middle period, occurring in the treatment of 125 mg As/kg at 0.0563%, significantly 95% confidence.

3) Efficiency of arsenic removal between *Colocasia esculenta* (L.) Schott

Efficiencies of arsenic removal of *Colocasia esculenta* (L.) Schott (dark violet) were mostly higher than of *Colocasia esculenta* (L.) Schott (green). Although total weight of *Colocasia esculenta* (L.) Schott (dark violet) was less than *Colocasia esculenta* (L.) Schott (green), arsenic accumulated in *Colocasia esculenta* (L.) Schott (dark violet) was also higher than in *Colocasia esculenta* (L.) Schott (green). However, the efficiency of both *Colocasia sp.* was not so different, both plants might be used for arsenic removal in arsenic contaminated area.

## 5.2 Recommendations

From this study, several recommendation for further study are given as follows

5.2.1 Consider to the survival of *Colocasia esculenta* (L.) Schott, all plants could grow as well as the controls. It is difficult to be certain that toxicity of arsenic had no effect upon characteristic and morphology of all plants throughout experimental period. It may suggest that the total time only 90-day seems not effect the analysis of growth, therefore, it should be taken more than 90 days to determine overall.

5.2.2 To increase effectiveness of arsenic removal, lamina and petiole of both *C. esculenta* should be cut at the highest accumulation. The maximum arsenic level in lamina of *Colocasia esculenta* (L.) Schott (dark violet) was 1.6656 mg As/kg, so it should be cut at day 30 whereas the lamina of *Colocasia esculenta* (L.) Schott (green) should be cut at day 60.

5.2.3 Arsenic conditions for this experiment was in low range. As a result, both plants may be adaptable and not effected to arsenic. Therefore, the arsenic concentration in soil should be expanded into higher than 150 mg As/kg soil such as 200- 2,000 mg As/kg.

5.2.4 High mobility of arsenic could conduct high removal efficiency, so feasible soil condition is essentially important fundament for study on arsenic removal from soil such as

1) High pH
2) Low clay (sand:silt:clay=16.83:58.17:25.00)
3) Low ferrous oxide and aluminium oxide (O'Neil, 1993)

5.2.5 Arsenic forms accumulated in plant tissues should be also studied.

5.2.6 In this study, there was no chelating agent to activate arsenic uptake by plant. For this reason, it should be studied for high efficiency of arsenic removal.

5.2.7 In natural characteristic of *C. esculenta*, marginal plant, it can be used for wastewater treatment and phytoremediation in contaminated marsh.

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# APPENDICES

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# APPENDIX A

## GROWTH of *Colocasia esculenta* (L.) Schott

Table A-1 Cumulative length of *Colocasia esculenta* (L.) Schott (dark violet)

| Level of As concentration in soil (mg As/kg) | Cumulative length at harvest time (cm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | day 0 | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 0 | 119.40 | 129.00 | 191.25 | 194.65 | 218.15 | 248.60 | 272.00 |
| | 115.00 | 150.05 | 184.30 | 199.75 | 216.45 | 237.10 | 278.45 |
| Average | 117.20 | 139.53 | 187.78 | 197.20 | 217.30 | 242.85 | 275.23 |
| 50 | 70.65 | 110.15 | 170.20 | 173.45 | 206.20 | 224.05 | 244.20 |
| | 87.15 | 112.80 | 164.25 | 175.10 | 185.20 | 215.40 | 247.35 |
| Average | 78.90 | 111.48 | 167.23 | 174.28 | 195.70 | 219.73 | 245.78 |
| 75 | 89.10 | 93.40 | 167.00 | 197.90 | 226.55 | 257.00 | 295.70 |
| | 120.75 | 151.20 | 195.95 | 225.80 | 250.10 | 279.35 | 299.80 |
| Average | 104.93 | 122.30 | 181.48 | 211.85 | 238.33 | 268.18 | 297.75 |
| 100 | 150.45 | 157.75 | 231.95 | 233.95 | 241.50 | 286.15 | 301.90 |
| | 123.85 | 151.20 | 212.95 | 240.40 | 269.10 | 295.40 | 327.25 |
| Average | 137.15 | 154.48 | 222.45 | 237.18 | 255.30 | 290.78 | 314.58 |
| 125 | 146.60 | 151.75 | 200.95 | 210.80 | 216.95 | 249.45 | 282.45 |
| | 140.15 | 165.80 | 210.75 | 230.20 | 245.45 | 287.85 | 290.20 |
| Average | 143.38 | 158.78 | 205.85 | 220.50 | 231.20 | 268.65 | 286.33 |
| 150 | 169.85 | 174.85 | 206.25 | 216.65 | 262.05 | 297.65 | 315.85 |
| | 115.75 | 145.70 | 195.65 | 212.10 | 225.75 | 269.80 | 285.95 |
| Average | 142.80 | 160.28 | 200.95 | 214.38 | 243.90 | 283.73 | 300.90 |

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Table A-2 Cumulative length of *Colocasia esculenta* (L.) Schott (green)

| Level of As concentration in soil (mg As/kg) | Cumulative length at harvest time (cm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | day 0 | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 0 | 85.80 | 87.25 | 181.45 | 185.65 | 198.90 | 254.65 | 301.90 |
| | 108.10 | 148.85 | 185.40 | 220.75 | 248.65 | 265.25 | 308.95 |
| Average | 96.95 | 118.05 | 183.43 | 203.20 | 223.78 | 259.95 | 305.43 |
| 50 | 95.05 | 143.85 | 205.05 | 208.30 | 262.95 | 288.85 | 336.15 |
| | 102.70 | 148.80 | 183.45 | 215.35 | 264.60 | 288.10 | 338.75 |
| Average | 98.88 | 146.33 | 194.25 | 211.83 | 263.78 | 288.48 | 337.45 |
| 75 | 136.15 | 138.65 | 201.65 | 219.10 | 263.25 | 293.00 | 337.50 |
| | 105.50 | 135.25 | 168.95 | 204.10 | 236.75 | 260.55 | 335.10 |
| Average | 120.83 | 136.95 | 185.30 | 211.60 | 250.00 | 276.78 | 336.30 |
| 100 | 126.60 | 170.55 | 209.80 | 228.50 | 259.20 | 296.45 | 312.50 |
| | 115.75 | 145.20 | 170.80 | 195.20 | 270.55 | 290.10 | 310.75 |
| Average | 121.18 | 157.88 | 190.30 | 211.85 | 264.88 | 293.28 | 311.63 |
| 125 | 106.25 | 141.15 | 175.90 | 176.15 | 198.90 | 253.90 | 295.80 |
| | 104.50 | 125.40 | 163.20 | 178.10 | 206.85 | 245.20 | 311.05 |
| Average | 105.38 | 133.28 | 169.55 | 177.13 | 202.88 | 249.55 | 303.43 |
| 150 | 114.00 | 145.50 | 185.00 | 191.55 | 245.55 | 297.10 | 315.40 |
| | 109.45 | 138.15 | 178.45 | 191.35 | 210.20 | 250.75 | 310.25 |
| Average | 111.73 | 141.83 | 181.73 | 191.45 | 227.88 | 273.93 | 312.83 |

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Table A-3 Weight of *Colocasia esculenta* (L.) Schott (dark violet)

| Level of As concentration in soil (mg As/kg) | Lamina | | Petiole | | Corm | | Root | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | wet (g) | dry (g) | wet (g) | dry (g) | wet (g) | dry (g) | wet (g) | dry (g) | wet (g) | dry (g) |
| First harvest | | | | | | | | | | |
| 0 | 10.7061 | 1.8752 | 44.3314 | 2.8087 | 19.8753 | 2.3051 | 51.2045 | 4.6545 | 126.1173 | 11.6435 |
| 50 | 6.7426 | 1.9878 | 26.8504 | 1.9536 | 16.5134 | 2.5169 | 49.5376 | 5.8112 | 99.6440 | 12.2695 |
| 75 | 7.1646 | 1.8506 | 33.8681 | 2.0237 | 17.8677 | 2.2484 | 22.1816 | 1.8716 | 81.0820 | 7.9943 |
| 100 | 7.4440 | 1.2871 | 45.1027 | 2.8839 | 25.7728 | 2.8238 | 37.0464 | 2.7026 | 115.3659 | 9.9674 |
| 125 | 11.4982 | 2.0340 | 53.0095 | 3.1394 | 28.5194 | 3.5617 | 21.5222 | 1.5254 | 114.5493 | 10.2605 |
| 150 | 5.2595 | 1.0250 | 27.4854 | 2.0989 | 21.6482 | 3.0840 | 11.4216 | 0.9581 | 65.8147 | 7.1660 |
| Second harvest | | | | | | | | | | |
| 0 | 10.4238 | 1.9883 | 38.3250 | 3.4176 | 25.9252 | 3.0293 | 90.2199 | 6.4716 | 164.8939 | 14.9068 |
| 50 | 11.0008 | 2.3062 | 59.2125 | 4.1243 | 16.1047 | 2.5048 | 51.7509 | 4.1037 | 138.0689 | 13.0390 |
| 75 | 9.0992 | 1.6464 | 41.1408 | 3.0129 | 13.9598 | 1.8902 | 53.6349 | 3.8004 | 117.8347 | 10.3499 |
| 100 | 10.2648 | 2.2255 | 34.1591 | 3.2117 | 22.7643 | 3.0116 | 61.2735 | 3.4822 | 128.4617 | 11.9310 |
| 125 | 8.6823 | 1.8742 | 38.4600 | 3.2499 | 17.8395 | 2.4049 | 30.6853 | 2.1499 | 95.6671 | 9.6789 |
| 150 | 8.1647 | 1.8147 | 40.8026 | 3.4628 | 23.6670 | 3.6416 | 54.7763 | 3.9371 | 127.4106 | 12.8562 |
| Third harvest | | | | | | | | | | |
| 0 | 9.0233 | 1.9608 | 29.4572 | 3.1797 | 14.2407 | 1.8404 | 46.2425 | 3.5382 | 98.9637 | 10.5191 |
| 50 | 10.0968 | 2.6289 | 35.8253 | 3.7679 | 37.3525 | 4.5347 | 89.6783 | 5.4217 | 172.9529 | 16.3532 |
| 75 | 8.6312 | 2.3568 | 38.6817 | 4.1298 | 31.8168 | 3.7771 | 39.5680 | 2.9323 | 118.6977 | 13.1960 |
| 100 | 12.6425 | 3.0154 | 44.1649 | 4.6151 | 44.5371 | 5.4134 | 94.2506 | 5.5492 | 195.5951 | 18.5931 |
| 125 | 7.1436 | 1.6402 | 30.4819 | 3.2277 | 30.0880 | 4.3043 | 78.2294 | 4.2950 | 145.9429 | 13.4672 |
| 150 | 11.3123 | 3.0770 | 46.8586 | 4.7475 | 22.7660 | 2.6101 | 83.0348 | 4.8618 | 163.9717 | 15.2964 |
| Forth harvest | | | | | | | | | | |
| 0 | 14.2933 | 3.4559 | 56.7007 | 5.8809 | 21.6321 | 3.0030 | 90.4538 | 5.5358 | 183.0799 | 17.8756 |
| 50 | 14.8673 | 3.8995 | 41.4476 | 4.2760 | 24.1947 | 3.0881 | 89.0825 | 4.7831 | 169.5921 | 16.0467 |
| 75 | 11.0099 | 2.4020 | 41.6945 | 4.5383 | 20.9700 | 2.9164 | 66.4625 | 4.0423 | 140.1369 | 13.8990 |
| 100 | 13.4495 | 3.3697 | 45.8331 | 5.7360 | 33.9928 | 3.9386 | 79.1807 | 4.8658 | 172.4561 | 17.9101 |
| 125 | 10.5323 | 2.6396 | 34.7085 | 3.9387 | 32.2127 | 4.0954 | 63.5749 | 3.8361 | 141.0284 | 14.5098 |
| 150 | 13.0034 | 3.5269 | 47.3497 | 5.2151 | 27.5043 | 3.4527 | 63.7176 | 4.0643 | 151.5750 | 16.2590 |

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Table A-3 Weight of *Colocasia esculenta* (L.) Schott (dark violet) (CONT.)

| Level of As Concentration in soil (mg As/kg) | Lamina | | Petiole | | Corm | | Root | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | wet (g) | dry (g) | wet (g) | dry (g) | wet (g) | Dry (g) | wet (g) | dry (g) | wet (g) | dry (g) |
| Fifth harvest | | | | | | | | | | |
| 0 | 8.6218 | 2.7286 | 27.7130 | 3.1856 | 17.1481 | 2.0006 | 20.1378 | 1.4541 | 73.6207 | 9.3689 |
| 50 | 11.3550 | 2.9606 | 38.4874 | 3.2323 | 26.9438 | 3.6385 | 82.0037 | 5.6505 | 158.7899 | 15.4819 |
| 75 | 13.5307 | 3.2356 | 57.7038 | 4.8664 | 17.9605 | 2.1151 | 78.3714 | 5.1916 | 167.5664 | 15.4087 |
| 100 | 14.9508 | 3.6592 | 60.8094 | 5.9483 | 24.7788 | 2.3496 | 95.7540 | 6.2018 | 196.2930 | 18.1589 |
| 125 | 13.2758 | 4.2697 | 67.6913 | 5.9309 | 25.7471 | 3.0406 | 66.6879 | 4.7813 | 173.4021 | 18.0225 |
| 150 | 9.8182 | 3.1453 | 38.1088 | 4.4813 | 41.5578 | 4.6095 | 50.2056 | 4.1733 | 139.6904 | 16.4094 |
| Sixth harvest | | | | | | | | | | |
| 0 | 21.6374 | 5.8928 | 73.6689 | 7.4040 | 39.0446 | 4.1360 | 121.1450 | 8.3346 | 255.4958 | 25.7674 |
| 50 | 22.1775 | 5.7581 | 72.0310 | 6.2489 | 31.6156 | 3.0162 | 148.5960 | 7.9945 | 274.4198 | 23.0177 |
| 75 | 19.7291 | 3.9152 | 83.1205 | 7.2144 | 24.4282 | 2.7457 | 116.8400 | 7.3827 | 244.1178 | 21.2580 |
| 100 | 15.2018 | 3.1360 | 64.3548 | 5.1820 | 25.5518 | 2.5286 | 114.0360 | 6.5560 | 219.1445 | 17.4026 |
| 125 | 8.1653 | 2.2006 | 30.0683 | 4.6137 | 25.7265 | 2.6064 | 49.4404 | 2.9617 | 113.4005 | 12.3824 |
| 150 | 14.4404 | 3.8256 | 64.3683 | 8.1908 | 39.4687 | 4.5851 | 70.51030 | 4.5364 | 188.7877 | 21.1379 |

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Table A-4 Weight of *Colocasia esculenta* (L.) Schott (green)

| Level of As concentration in soil (mg As/kg) | Lamina | | Petiole | | Corm | | Root | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | wet (g) | dry (g) | wet (g) | dry (g) | wet (g) | dry (g) | wet (g) | dry (g) | wet (g) | dry (g) |
| First harvest | | | | | | | | | | |
| 0 | 54.4827 | 4.2518 | 58.4258 | 4.0984 | 21.4078 | 3.2331 | 54.4827 | 4.2518 | 149.1042 | 13.8021 |
| 50 | 31.5318 | 3.7317 | 46.1190 | 3.4157 | 40.9003 | 4.1001 | 31.5318 | 3.7317 | 128.7900 | 13.6071 |
| 75 | 32.4654 | 2.4606 | 50.5999 | 3.4530 | 33.0705 | 3.7785 | 32.4654 | 2.4606 | 128.6589 | 12.0616 |
| 100 | 24.3686 | 2.8184 | 66.7254 | 4.6415 | 20.3624 | 3.1684 | 24.3686 | 2.8184 | 123.7569 | 13.3326 |
| 125 | 16.7130 | 1.4280 | 53.4500 | 3.7130 | 31.4678 | 4.0301 | 16.7130 | 1.4280 | 110.4830 | 10.9264 |
| 150 | 20.7557 | 2.0347 | 58.5931 | 3.6078 | 32.9211 | 3.9212 | 20.7557 | 2.0347 | 121.1761 | 11.3573 |
| Second harvest | | | | | | | | | | |
| 0 | 8.1355 | 1.7086 | 55.1591 | 4.2922 | 25.7609 | 3.5850 | 56.3449 | 3.7239 | 145.4004 | 13.3097 |
| 50 | 14.6552 | 2.5572 | 42.9888 | 3.8271 | 34.2030 | 3.5008 | 60.1980 | 4.1086 | 152.0450 | 13.9937 |
| 75 | 11.3642 | 2.6207 | 43.7911 | 4.1529 | 36.4011 | 3.9974 | 86.6688 | 4.5143 | 178.2252 | 15.2853 |
| 100 | 11.0927 | 3.2113 | 55.6475 | 5.3948 | 43.9370 | 5.1733 | 51.4407 | 4.0074 | 162.1179 | 17.7868 |
| 125 | 9.0820 | 2.1617 | 33.3885 | 3.0612 | 33.7355 | 3.7796 | 35.6230 | 2.0653 | 111.8290 | 11.0678 |
| 150 | 10.9462 | 2.3781 | 55.5047 | 4.8612 | 35.8906 | 4.7994 | 45.2967 | 2.9085 | 147.6382 | 14.9472 |
| Third harvest | | | | | | | | | | |
| 0 | 8.7265 | 1.9578 | 35.9495 | 3.7196 | 40.3418 | 5.3497 | 97.7594 | 6.3282 | 182.7772 | 17.3553 |
| 50 | 10.2382 | 2.5303 | 29.0921 | 3.2968 | 25.8860 | 3.2483 | 82.5435 | 5.2676 | 147.7598 | 14.3430 |
| 75 | 11.5504 | 2.7657 | 36.9301 | 4.1135 | 27.8903 | 3.8950 | 80.5050 | 5.2288 | 156.8758 | 16.0030 |
| 100 | 9.2731 | 2.1217 | 40.8567 | 4.0637 | 32.6561 | 3.7952 | 55.8678 | 3.2163 | 138.6537 | 13.1969 |
| 125 | 7.1297 | 1.7971 | 45.5234 | 3.8209 | 21.1814 | 2.6546 | 53.1807 | 3.1066 | 127.0152 | 11.3792 |
| 150 | 10.4975 | 3.1423 | 44.2464 | 4.7765 | 26.5333 | 3.9393 | 55.6412 | 3.1416 | 136.9184 | 14.9997 |
| Forth harvest | | | | | | | | | | |
| 0 | 13.1760 | 4.0752 | 35.6239 | 5.1644 | 28.7826 | 3.7267 | 95.1001 | 5.7513 | 172.6826 | 18.7176 |
| 50 | 14.0973 | 3.6884 | 44.0570 | 5.0753 | 37.9870 | 4.8258 | 92.9264 | 5.5482 | 189.0677 | 19.1377 |
| 75 | 12.6807 | 2.4770 | 44.0438 | 4.8828 | 23.5400 | 2.8047 | 88.1050 | 5.1819 | 168.3695 | 15.3464 |
| 100 | 13.5546 | 3.2901 | 43.2562 | 4.5954 | 27.8294 | 3.1058 | 71.2850 | 4.2100 | 155.9252 | 15.2013 |
| 125 | 11.1529 | 2.4351 | 33.9214 | 3.5913 | 30.8388 | 3.9403 | 66.5278 | 3.9112 | 142.4409 | 13.8779 |
| 150 | 13.2902 | 3.2845 | 40.7345 | 5.2445 | 27.6326 | 3.9979 | 41.6841 | 2.8399 | 123.3414 | 15.3668 |

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Table A-4 Weight of *Colocasia esculenta* (L.) Schott (green) (CONT.)

| Level of As | Lamina | | Petiole | | Corm | | Root | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| concentration | wet | dry | wet | Dry | wet | dry | wet | dry | wet | dry |
| in soil (mg As/kg) | (g) | (g) | (g) | (g) | (g) | (g) | (g) | (g) | (g) | (g) |
| Fifth harvest | | | | | | | | | | |
| 0 | 13.2340 | 4.8927 | 37.1913 | 5.7789 | 43.7373 | 4.0943 | 82.6693 | 5.4374 | 176.8319 | 20.2033 |
| 50 | 13.9758 | 4.9604 | 49.7979 | 5.2990 | 39.4033 | 3.8015 | 115.3603 | 6.6268 | 218.5373 | 20.6877 |
| 75 | 12.0156 | 2.4695 | 38.4665 | 4.1563 | 31.6812 | 3.4976 | 71.9378 | 4.5537 | 154.1011 | 14.6771 |
| 100 | 15.7009 | 5.0470 | 52.8130 | 6.4066 | 54.1905 | 5.8461 | 94.9818 | 5.6865 | 217.6862 | 22.9862 |
| 125 | 14.1210 | 3.1830 | 46.6395 | 4.6772 | 37.0690 | 3.9396 | 76.7199 | 4.4700 | 174.5494 | 16.2698 |
| 150 | 14.7736 | 3.9452 | 48.3074 | 4.5808 | 50.9855 | 5.5055 | 64.2968 | 4.6978 | 178.3633 | 18.7293 |
| Sixth harvest | | | | | | | | | | |
| 0 | 11.7484 | 3.2714 | 46.6637 | 4.8487 | 29.1279 | 2.9247 | 85.5316 | 4.8087 | 173.0716 | 15.8535 |
| 50 | 19.5998 | 5.4676 | 69.9163 | 7.8674 | 48.1366 | 4.1620 | 113.1192 | 3.4428 | 250.7719 | 20.9398 |
| 75 | 16.4634 | 4.5307 | 63.1911 | 6.8670 | 42.0309 | 4.4230 | 140.5643 | 7.9782 | 262.2497 | 23.7989 |
| 100 | 18.1222 | 5.0224 | 55.7809 | 7.7193 | 37.9444 | 4.6602 | 102.6079 | 5.6951 | 214.4554 | 23.0970 |
| 125 | 14.7902 | 4.6659 | 53.3602 | 6.5026 | 40.6237 | 3.6165 | 105.7529 | 5.9683 | 214.5270 | 20.7533 |
| 150 | 17.6066 | 5.1959 | 67.2961 | 7.4400 | 40.3781 | 3.6457 | 99.4123 | 5.6871 | 224.6931 | 21.9687 |

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# APPENDIX B

## ARSENIC ACCUMULATION OF *Colocasia esculenta* (L.) Schott

Table B-1 Arsenic accumulation in lamina of *Colocasia esculenta* (L.) Schott (dark violet)

| Level of arsenic concentration in soil (mg As/kg) | Arsenic accumulation in lamina at harvest time (mg As/kg) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 0.7779 | 1.1049 | 0.8782 | 0.8255 | 0.8321 | 0.9839 |
| | 0.7622 | 1.0729 | 0.8847 | 0.8001 | 0.8050 | 0.9380 |
| | 0.7636 | 1.1003 | 0.8767 | 0.7972 | 0.8457 | 0.9656 |
| Average | 0.7679 | 1.0927 | 0.8799 | 0.8076 | 0.8276 | 0.9625 |
| 75 | 0.8738 | 1.1230 | 1.1368 | 0.8924 | 0.9963 | 0.9743 |
| | 0.8689 | 1.2019 | 1.1304 | 0.9885 | 0.9886 | 0.9682 |
| | 0.8570 | 1.1432 | 1.1143 | 1.0226 | 0.9717 | 1.0470 |
| Average | 0.8666 | 1.1560 | 1.1272 | 0.9678 | 0.9855 | 0.9965 |
| 100 | 1.3218 | 1.6379 | 1.2087 | 0.9940 | 1.1287 | 1.1389 |
| | 1.4113 | 1.7041 | 1.2251 | 0.9925 | 1.0777 | 1.0984 |
| | 1.2802 | 1.7041 | 1.2451 | 0.9817 | 1.0870 | 1.1421 |
| Average | 1.3378 | 1.6814 | 1.2251 | 0.9894 | 1.0978 | 1.1265 |
| 125 | 1.2505 | 1.6500 | 1.3784 | 1.1048 | 1.1602 | 1.3181 |
| | 1.2638 | 1.6617 | 1.4790 | 1.1375 | 1.1477 | 1.3165 |
| | 1.2903 | 1.6851 | 1.5086 | 1.1125 | 1.1150 | 1.3347 |
| Average | 1.2682 | 1.6656 | 1.4553 | 1.1183 | 1.1415 | 1.3231 |
| 150 | 1.3815 | 1.4994 | 1.5195 | 1.3557 | 1.3150 | 1.4751 |
| | 1.3933 | 1.5138 | 1.4039 | 1.3442 | 1.3150 | 1.4579 |
| | 1.4051 | 1.4652 | 1.4144 | 1.3623 | 1.3475 | 1.4521 |
| Average | 1.3933 | 1.4922 | 1.4459 | 1.3541 | 1.3258 | 1.4617 |

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Table B-2 Arsenic accumulation in lamina of *Colocasia esculenta* (L.) Schott (green)

| Level of arsenic concentration in soil (mg As/kg) | Arsenic accumulation in lamina at harvest time (mg As/kg) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 0.7765 | 0.7754 | 0.7849 | 0.8705 | 0.8859 | 0.8162 |
| | 0.7827 | 0.7813 | 0.7943 | 0.8718 | 0.8632 | 0.8072 |
| | 0.7888 | 0.7740 | 0.7942 | 0.8896 | 0.8632 | 0.7802 |
| Average | 0.7827 | 0.7769 | 0.7911 | 0.8773 | 0.8708 | 0.8012 |
| 75 | 1.0190 | 1.0396 | 1.0612 | 1.0698 | 1.0554 | 1.0707 |
| | 1.0506 | 1.0719 | 1.0866 | 1.969 | 1.0913 | 1.1058 |
| | 1.0009 | 1.0211 | 1.0886 | 1.0553 | 1.0801 | 1.0671 |
| Average | 1.0235 | 1.0442 | 1.0788 | 1.0740 | 1.0756 | 1.0812 |
| 100 | 1.0003 | 0.9597 | 1.2195 | 1.2549 | 1.2115 | 1.0795 |
| | 1.0328 | 0.9811 | 1.2103 | 1.2046 | 1.1594 | 1.0362 |
| | 1.0350 | 0.9155 | 1.2842 | 1.1920 | 1.1427 | 1.0253 |
| Average | 1.0227 | 0.9521 | 1.2380 | 1.2172 | 1.1712 | 1.0470 |
| 125 | 1.2536 | 1.1684 | 1.1505 | 1.1784 | 1.0812 | 1.2198 |
| | 1.2450 | 1.1480 | 1.1571 | 1.1628 | 1.0827 | 1.2032 |
| | 1.2931 | 1.1369 | 1.1439 | 1.1425 | 1.1165 | 1.1644 |
| Average | 1.2639 | 1.1511 | 1.1505 | 1.1612 | 1.0935 | 1.1958 |
| 150 | 1.2146 | 1.2733 | 1.1638 | 1.2899 | 1.0731 | 1.1279 |
| | 1.1982 | 1.2638 | 1.1668 | 1.2899 | 1.0776 | 1.2126 |
| | 1.2064 | 1.2496 | 1.1518 | 1.2138 | 1.1004 | 1.2189 |
| Average | 1.2064 | 1.2622 | 1.1608 | 1.2645 | 1.0837 | 1.1865 |

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Table B-3 Arsenic accumulation in petiole of *Colocasia esculenta* (L.) Schott (dark violet)

| Level of arsenic concentration in soil (mg As/kg) | Arsenic accumulation in petiole at harvest time (mg As/kg) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 0.3920 | 0.5094 | 0.5002 | 0.5321 | 0.5725 | 0.5612 |
| | 0.3852 | 0.5276 | 0.5472 | 0.5576 | 0.5826 | 0.5629 |
| | 0.4144 | 0.5160 | 0.5438 | 0.5473 | 0.5926 | 0.5595 |
| Average | 0.3972 | 0.5177 | 0.5304 | 0.5457 | 0.5826 | 0.5612 |
| 75 | 0.5546 | 0.6103 | 0.6882 | 0.6253 | 0.6635 | 0.5191 |
| | 0.6067 | 0.5824 | 0.6959 | 0.6253 | 0.6602 | 0.5232 |
| | 0.6030 | 0.6143 | 0.6990 | 0.6438 | 0.5914 | 0.5464 |
| Average | 0.5881 | 0.6023 | 0.6946 | 0.6315 | 0.6384 | 0.5295 |
| 100 | 0.7003 | 0.7921 | 0.8235 | 0.6727 | 0.7633 | 0.7143 |
| | 0.6800 | 0.7741 | 0.8511 | 0.7433 | 0.7642 | 0.8016 |
| | 0.6901 | 0.7864 | 0.8543 | 0.6777 | 0.7423 | 0.7807 |
| Average | 0.6901 | 0.7842 | 0.8430 | 0.6979 | 0.7566 | 0.7655 |
| 125 | 0.9649 | 0.9116 | 0.8712 | 0.8181 | 0.8782 | 0.7746 |
| | 0.9500 | 0.9253 | 0.8451 | 0.8415 | 0.8435 | 0.7422 |
| | 0.9450 | 0.9264 | 0.8464 | 0.8298 | 0.7691 | 0.7293 |
| Average | 0.9533 | 0.9211 | 0.8542 | 0.8298 | 0.8303 | 0.7487 |
| 150 | 0.8456 | 0.9163 | 0.8019 | 0.8975 | 0.8576 | 0.9129 |
| | 0.8528 | 0.8386 | 0.8965 | 0.8824 | 0.8692 | 0.8642 |
| | 0.8600 | 0.8226 | 0.8322 | 0.8975 | 0.8855 | 0.8902 |
| Average | 0.8528 | 0.8591 | 0.8435 | 0.8925 | 0.8708 | 0.8902 |

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Table B-4 Arsenic accumulation in petiole of *Colocasia esculenta* (L.) Schott (green)

| Level of arsenic concentration in soil (mg As/kg) | Arsenic accumulation in petiole at harvest time (mg As/kg) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 0.5647 | 0.6083 | 0.6348 | 0.6342 | 0.6901 | 0.6435 |
| | 0.5356 | 0.6166 | 0.6591 | 0.6411 | 0.6101 | 0.5932 |
| | 0.5260 | 0.6099 | 0.6737 | 0.6167 | 0.5841 | 0.5912 |
| Average | 0.5421 | 0.6116 | 0.6558 | 0.6307 | 0.6281 | 0.6093 |
| 75 | 0.6867 | 0.6203 | 0.6347 | 0.6077 | 0.8058 | 0.7327 |
| | 0.6131 | 0.6587 | 0.6880 | 0.6542 | 0.7823 | 0.6582 |
| | 0.6834 | 0.6119 | 0.6064 | 0.6521 | 0.7639 | 0.7652 |
| Average | 0.6611 | 0.6303 | 0.6430 | 0.6380 | 0.7840 | 0.7187 |
| 100 | 0.9335 | 0.8962 | 0.9143 | 0.9655 | 0.9965 | 0.9933 |
| | 0.8864 | 0.9026 | 0.8883 | 0.9589 | 0.9675 | 0.9542 |
| | 0.9188 | 0.9378 | 0.9403 | 0.9424 | 0.9765 | 0.9224 |
| Average | 0.9129 | 0.9122 | 0.9143 | 0.9556 | 0.9801 | 0.9566 |
| 125 | 0.9659 | 0.9935 | 1.0225 | 0.9939 | 0.9872 | 1.0505 |
| | 0.9511 | 1.0108 | 1.0357 | 1.0077 | 0.9888 | 1.0404 |
| | 0.9708 | 1.0065 | 0.9553 | 1.0215 | 1.0429 | 1.1154 |
| Average | 0.9626 | 1.0036 | 1.0045 | 1.0077 | 1.0063 | 1.0688 |
| 150 | 0.9800 | 1.0807 | 1.1102 | 1.0951 | 1.1932 | 1.1519 |
| | 0.9594 | 1.0199 | 1.0612 | 1.1404 | 1.0348 | 1.1389 |
| | 0.9883 | 1.0501 | 1.0857 | 1.0552 | 1.1188 | 1.0967 |
| Average | 0.9759 | 1.0502 | 1.0857 | 1.0969 | 1.1156 | 1.1291 |

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Table B-5 Arsenic accumulation in corm of *Colocasia esculenta* (L.) Schott (dark violet)

| Level of arsenic concentration in soil (mg As/kg) | Arsenic accumulation in corm at harvest time (mg As/kg) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 1.0219 | 1.0191 | 0.6915 | 0.7343 | 0.9416 | 0.9844 |
| | 0.9943 | 1.0346 | 0.7405 | 0.6637 | 0.9400 | 1.0322 |
| | 1.0351 | 1.0501 | 0.7796 | 0.7293 | 0.9234 | 0.9267 |
| Average | 1.0171 | 1.0346 | 0.7372 | 0.7091 | 0.9350 | 0.9811 |
| 75 | 1.0374 | 1.0998 | 1.1770 | 0.9712 | 0.7335 | 0.7222 |
| | 1.0355 | 1.0771 | 1.1608 | 0.9726 | 0.7397 | 0.7231 |
| | 1.0247 | 1.1279 | 1.0865 | 0.9398 | 0.7125 | 0.7403 |
| Average | 1.0325 | 1.1016 | 1.1414 | 0.9612 | 0.7285 | 0.9817 |
| 100 | 1.1301 | 0.8873 | 1.3734 | 0.9142 | 1.3543 | 1.2036 |
| | 1.1322 | 0.8982 | 1.3718 | 0.8425 | 1.3785 | 1.3109 |
| | 1.1583 | 0.8968 | 1.3653 | 0.8722 | 1.3032 | 1.3132 |
| Average | 1.1402 | 0.8941 | 1.3702 | 0.8763 | 1.3453 | 1.2759 |
| 125 | 1.3311 | 1.8549 | 1.8218 | 1.8639 | 2.0352 | 1.7969 |
| | 1.3559 | 1.8549 | 1.771 | 2.0008 | 2.0486 | 1.8398 |
| | 1.3435 | 1.8920 | 1.8316 | 1.9877 | 2.0217 | 1.6679 |
| Average | 1.3435 | 1.8673 | 1.8081 | 1.9508 | 2.0352 | 1.7682 |
| 150 | 1.6398 | 1.7873 | 1.9087 | 1.9570 | 1.8746 | 2.0780 |
| | 1.6864 | 1.8767 | 1.9671 | 1.8661 | 1.7757 | 2.0323 |
| | 1.5932 | 1.8231 | 1.9837 | 1.8510 | 1.8157 | 2.0430 |
| Average | 1.6398 | 1.8291 | 1.9532 | 1.8913 | 1.8220 | 2.0511 |

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Table B-6 Arsenic accumulation in corm of *Colocasia esculenta* (L.) Schott (green)

| Level of arsenic concentration in soil (mg As/kg) | Arsenic accumulation in corm at harvest time (mg As/kg) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 0.7979 | 1.0016 | 1.0468 | 0.9403 | 0.9408 | 0.9796 |
| | 0.8021 | 1.0467 | 1.0925 | 0.9420 | 0.8862 | 0.9648 |
| | 0.7877 | 1.0579 | 0.9863 | 0.9635 | 1.0005 | 0.9746 |
| Average | 0.7949 | 1.0354 | 1.0419 | 0.9486 | 0.9425 | 0.9730 |
| 75 | 1.3424 | 1.3585 | 1.1057 | 1.1273 | 1.0225 | 1.6170 |
| | 1.3798 | 1.3168 | 1.1088 | 1.1228 | 1.0892 | 1.6777 |
| | 1.3713 | 1.3702 | 1.1268 | 1.1117 | 1.0740 | 1.5946 |
| Average | 1.3645 | 1.3485 | 1.1138 | 1.1206 | 1.0619 | 1.6298 |
| 100 | 1.8370 | 1.7264 | 1.9187 | 1.8883 | 1.6601 | 2.0236 |
| | 1.9135 | 1.8005 | 1.8926 | 1.8803 | 1.6128 | 1.9682 |
| | 1.9263 | 1.8252 | 1.9643 | 1.9044 | 1.5891 | 1.9128 |
| Average | 1.8923 | 1.7840 | 1.9252 | 1.8910 | 1.6207 | 1.9682 |
| 125 | 2.0677 | 1.5993 | 1.7074 | 1.6771 | 1.6518 | 1.6946 |
| | 2.1673 | 1.6468 | 1.6913 | 1.5854 | 1.6618 | 1.7715 |
| | 2.1175 | 1.6171 | 1.7115 | 1.6249 | 1.6419 | 1.7226 |
| Average | 2.1175 | 1.6210 | 1.7034 | 1.6291 | 1.6518 | 1.7296 |
| 150 | 1.4567 | 1.5750 | 1.8216 | 1.6598 | 1.4567 | 1.9813 |
| | 1.5184 | 1.5463 | 1.7962 | 1.6337 | 1.5184 | 2.0714 |
| | 1.5432 | 1.5692 | 1.8597 | 1.6078 | 1.5432 | 2.0140 |
| Average | 1.5061 | 1.5635 | 1.8258 | 1.6338 | 1.5061 | 2.0222 |

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Table B-7 Arsenic accumulation in root of *Colocasia esculenta* (L.) Schott (dark violet)

| Level of arsenic concentration in soil (mg As/kg) | Arsenic accumulation in root at harvest time (mg As/kg) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 11.0188 | 11.6008 | 11.5336 | 17.9646 | 11.2212 | 10.9969 |
| | 11.1985 | 11.4279 | 10.2539 | 17.2600 | 11.2999 | 11.5477 |
| | 11.1986 | 11.3493 | 11.1481 | 17.6325 | 11.1425 | 11.5791 |
| Average | 11.1386 | 11.4593 | 10.9785 | 17.5290 | 11.2212 | 11.3746 |
| 75 | 14.9215 | 12.1469 | 19.5442 | 16.1898 | 14.4636 | 16.8482 |
| | 14.7906 | 12.1628 | 19.5004 | 16.2097 | 14.4635 | 17.0102 |
| | 15.1546 | 12.2267 | 18.3418 | 16.7057 | 14.4636 | 16.9292 |
| Average | 14.9589 | 12.1788 | 19.1288 | 16.3684 | 14.4636 | 16.9292 |
| 100 | 30.6856 | 56.2752 | 60.2599 | 48.9023 | 48.4126 | 51.0018 |
| | 30.3760 | 52.6030 | 59.8820 | 49.1266 | 47.9659 | 50.4840 |
| | 30.8920 | 53.9924 | 59.7876 | 49.5191 | 48.6917 | 50.2251 |
| Average | 30.6512 | 54.2902 | 59.9765 | 49.1827 | 48.3568 | 50.5703 |
| 125 | 71.8558 | 63.7752 | 55.5621 | 53.7628 | 62.4622 | 57.3356 |
| | 73.6838 | 63.0422 | 55.3618 | 53.2687 | 61.9150 | 57.2009 |
| | 72.5589 | 62.3092 | 54.8613 | 53.0710 | 62.1886 | 56.6626 |
| Average | 72.6995 | 63.0422 | 55.2617 | 53.3675 | 62.1886 | 57.0664 |
| 150 | 94.3391 | 58.9879 | 54.0615 | 60.913 | 57.4239 | 53.8262 |
| | 92.9558 | 60.0516 | 57.0650 | 60.4445 | 56.0331 | 52.5958 |
| | 94.0624 | 59.0846 | 56.1640 | 59.6948 | 56.1324 | 52.5958 |
| Average | 93.7858 | 59.3747 | 55.7635 | 60.3508 | 56.5298 | 53.0059 |

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Table B-8 Arsenic accumulation in root of *Colocasia esculenta* (L.) Schott (green)

| Level of arsenic concentration in soil (mg As/kg) | Arsenic accumulation in root at harvest time (mg As/kg) | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 8.0665 | 10.7801 | 11.5848 | 11.5461 | 8.3165 | 12.5690 |
| | 8.8580 | 10.5951 | 11.5690 | 11.3405 | 8.1295 | 12.6830 |
| | 8.1884 | 10.5025 | 11.7905 | 11.2772 | 8.2446 | 12.7500 |
| Average | 8.3710 | 10.6259 | 11.6481 | 11.3879 | 8.2302 | 12.6673 |
| 75 | 20.7788 | 16.9024 | 17.1065 | 18.0847 | 19.1911 | 13.5394 |
| | 21.1013 | 16.9429 | 17.3306 | 18.2970 | 19.1692 | 13.7365 |
| | 21.1474 | 16.9227 | 17.1269 | 18.3819 | 19.0816 | 13.7187 |
| Average | 21.0092 | 16.9227 | 17.1880 | 18.2545 | 19.1473 | 13.6649 |
| 100 | 19.7154 | 16.6054 | 52.4594 | 59.3967 | 21.3139 | 21.3084 |
| | 20.3681 | 17.0839 | 53.2807 | 59.0165 | 21.1513 | 21.3318 |
| | 19.9406 | 17.0839 | 54.1020 | 58.0661 | 21.3371 | 21.4957 |
| Average | 20.008 | 16.9244 | 53.2807 | 58.8264 | 21.2674 | 21.3786 |
| 125 | 74.5193 | 60.6148 | 64.6233 | 58.6587 | 60.0095 | 55.9075 |
| | 73.8905 | 60.7627 | 63.9817 | 58.2790 | 58.0972 | 56.1016 |
| | 73.7333 | 60.7627 | 65.2648 | 58.7536 | 58.3704 | 55.4221 |
| Average | 74.0477 | 60.7134 | 64.6233 | 58.5638 | 58.8257 | 55.8104 |
| 150 | 73.3000 | 61.4607 | 64.6465 | 69.7881 | 59.0433 | 59.7938 |
| | 72.5559 | 62.1087 | 65.5519 | 68.4836 | 59.3289 | 60.4487 |
| | 72.1838 | 62.2013 | 64.2844 | 67.4587 | 59.3290 | 60.8230 |
| Average | 72.6799 | 61.9236 | 64.8276 | 68.5768 | 59.2338 | 60.3551 |

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# APPENDIX C

# EFFICIENCY OF ARSENIC REMOVAL

Table C-1 Efficiency of arsenic removal of *Colocasia esculenta*. (L.) Schott (dark violet)

| Level of As concentration in soil (mg As/kg) | Efficiency of arsenic removal of *Colocasia sp*. (dark violet) % | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 0.0276 | 0.0219 | 0.0279 | 0.0375 | 0.0285 | 0.0400 |
| | 0.0279 | 0.0217 | 0.0253 | 0.0360 | 0.0286 | 0.0417 |
| | 0.0280 | 0.0215 | 0.0273 | 0.0368 | 0.0283 | 0.0418 |
| Average | 0.0278 | 0.0217 | 0.0269 | 0.0366 | 0.0285 | 0.0412 |
| 75 | 0.0088 | 0.0138 | 0.0179 | 0.0195 | 0.0222 | 0.0357 |
| | 0.0088 | 0.0139 | 0.0180 | 0.0196 | 0.0222 | 0.0360 |
| | 0.0089 | 0.0140 | 0.0169 | 0.0202 | 0.0220 | 0.0360 |
| Average | 0.0088 | 0.0139 | 0.0176 | 0.0198 | 0.0221 | 0.0361 |
| 100 | 0.0180 | 0.0410 | 0.0699 | 0.0498 | 0.0607 | 0.0689 |
| | 0.0178 | 0.0384 | 0.0695 | 0.0500 | 0.0601 | 0.0684 |
| | 0.0181 | 0.0394 | 0.0694 | 0.0503 | 0.0609 | 0.0680 |
| Average | 0.0180 | 0.0396 | 0.0696 | 0.0500 | 0.0606 | 0.0685 |
| 125 | 0.0192 | 0.0236 | 0.0402 | 0.0352 | 0.0504 | 0.0290 |
| | 0.0196 | 0.0234 | 0.0401 | 0.0350 | 0.0499 | 0.0289 |
| | 0.0194 | 0.0231 | 0.0398 | 0.0349 | 0.0500 | 0.0286 |
| Average | 0.0194 | 0.0234 | 0.0400 | 0.0350 | 0.0501 | 0.0288 |
| 150 | 0.0132 | 0.0326 | 0.0368 | 0.0352 | 0.0342 | 0.0356 |
| | 0.0130 | 0.0332 | 0.0388 | 0.0349 | 0.0333 | 0.0347 |
| | 0.0131 | 0.0326 | 0.0382 | 0.0345 | 0.0334 | 0.0348 |
| Average | 0.0131 | 0.0328 | 0.0380 | 0.0348 | 0.0337 | 0.0350 |

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Table C-2 Efficiency of arsenic removal of *Colocasia esculenta*. (L.) Schott (green)

| Level of As concentration in soil (mg As/kg) | Efficiency of arsenic removal of *Colocasia sp*. (green) % | | | | | |
|---|---|---|---|---|---|---|
| | day 15 | day 30 | day 45 | day 60 | day 75 | day 90 |
| 50 | 0.0149 | 0.0208 | 0.0274 | 0.0300 | 0.0267 | 0.0228 |
| | 0.0160 | 0.0206 | 0.0275 | 0.0296 | 0.0259 | 0.0227 |
| | 0.0150 | 0.0205 | 0.0278 | 0.0295 | 0.0263 | 0.0227 |
| Average | 0.0153 | 0.0206 | 0.0276 | 0.0297 | 0.0263 | 0.0227 |
| 75 | 0.0171 | 0.0232 | 0.0265 | 0.0273 | 0.0258 | 0.0333 |
| | 0.0167 | 0.0233 | 0.0269 | 0.0283 | 0.0259 | 0.0337 |
| | 0.0165 | 0.0232 | 0.0265 | 0.0278 | 0.0257 | 0.0338 |
| Average | 0.0164 | 0.0232 | 0.0266 | 0.0276 | 0.0258 | 0.0336 |
| 100 | 0.0137 | 0.0167 | 0.0365 | 0.0529 | 0.0287 | 0.0288 |
| | 0.0141 | 0.0172 | 0.0369 | 0.0525 | 0.0284 | 0.0286 |
| | 0.0139 | 0.0172 | 0.0376 | 0.0517 | 0.0285 | 0.0287 |
| Average | 0.0139 | 0.0170 | 0.0370 | 0.0524 | 0.0285 | 0.0287 |
| 125 | 0.0193 | 0.0219 | 0.0338 | 0.0388 | 0.0452 | 0.0564 |
| | 0.0192 | 0.0220 | 0.0335 | 0.0385 | 0.0438 | 0.0566 |
| | 0.0192 | 0.0219 | 0.0341 | 0.0388 | 0.0440 | 0.0560 |
| Average | 0.0192 | 0.0219 | 0.0338 | 0.0387 | 0.0443 | 0.0563 |
| 150 | 0.0214 | 0.0259 | 0.0292 | 0.0286 | 0.0393 | 0.0482 |
| | 0.0212 | 0.0262 | 0.0296 | 0.0282 | 0.0395 | 0.0488 |
| | 0.0212 | 0.0262 | 0.0291 | 0.0277 | 0.0396 | 0.0490 |
| Average | 0.0213 | 0.0261 | 0.0293 | 0.0282 | 0.0395 | 0.0487 |

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# APPENDIX D

## STATISTICAL ANALYSIS

### Cumulative length tested by ANOVA at day 0

| | | Sum of squares | df | Mean square | F | Sig. |
|---|---|---|---|---|---|---|
| LENGTH C | Between Groups | 6563.010 | 5 | 1312.602 | 3.170 | 0.096 |
| | Within Groups | 2484.652 | 6 | 414.109 | | |
| | Total | 9047.662 | 11 | | | |
| LENGTH K | Between Groups | 1112.406 | 5 | 222.481 | 1.631 | 0.283 |
| | Within Groups | 818.361 | 6 | 136.394 | | |
| | Total | 1930.767 | 11 | | | |

### Cumulative length tested by ANOVA at day 15

| | | Sum of squares | df | Mean square | F | Sig. |
|---|---|---|---|---|---|---|
| LENGTH C | Between Groups | 4185.059 | 5 | 837.012 | 2.058 | 0.203 |
| | Within Groups | 2440.496 | 6 | 406.749 | | |
| | Total | 6625.556 | 11 | | | |
| LENGTH K | Between Groups | 15834.202 | 5 | 3166.840 | 5.332 | 0.033 |
| | Within Groups | 3563.665 | 6 | 593.944 | | |
| | Total | 19397.867 | 11 | | | |

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### Cumulative length tested by ANOVA at day 30

| | | Sum of squares | df | Mean square | F | Sig. |
|---|---|---|---|---|---|---|
| LENGTH C | Between Groups | 3820.317 | 5 | 764.063 | 6.149 | 0.024 |
| | Within Groups | 745.604 | 6 | 124.267 | | |
| | Total | 4565.921 | 11 | | | |
| LENGTH K | Between Groups | 721.402 | 5 | 144.280 | 0.528 | 0.750 |
| | Within Groups | 1638.323 | 6 | 273.054 | | |
| | Total | 2359.724 | 11 | | | |

Cumulative length tested by ANOVA at day 45

| | | Sum of squares | df | Mean square | F | Sig. |
|---|---|---|---|---|---|---|
| LENGTH C | Between Groups | 4615.689 | 5 | 923.138 | 8.892 | 0.010 |
| | Within Groups | 622.904 | 6 | 103.817 | | |
| | Total | 5238.592 | 11 | | | |
| LENGTH K | Between Groups | 2026.275 | 5 | 405.255 | 1.857 | 0.236 |
| | Within Groups | 1309.722 | 6 | 218.287 | | |
| | Total | 3335.997 | 11 | | | |

Cumulative length tested by ANOVA at day 60

| | | Sum of squares | df | Mean square | F | Sig. |
|---|---|---|---|---|---|---|
| LENGTH C | Between Groups | 4482.659 | 5 | 896.532 | 2.766 | 0.124 |
| | Within Groups | 1945.096 | 6 | 324.183 | | |
| | Total | 6427.756 | 11 | | | |
| LENGTH K | Between Groups | 6129.777 | 5 | 1225.955 | 3.183 | 0.096 |
| | Within Groups | 2310.887 | 6 | 385.148 | | |
| | Total | 8440.664 | 11 | | | |

Cumulative length tested by ANOVA at day 75

| | | Sum of squares | df | Mean square | F | Sig. |
|---|---|---|---|---|---|---|
| LENGTH C | Between Groups | 7071.252 | 5 | 1414.250 | 5.578 | 0.029 |
| | Within Groups | 1521.170 | 6 | 253.528 | | |
| | Total | 8592.422 | 11 | | | |
| LENGTH K | Between Groups | 2766.524 | 5 | 553.305 | 1.936 | 0.222 |
| | Within Groups | 1715.130 | 6 | 285.855 | | |
| | Total | 4481.654 | 11 | | | |

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Cumulative length tested by ANOVA at day 90

| | | Sum of squares | df | Mean square | F | Sig. |
|---|---|---|---|---|---|---|
| LENGTH C | Between Groups | 5814.819 | 5 | 1162.964 | 8.382 | 0.011 |
| | Within Groups | 832.515 | 6 | 138.753 | | |
| | Total | 6647.334 | 11 | | | |
| LENGTH K | Between Groups | 6546.937 | 5 | 1309.387 | 128.151 | 0.002 |
| | Within Groups | 61.305 | 6 | 10.217 | | |
| | Total | 6608.242 | 11 | | | |

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Test of arsenic concentration in lamina of *Colocasia esculenta* (L.) Schott (dark violet)

**Tests of Between-Subjects Effects**

Dependent Variable: ASLAMINA

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 5.433[a] | 29 | .187 | 190.266 | .000 |
| Intercept | 124.910 | 1 | 124.910 | 126864.0 | .000 |
| ASINSOIL | 3.438 | 4 | .859 | 872.891 | .000 |
| TIME | 1.351 | 5 | .270 | 274.527 | .000 |
| ASINSOIL * TIME | .643 | 20 | 3.217E-02 | 32.676 | .000 |
| Error | 5.908E-02 | 60 | 9.846E-04 | | |
| Total | 130.402 | 90 | | | |
| Corrected Total | 5.492 | 89 | | | |

[a] R Squared = .989 (Adjusted R Squared = .984)

Post Hoc Tests

Homogeneous Subsets

**ASLAMINA**

Duncan [a,b]

| ASINSOIL | N | Subset 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 50.00 | 18 | .889694 | | | | |
| 75.00 | 18 | | 1.016606 | | | |
| 100.00 | 18 | | | 1.243294 | | |
| 125.00 | 18 | | | | 1.328578 | |
| 150.00 | 18 | | | | | 1.412272 |
| Sig. | | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 9.846E-04.

[a] Uses Harmonic Mean Sample Size = 18.000.

[b] Alpha = .05.

**ASLAMINA**

Duncan [a,b]

| TIME | N | Subset 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 60.00 | 15 | 1.047433 | | | | | |
| 75.00 | 15 | | 1.075547 | | | | |
| 15.00 | 15 | | | 1.126747 | | | |
| 90.00 | 15 | | | | 1.174053 | | |
| 45.00 | 15 | | | | | 1.226920 | |
| 30.00 | 15 | | | | | | 1.417833 |
| Sig. | | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 9.846E-04.

[a] Uses Harmonic Mean Sample Size = 15.000.

[b] Alpha = .05.

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Test of arsenic concentration in petiole of *Colocasia esculenta* (L.) Schott (dark violet)

**Tests of Between-Subjects Effects**

Dependent Variable: ASPETIOL

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 1.900[a] | 29 | 6.550E-02 | 105.415 | .000 |
| Intercept | 47.095 | 1 | 47.095 | 75790.485 | .000 |
| ASINSOIL | 1.655 | 4 | .414 | 665.997 | .000 |
| TIME | 3.854E-02 | 5 | 7.709E-03 | 12.405 | .000 |
| ASINSOIL * TIME | .206 | 20 | 1.029E-02 | 16.552 | .000 |
| Error | 3.728E-02 | 60 | 6.214E-04 | | |
| Total | 49.032 | 90 | | | |
| Corrected Total | 1.937 | 89 | | | |

a. R Squared = .981 (Adjusted R Squared = .971)

Post Hoc Tests

Homogeneous Subsets

**ASPETIOL**

Duncan [a,b]

| | | Subset | | | |
|---|---|---|---|---|---|
| ASINSOIL | N | 1 | 2 | 3 | 4 |
| 50.00 | 18 | .522450 | | | |
| 75.00 | 18 | | .614033 | | |
| 100.00 | 18 | | | .756222 | |
| 125.00 | 18 | | | | .856233 |
| 150.00 | 18 | | | | .867972 |
| Sig. | | 1.000 | 1.000 | 1.000 | .163 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 6.214E-04.

a. Uses Harmonic Mean Sample Size = 18.000.

b. Alpha = .05.

**ASPETIOL**

Duncan [a,b]

| | | Subset | | |
|---|---|---|---|---|
| TIME | N | 1 | 2 | 3 |
| 15.00 | 15 | .696307 | | |
| 90.00 | 15 | .698820 | | |
| 60.00 | 15 | | .719460 | |
| 75.00 | 15 | | .735713 | .735713 |
| 30.00 | 15 | | .736893 | .736893 |
| 45.00 | 15 | | | .753100 |
| Sig. | | .783 | .074 | .075 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 6.214E-04.

a. Uses Harmonic Mean Sample Size = 15.000.

b. Alpha = .05.

Test of arsenic concentration in corm of *Colocasia esculenta* (L.) Schott (dark violet)

**Tests of Between-Subjects Effects**

Dependent Variable: ASCORM

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 18.224[a] | 29 | .628 | 415.394 | .000 |
| Intercept | 159.756 | 1 | 159.756 | 105601.5 | .000 |
| ASINSOIL | 15.527 | 4 | 3.882 | 2565.904 | .000 |
| TIME | .301 | 5 | 6.012E-02 | 39.743 | .000 |
| ASINSOIL * TIME | 2.396 | 20 | .120 | 79.205 | .000 |
| Error | 9.077E-02 | 60 | 1.513E-03 | | |
| Total | 178.071 | 90 | | | |
| Corrected Total | 18.315 | 89 | | | |

[a] R Squared = .995 (Adjusted R Squared = .993)

Post Hoc Tests

Homogeneous

Subsets

**ASCORM**

Duncan [a,b]

| ASINSOIL | N | Subset<br>1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 50.00 | 18 | .902350 | | | | |
| 75.00 | 18 | | .948978 | | | |
| 100.00 | 18 | | | 1.150333 | | |
| 125.00 | 18 | | | | 1.795511 | |
| 150.00 | 18 | | | | | 1.864411 |
| Sig. | | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 1.513E-03.

[a] Uses Harmonic Mean Sample Size = 18.000.

[b] Alpha = .05.

**ASCORM**

Duncan [a,b]

| TIME | N | Subset<br>1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 15 | 15 | 1.234627 | | | |
| 60 | 15 | | 1.277753 | | |
| 30 | 15 | | | 1.345320 | |
| 90 | 15 | | | 1.360967 | |
| 75 | 15 | | | 1.373213 | |
| 45 | 15 | | | | 1.402020 |
| Sig. | | 1.000 | 1.000 | .067 | 1.000 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 1.513E-03.

[a] Uses Harmonic Mean Sample Size = 15.000.

[b] Alpha = .05.

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Test of arsenic concentration in root of *Colocasia esculenta* (L.) Schott (dark violet)

**Tests of Between-Subjects Effects**

Dependent Variable: ASROOT

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 49028.798[a] | 29 | 1690.648 | 4286.516 | .000 |
| Intercept | 144788.2 | 1 | 144788.2 | 367099.9 | .000 |
| ASINSOIL | 43147.856 | 4 | 10786.964 | 27349.562 | .000 |
| TIME | 434.103 | 5 | 86.821 | 220.127 | .000 |
| ASINSOIL * TIME | 5446.840 | 20 | 272.342 | 690.503 | .000 |
| Error | 23.665 | 60 | .394 | | |
| Total | 193840.6 | 90 | | | |
| Corrected Total | 49052.463 | 89 | | | |

a. R Squared = 1.000 (Adjusted R Squared = .999)

Post Hoc Tests

Homogeneous Subsets

**ASROOT**

Duncan [a,b]

| | | Subset | | | | |
|---|---|---|---|---|---|---|
| ASINSOIL | N | 1 | 2 | 3 | 4 | 5 |
| 50.00 | 18 | 12.298550 | | | | |
| 75.00 | 18 | | 15.670722 | | | |
| 100.00 | 18 | | | 48.837933 | | |
| 125.00 | 18 | | | | 60.604317 | |
| 150.00 | 18 | | | | | 63.135078 |
| Sig. | | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = .394.

a. Uses Harmonic Mean Sample Size = 18.000.

b. Alpha = .05.

**ASROOT**

Duncan [a,b]

| | | Subset | | | | |
|---|---|---|---|---|---|---|
| TIME | N | 1 | 2 | 3 | 4 | 5 |
| 90 | 15 | 37.789273 | | | | |
| 75 | 15 | | 38.551980 | | | |
| 60 | 15 | | | 39.377673 | | |
| 30 | 15 | | | | 40.069047 | |
| 45 | 15 | | | | 40.221813 | |
| 15 | 15 | | | | | 44.646133 |
| Sig. | | 1.000 | 1.000 | 1.000 | .508 | 1.000 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = .394.

a. Uses Harmonic Mean Sample Size = 15.000.

b. Alpha = .05.

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## Test of arsenic concentration in lamina of *Colocasia esculenta* (L.) Schott (green)

**Tests of Between-Subjects Effects**

Dependent Variable: ASLAMINA

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 2.250[a] | 29 | 7.757E-02 | 8.002 | .000 |
| Intercept | 104.952 | 1 | 104.952 | 10827.223 | .000 |
| ASINSOIL | 1.658 | 4 | .414 | 42.754 | .000 |
| TIME | .186 | 5 | 3.722E-02 | 3.840 | .004 |
| ASINSOIL * TIME | .406 | 20 | 2.029E-02 | 2.093 | .015 |
| Error | .582 | 60 | 9.693E-03 | | |
| Total | 107.783 | 90 | | | |
| Corrected Total | 2.831 | 89 | | | |

a. R Squared = .795 (Adjusted R Squared = .695)

Post Hoc Tests

Homogeneous Subsets

**ASLAMINA**

Duncan[a,b]

| ASINSOIL | N | Subset | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| 50.00 | 18 | .816661 | | |
| 100.00 | 18 | | 1.108028 | |
| 75.00 | 18 | | 1.111333 | |
| 125.00 | 18 | | 1.169333 | 1.169333 |
| 150.00 | 18 | | | 1.194022 |
| Sig. | | 1.000 | .082 | .455 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 9.693E-03.

a. Uses Harmonic Mean Sample Size = 18.000.

b. Alpha = .05.

**ASLAMINA**

Duncan[a,b]

| TIME | N | Subset | |
|---|---|---|---|
| | | 1 | 2 |
| 30 | 15 | 1.037307 | |
| 75 | 15 | 1.058947 | |
| 15 | 15 | 1.059833 | |
| 90 | 15 | 1.062333 | |
| 45 | 15 | 1.083847 | |
| 60 | 15 | | 1.176987 |
| Sig. | | .257 | 1.000 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 9.693E-03.

a. Uses Harmonic Mean Sample Size = 15.000.

b. Alpha = .05.

## Test of arsenic concentration in petiole of *Colocasia esculenta* (L.) Schott (green)

**Tests of Between-Subjects Effects**

Dependent Variable: ASPETIOL

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 3.187[a] | 29 | .110 | 102.842 | .000 |
| Intercept | 67.037 | 1 | 67.037 | 62723.757 | .000 |
| ASINSOIL | 3.033 | 4 | .758 | 709.553 | .000 |
| TIME | 8.842E-02 | 5 | 1.768E-02 | 16.546 | .000 |
| ASINSOIL * TIME | 6.570E-02 | 20 | 3.285E-03 | 3.073 | .000 |
| Error | 6.413E-02 | 60 | 1.069E-03 | | |
| Total | 70.289 | 90 | | | |
| Corrected Total | 3.252 | 89 | | | |

a. R Squared = .980 (Adjusted R Squared = .971)

Post Hoc Tests

Homogeneous Subsets

**ASPETIOL**

Duncan[a,b]

| | | Subset | | | | |
|---|---|---|---|---|---|---|
| ASINSOIL | N | 1 | 2 | 3 | 4 | 5 |
| 50.00 | 18 | .612939 | | | | |
| 75.00 | 18 | | .679183 | | | |
| 100.00 | 18 | | | .938633 | | |
| 125.00 | 18 | | | | 1.008911 | |
| 150.00 | 18 | | | | | 1.075583 |
| Sig. | | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 1.069E-03.

a. Uses Harmonic Mean Sample Size = 18.000.

b. Alpha = .05.

**ASPETIOL**

Duncan[a,b]

| | | Subset | | |
|---|---|---|---|---|
| TIME | N | 1 | 2 | 3 |
| 15 | 15 | .810913 | | |
| 30 | 15 | | .841587 | |
| 45 | 15 | | .860680 | |
| 60 | 15 | | .865773 | |
| 90 | 15 | | | .896513 |
| 75 | 15 | | | .902833 |
| Sig. | | 1.000 | .059 | .598 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 1.069E-03.

a. Uses Harmonic Mean Sample Size = 15.000.

b. Alpha = .05.

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## Test of arsenic concentration in corm of *Colocasia esculenta* (L.) Schott (green)

**Tests of Between-Subjects Effects**

Dependent Variable: ASCORM

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 12.270[a] | 29 | .423 | 339.336 | .000 |
| Intercept | 202.209 | 1 | 202.209 | 162179.4 | .000 |
| ASINSOIL | 10.029 | 4 | 2.507 | 2010.873 | .000 |
| TIME | .799 | 5 | .160 | 128.243 | .000 |
| ASINSOIL * TIME | 1.441 | 20 | 7.207E-02 | 57.802 | .000 |
| Error | 7.481E-02 | 60 | 1.247E-03 | | |
| Total | 214.554 | 90 | | | |
| Corrected Total | 12.345 | 89 | | | |

a. R Squared = .994 (Adjusted R Squared = .991)

Post Hoc Tests

Homogeneous Subsets

**ASCORM**

Duncan [a,b]

| | | Subset | | | | |
|---|---|---|---|---|---|---|
| ASINSOIL | N | 1 | 2 | 3 | 4 | 5 |
| 50.00 | 18 | .956211 | | | | |
| 75.00 | 18 | | 1.273172 | | | |
| 150.00 | 18 | | | 1.676256 | | |
| 125.00 | 18 | | | | 1.742083 | |
| 100.00 | 18 | | | | | 1.846894 |
| Sig. | | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 1.247E-03.

a. Uses Harmonic Mean Sample Size = 18.000.

b. Alpha = .05.

**ASCORM**

Duncan [a,b]

| | | Subset | | | | |
|---|---|---|---|---|---|---|
| TIME | N | 1 | 2 | 3 | 4 | 5 |
| 75 | 15 | 1.356600 | | | | |
| 60 | 15 | | 1.444620 | | | |
| 30 | 15 | | | 1.470500 | | |
| 45 | 15 | | | | 1.522013 | |
| 15 | 15 | | | | 1.535253 | |
| 90 | 15 | | | | | 1.664553 |
| Sig. | | 1.000 | 1.000 | 1.000 | .309 | 1.000 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 1.247E-03.

a. Uses Harmonic Mean Sample Size = 15.000.

b. Alpha = .05.

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## Test of arsenic concentration in root of *Colocasia esculenta* (L.) Schott (green)

**Tests of Between-Subjects Effects**

Dependent Variable: ASROOT

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 51356.957[a] | 29 | 1770.930 | 8680.115 | .000 |
| Intercept | 125660.4 | 1 | 125660.4 | 615917.7 | .000 |
| ASINSOIL | 44854.310 | 4 | 11213.577 | 54962.739 | .000 |
| TIME | 1708.335 | 5 | 341.667 | 1674.662 | .000 |
| ASINSOIL * TIME | 4794.312 | 20 | 239.716 | 1174.953 | .000 |
| Error | 12.241 | 60 | .204 | | |
| Total | 177029.6 | 90 | | | |
| Corrected Total | 51369.198 | 89 | | | |

a. R Squared = 1.000 (Adjusted R Squared = 1.000)

Post Hoc Tests

Homogeneous Subsets

**ASROOT**

Duncan [a,b]

| ASINSOIL | N | Subset | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| 50.00 | 18 | 10.488406 | | | | |
| 75.00 | 18 | | 17.697756 | | | |
| 100.00 | 18 | | | 31.947606 | | |
| 125.00 | 18 | | | | 62.097372 | |
| 150.00 | 18 | | | | | 64.599461 |
| Sig. | | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = .204.

a. Uses Harmonic Mean Sample Size = 18.000.

b. Alpha = .05.

**ASROOT**

Duncan [a,b]

| TIME | N | Subset | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| 90 | 15 | 32.775280 | | | | |
| 75 | 15 | | 33.340873 | | | |
| 30 | 15 | | 33.421987 | | | |
| 15 | 15 | | | 39.223153 | | |
| 45 | 15 | | | | 42.313533 | |
| 60 | 15 | | | | | 43.121893 |
| Sig. | | 1.000 | .625 | 1.000 | 1.000 | 1.000 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = .204.

a. Uses Harmonic Mean Sample Size = 15.000.

b. Alpha = .05.

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## Test of efficiency of arsenic removal of *Colocasia esculenta* (L.) Schott (dark violet)

**Tests of Between-Subjects Effects**

Dependent Variable: EFFICIEN

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 2.030E-02[a] | 29 | 6.999E-04 | 2485.814 | .000 |
| Intercept | 9.825E-02 | 1 | 9.825E-02 | 348969.7 | .000 |
| ASINSOIL | 9.216E-03 | 4 | 2.304E-03 | 8183.227 | .000 |
| TIME | 6.550E-03 | 5 | 1.310E-03 | 4652.891 | .000 |
| ASINSOIL * TIME | 4.531E-03 | 20 | 2.265E-04 | 804.562 | .000 |
| Error | 1.689E-05 | 60 | 2.816E-07 | | |
| Total | .119 | 90 | | | |
| Corrected Total | 2.031E-02 | 89 | | | |

[a] R Squared = .999 (Adjusted R Squared = .999)

Post Hoc Tests

Homogeneous Subsets

**EFFICIEN**

Duncan [a,b]

| | | Subset | | | | |
|---|---|---|---|---|---|---|
| ASINSOIL | N | 1 | 2 | 3 | 4 | 5 |
| 75.00 | 18 | 1.97E-02 | | | | |
| 50.00 | 18 | | 3.05E-02 | | | |
| 150.00 | 18 | | | 3.12E-02 | | |
| 125.00 | 18 | | | | 3.28E-02 | |
| 100.00 | 18 | | | | | 5.10E-02 |
| Sig. | | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 2.816E-07.

[a] Uses Harmonic Mean Sample Size = 18.000.

[b] Alpha = .05.

**EFFICIEN**

Duncan [a,b]

| | | Subset | | | | | |
|---|---|---|---|---|---|---|---|
| TIME | N | 1 | 2 | 3 | 4 | 5 | 6 |
| 15.00 | 15 | 1.74E-02 | | | | | |
| 30.00 | 15 | | 2.63E-02 | | | | |
| 60.00 | 15 | | | 3.53E-02 | | | |
| 45.00 | 15 | | | | 3.84E-02 | | |
| 75.00 | 15 | | | | | 3.90E-02 | |
| 90.00 | 15 | | | | | | 4.19E-02 |
| Sig. | | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 2.816E-07.

[a] Uses Harmonic Mean Sample Size = 15.000.

[b] Alpha = .05.

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## Test of efficiency of arsenic removal of *Colocasia esculenta* (L.) Schott (green)

### **Tests of Between-Subjects Effects**

Dependent Variable: EFFICIEN

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 9.947E-03[a] | 29 | 3.430E-04 | 3121.377 | .000 |
| Intercept | 7.760E-02 | 1 | 7.760E-02 | 706154.0 | .000 |
| ASINSOIL | 1.696E-03 | 4 | 4.239E-04 | 3857.362 | .000 |
| TIME | 4.924E-03 | 5 | 9.848E-04 | 8961.383 | .000 |
| ASINSOIL * TIME | 3.328E-03 | 20 | 1.664E-04 | 1514.179 | .000 |
| Error | 6.593E-06 | 60 | 1.099E-07 | | |
| Total | 8.755E-02 | 90 | | | |
| Corrected Total | 9.954E-03 | 89 | | | |

a. R Squared = .999 (Adjusted R Squared = .999)

## Post Hoc Tests

## Homogeneous Subsets

### **EFFICIEN**

Duncan[a,b]

| | | Subset | | | | |
|---|---|---|---|---|---|---|
| ASINSOIL | N | 1 | 2 | 3 | 4 | 5 |
| 50.00 | 18 | 2.37E-02 | | | | |
| 75.00 | 18 | | 2.56E-02 | | | |
| 100.00 | 18 | | | 2.96E-02 | | |
| 150.00 | 18 | | | | 3.22E-02 | |
| 125.00 | 18 | | | | | 3.57E-02 |
| Sig. | | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 1.099E-07.

a. Uses Harmonic Mean Sample Size = 18.000.

b. Alpha = .05.

### **EFFICIEN**

Duncan[a,b]

| | | Subset | | | | | |
|---|---|---|---|---|---|---|---|
| TIME | N | 1 | 2 | 3 | 4 | 5 | 6 |
| 15.00 | 15 | 1.73E-02 | | | | | |
| 30.00 | 15 | | 2.18E-02 | | | | |
| 45.00 | 15 | | | 3.09E-02 | | | |
| 75.00 | 15 | | | | 3.29E-02 | | |
| 60.00 | 15 | | | | | 3.53E-02 | |
| 90.00 | 15 | | | | | | 3.80E-02 |
| Sig. | | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 1.099E-07.

a. Uses Harmonic Mean Sample Size = 15.000.

b. Alpha = .05.

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# BIOGRAPHY

Jirawan Jampanil was born on the 7th of December 1976 in Suphanburi Province. She entered Chulalongkorn University in 1994 and graduated a Bachelor Degree of Science in 1998 from Department of General Science, Faculty of Science, Chulalongkorn University. Then, she continued her further education at Inter-Department of Environmental Science, Chulalongkorn University.

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