CHAPTER IV
RESULT AND DISCUSSION

4.1 The amount and efficiency of total arsenic accumulation in various organs of *Canna* sp., *Colocasia esculenta* (L.), *Cyperus papyrus* (L.), and *Typha angustifolia* (L.)

All raw data were tabulated in table A.3 to table A.14.

4.1.1 Effect of arsenic on plant growth

Growth performance of the tested plant species were affected by both types of arsenics. The As(III) was more harmful to the plants than As(V) when incorporated into the soil at the same accumulation. Results from Table 4.1 and Figure 4.1 showed dry weight (g) of *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* planted in As(III) and As(V) contaminated soil. The result expressed that dry biomass of contaminated *Canna* sp. was significantly reduced in all periodically sampling stages when compared with control plant. Similar growth performances were also found in *C. papyrus* and *T. angustifolia*.

Table 4.1 Dry weight (g) of *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* in As(III) and As(V) contaminated soil

plants	Treatments	Dry weight (g)			
		15 days	30 days	45 days	60 days
Canna sp.	Control	13.7 ^{de}	15.8 ^{de}	21.2 ^{cd}	29.1 ^{b}
	As(III)	7.0 ^{f}	7.4 ^{f}	10.1 ^{f}	10.5 ^{d}
	As(V)	7.8 ^{f}	10.9 ^{ef}	14.1 ^{def}	19.9 ^{bcd}
C. esculenta	Control	18.2 ^{cd}	20.7 ^{cd}	21.8 ^{c}	30.2 ^{b}
	As(III)	9.9 ^{ef}	10.5 ^{f}	11.5 ^{ef}	12.8 ^{cd}
	As(V)	10.1 ^{ef}	11.9 ^{ef}	18.0 ^{cde}	22.1 ^{bc}
C. papyrus	Control	44.3 ^{a}	46.3 ^{a}	60.8 ^{a}	68.7 ^{a}
	As(III)	32.7 ^{b}	35.6 ^{b}	50.6 ^{b}	59.2 ^{a}
	As(V)	39.4 ^{a}	40.7 ^{b}	57.5 ^{ab}	62.9 ^{a}
T. angustifolia	Control	20.6 ^{c}	21.5 ^{c}	23.4 ^{c}	25.1 ^{b}
	As(III)	17.4 ^{cd}	17.4 ^{cd}	21.5 ^{c}	23.8 ^{bc}
	As(V)	19.2 ^{c}	20.8 ^{cd}	22.9 ^{c}	24.2 ^{b}

Note: Superscripts in each harvest time by the same letters are not significantly different ($P \leq 0.05$).

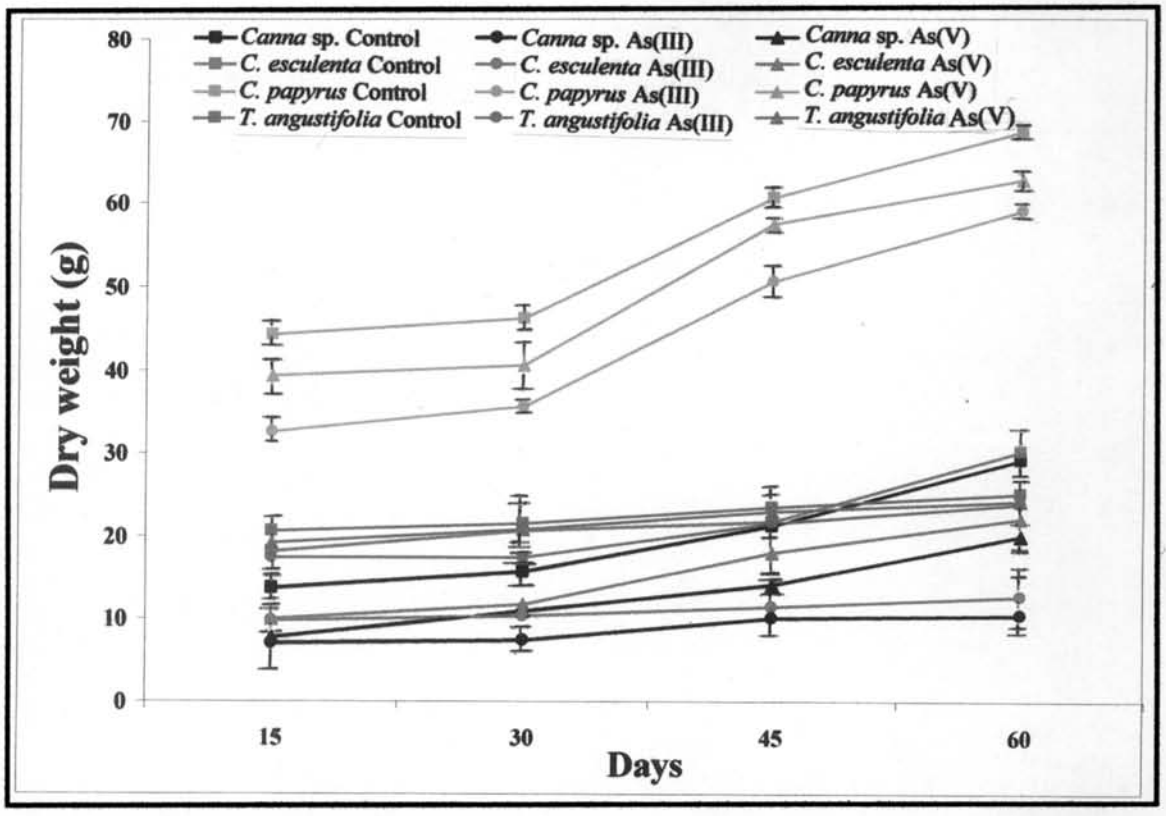

Figure 4.1 Dry weight of *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* planted in As(V) and As(III) treatments

Table 4.2 displayed dry weight decrease (%) of *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* planted in As(III) and As(V) contaminated soil. In As(III) contaminated soil, the greatest percentage decrease of dry biomass was found in *Canna* sp. at the average of 54% (49 - 64%) followed by that of *C. esculenta*, *C. papyrus* and *T. angustifolia* at 49% (45 – 56%), 20% (13 – 27%) and 11.80% (5 – 18%), respectively; on the other hand, As(V) reduced plant dry weight of *C. esculenta*, *Canna* sp., *C. papyrus* and *T. angustifolia* as following at the average 32% (19 – 44%), 34% (30 – 43%), 9% (6 – 12%) and 4% (2 – 7%), respectively.

These results indicated that the poisonous symptom of arsenic on the plants depended on plant species, the concentration and types of arsenic contaminated in growth environment. Some plants died at early growth stage and some of them stunted and showed the symptoms of straight-head disease, which agreed with the former researches (Meharg & Macnair, 1991, Barrachina *et al.*, 1995; Quaghebeur and Rengel, 2005). This result apparently contradicted to Carbonell *et al.*, (1998) who found that when arsenic was applied as inorganic arsenicals(As(III)) and (As(V)) at the rates of 0.2 and 0.8 mg $As.L^{-1}$, an increase in the total dry matter of *Spartina*

alterniflora was observed as compared with control plants. However, this result agreed with Wei *et al.*, (2006) showed that (As(V)) reduced the plant biomass of *P. ensiformis* after 1, 5 or 10 days of arsenic exposure at 33 or 267 μM, with greater accumulation leading to lower plant biomass (Tu and Ma, 2002). The arsenic tolerance of plants depended on types of plant. High accumulation of arsenic may interfere with plant metabolism, impair nutrient uptake and/or may simply compete with essential plant nutrient (Meharg and Macnair, 1990). Plants also vary in their sensitivity or resistance to As(III) (Meharg and Hartley-Whitaker, 2002).

Table 4.2 Dry weight decrease (%) of *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* in As(III) and As(V) contaminated soil

Plants	Treatments	Dry weight decrease (%)			
		15 days	30 days	45 days	60 days
Canna sp.	Control	0 ^{d}	0 ^{f}	0 ^{e}	0 ^{d}
	As(III)	49 ^{a}	53 ^{a}	52 ^{a}	64 ^{a}
	As(V)	43 ^{a}	30 ^{bc}	33 ^{b}	31 ^{b}
C. esculenta	Control	0 ^{d}	0 ^{f}	0 ^{e}	0 ^{d}
	As(III)	45 ^{a}	49 ^{a}	47 ^{a}	56 ^{a}
	As(V)	44 ^{a}	43 ^{ab}	19 ^{c}	24 ^{bc}
C. papyrus	Control	0 ^{d}	0 ^{f}	0 ^{e}	0 ^{d}
	As(III)	27 ^{b}	23 ^{cd}	17 ^{cd}	13 ^{cd}
	As(V)	12 ^{c}	12 ^{def}	6 ^{de}	9 ^{cd}
T. angustifolia	Control	0 ^{d}	0 ^{f}	0 ^{e}	0 ^{d}
	As(III)	16 ^{c}	18 ^{cde}	8 ^{cde}	5 ^{d}
	As(V)	7 ^{cd}	3 ^{ef}	2 ^{e}	4 ^{d}

Note: Superscripts in each harvest time by the same letters are not significantly different ($P \leq 0.05$).

The ability of *C. esculenta* to survive in soil with 175 $mg.kg^{-1}$ of arsenic was contrast to the results of Tambamroogn (2002). The decrease of *T. angustifolia* agreed with other studies showed that it had the most tolerance. Therefore *T. angustifolia* can commonly be found in arsenic contaminated soil (Dushenko *et al.*, 1995 referred by Zhang *et al.*, 2002).

Injury symptom on plants resulting from toxic quantities of arsenic in soil were noted in the 1930s, when it was found that young plants that had been treated with arsenic grew slowly and were stunted. In addition to being stunted, plants had leaf symptoms that indicated water-deficiency stress, which implied injury to the roots (Gomez-Caminero *et al.*, 2001). The inorganic arsenic species that were As(V) and As(III) cause a variety of symptoms ranging from inhibitor of root growth to plant

death (Quaghebeur and Rengel, 2005). Phytotoxic symptoms were wilting, and stunted growth with foliar chlorosis and necrosis. Beside the visual toxicity symptom, plant also showed a greater reduction in biomass (Wei *et al.*, 2006).

As(III) was more toxic than As(V) (Federation Remediation Technologies Roundtable., 2007; Quaghebeur and Rengel, 2005; Oremland and Stolz, 2005). As(V) and phosphates have the same characteristics (Meharg and Macnair, 1991; Tripathi *et al.*, 2007). Therefore As(V) was a competitive inhibitor of phosphates and acts as uncouple of oxidative phosphorylation. As(V) competes with phosphates for binding to ADP; the formation of the As(V)-ADP analogues deprives the cells of energy, ultimately leading to cell death (Meharg and Macnair,1994; Oremland and Stolz, 2005). Moreover the plants behave the lack phosphate that was dark green leaf which begins at base to top leaf. As(III), on the other hand, was a well-known thiol reagent that combined rapidly with dithiol groups on proteins and was hence an effective inhibitor of enzymes requiring free sulfhydryl(-sh) group (Ullrich-Eberius *et al.*, 1989 refered by Meharg, and Hartley-Whitaker, 2002; Oremland and Stolz, 2005).

The toxicity of arsenic may be dependent on As/P ratios within plant tissue, not absolute arsenic concentrations in tissue. A molar P/As ratio of at least 12 is needed to protect plants against As(V) toxicity (Walsh and Keeny, 1975 referred by Geng *et al.*, 2005)

4.1.2 Total arsenic accumulation in different organs of plants

Arsenic was significant difference ($p \leq 0.05$) accumulated in different organs of the tested plants. A much large fraction of arsenic was found accumulated in root, rhizome, pseudostem or leaf depended on plant species and types of arsenic incorporated in the soil.

4.1.2.1 *Canna* sp.

Arsenic accumulation in *Canna* sp. at different growth stages, 15, 30, 45 and 60 days was found that at 15 days (Table 4.3).

The highest of total arsenic accumulation was an the rhizome for As(V) treatment while in As(III) treatment it was in the root followed by in the pseudostem of arsenic at this stage of growth was in the leaf. At 30 days, the maximum of total

arsenic accumulation was rhizome for As(V) contaminated soil, but in As(III) treatment, the root and rhizome were the highest accumulation. The second was the pseudostem, and the other was leaf which was the lowest arsenic accumulation. At 45 days, the rhizome could accumulate the best of arsenic accumulation for As(V) and As(III) contaminated soil followed by root, pseudostem, and leaf in both of arsenic treatment, respectively. At 60 days, the highest accumulation organ was rhizome which was similarly at 30 and 45 days. It could collect maximum in both of arsenic species. The root was the second; however leaf and pseudostem had total arsenic nearly accumulation.

Table 4.3 Total arsenic accumulation ($mg.kg^{-1}$) in organs of *Canna* sp. at 15, 30, 45, and 60 days

Days	Organs	Total arsenic accumulation ($mg.kg^{-1}$) *		
		Control	As(III)	As(V)
15	leaf	1^{de}	15^{e}	35^{d}
	pseudostem	4^{de}	41^{cd}	53^{c}
	rhizome	2^{de}	95^{b}	184^{a}
	root	1^{de}	183^{a}	87^{b}
	mean	2	84	90
30	leaf	1^{f}	23^{e}	103^{c}
	pseudostem	1^{f}	95^{d}	93^{d}
	rhizome	1^{f}	196^{a}	198^{a}
	root	2^{f}	196^{a}	153^{b}
	mean	1	128	137
45	leaf	1^{g}	33^{f}	109^{d}
	pseudostem	1^{g}	91^{de}	97^{de}
	rhizome	2^{g}	184^{b}	237^{a}
	root	2^{g}	139^{c}	177^{b}
	mean	1	111	155
60	leaf	0^{f}	90^{e}	105^{d}
	pseudostem	0^{f}	93^{de}	103^{de}
	rhizome	1^{f}	190^{b}	265^{a}
	root	1^{f}	167^{c}	157^{c}
	mean	1	135	157

Note: Superscript in each harvest time by the same letters are not significantly different ($P \leq 0.05$).
* : arsenic in organ (mg) / dry weight of organ (kg)

The average of total arsenic accumulation showed in Figure 4.2 indicated overall fractions of arsenic in arsenic organs of *Canna* sp. Mostly, the deposition of arsenic in each organ at the beginning of growth stages (15 and 30 days) was

increased, but after that arsenic accumulation in rhizome at As(V) treatment increased from 15 days to the highest at 60 days, but in As(III) treatment, arsenic accumulation increased to the highest at 30 days. In root, the range of arsenic accumulation at As(III) treatment was 139 – 196 $mg.kg^{-1}$, and at As(V) treatment increased to the highest at 45 days, that was 177 $mg.kg^{-1}$. At 15 days, pseudostem accumulated similarly total arsenic in both of As(III) and As(V) that were 41 and 53 $mg.kg^{-1}$, respectively; moreover at 60 days, pseudostem accumulated to the highest that were 93 and 103 $mg.kg^{-1}$ in As(III) and As(V) treatment. Leaf of *Canna* sp. in As(V) treatment accumulated total arsenic higher than As(III) treatment. There was 35 and 15 $mg.kg^{-1}$ in As(V) and As(III) treatment at 15 days. At 60 days, leaf accumulated the highest total arsenic that was 105 and 90 $mg.kg^{-1}$ at As(V) and As(III) treatments.

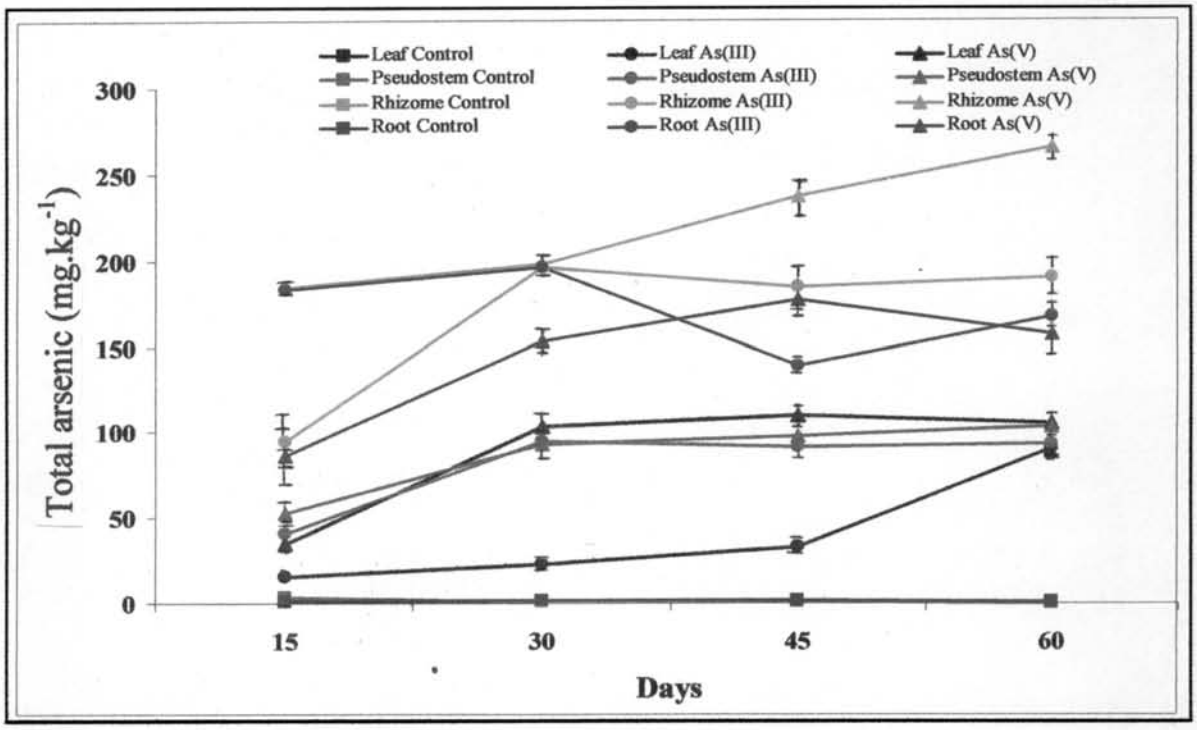

Figure 4.2 Arsenic accumulation ($mg.kg^{-1}$) in leaf, pseudostem, rhizome, and root of *Canna* sp. at 15, 30, 45 and 60 day

Plants arsenic uptake depends on arsenic sources and solubility. It has been suggested that arsenic uptake by plants is passive and direct related to water flow (Kertulis *et al.*, 2005). The main route of As(V) uptake in plants is through the phosphates transporters as a phosphate analogue, whereas As(III) is transported in the neutral $As(OH)_3$ form through aquaglyceroporins (Tripathi *et al.*, 2007). Therefore,

the root uptake rates of As(III) and As(V) into the plant roots are likely different. Arsenic is first taken into apoplast of the roots. Some of total amount is transported into the cell, while some are transported into the apoplast diffusion into the vascular system (Eapen and D'Souza, 2005). The uptake of arsenic speciation by rice in long term hydroponics culture was DMA < As(V) < MMA < As(III) (Marin *et al.*, 1992). This result agreed with accumulation of *Canna* sp. Plants that accumulated arsenic may either store arsenic in the root or translocation it to the above-ground biomass. These differences in storage of arsenic suggest different process for arsenic accumulation and transport mechanism within different plants (Zhang *et al.*, 2002).

4.1.2.2 *Cyperus papyrus* (L.)

Table 4.4 Total arsenic accumulation ($mg.kg^{-1}$) in organs of *C. papyrus* at 15, 30, 45, and 60 days

Days	Organs	Total arsenic accumulation ($mg.kg^{-1}$)*		
		Control	As(III)	As(V)
15	leaf	1 ^{g}	72 ^{e}	203 ^{b}
	culm	1 ^{g}	56 ^{f}	128 ^{c}
	rhizome	2 ^{g}	109 ^{d}	129 ^{c}
	root	1 ^{g}	233 ^{a}	123 ^{c}
	mean	1	11 8	146
30	leaf	2 ^{h}	128 ^{e}	185 ^{c}
	culm	2 ^{h}	75 ^{g}	135 ^{de}
	rhizome	1 ^{h}	142 ^{d}	109 ^{f}
	root	1 ^{h}	315 ^{b}	328 ^{a}
	mean	2	165	189
45	leaf	1 ^{e}	159 ^{b}	147 ^{b}
	culm	1 ^{e}	67 ^{d}	113 ^{c}
	rhizome	1 ^{e}	75 ^{d}	100 ^{c}
	root	1 ^{e}	184 ^{a}	195 ^{a}
	mean	1	121	139
60	leaf	1 ^{f}	176 ^{a}	139 ^{b}
	culm	1 ^{f}	63 ^{e}	120 ^{c}
	rhizome	1 ^{f}	68 ^{e}	91 ^{d}
	root	2 ^{f}	120 ^{c}	188 ^{a}
	mean	1	107	135

Note: Superscripts in each harvest time by the same letters are not significantly different ($P \leq 0.05$).
* : arsenic in organ (mg) / dry weight of organ (kg)

At 15 days, the highest of total arsenic accumulation was in the leaf for As(V) treatment soil, while it was in the root followed by rhizome in As(III) treatment soil. The minimum accumulation of arsenic at this stage of growth was in the culm (Table 4.4).

At 30 days, root accumulated dramatically the highest arsenic in As(V) and As(III) treatment soil, which was the maximum value of all organs in every harvest time. Leaf was in the form of As(V) and rhizome was in the form of As(III) while could accumulate arsenic in the second order. The lowest organ of arsenic accumulation was culm in As(III) and As(V) contaminated soil. At 45 days, the best accumulation organ was root in both of arsenic speciation, followed by leaf, culm, and rhizome, respectively. At 60 days, the most total arsenic deposited was in the root for As(V) contaminated pots, although in the form of As(III) it was leaf, followed by culm. The lowest was rhizome.

Figure 4.3 showed arsenic accumulation in various organs of *C. papyrus* at 15, 30, 45, and 60 days. At 15 days, arsenic accumulation in root, leaf, rhizome, and culm of As(V) treatment soil were 123, 202, 129, and 128 $mg.kg^{-1}$, respectively, and of As(III) treatment soil were 233, 72, 109, and 56 $mg.kg^{-1}$, respectively. Arsenic accumulation in root of As(III) and As(V) treatments increased to the highest at 30 days, which was 314 and 328 $mg.kg^{-1}$ respectively. After that it decreased to the lowest at 60 days. Leaf, rhizome, and culm of *C. papyrus* in As(V) treatment was the highest at 15 days , and then decreased continuously to the lowest at 60 days that was 139, 91, and 120 $mg.kg^{-1}$,respectively. Arsenic accumulation of culm and rhizome in As(III) treatment was similarly with As(V) treatment. Arsenic accumulation of leaf of *C. papyrus* in As(III) treatment increased to the highest at 60 days, which was 176 $mg.kg^{-1}$.

Arsenic accumulation in root of *C. papyrus* in As(V) treatment was the highest at 30 days. At 15 days, arsenic accumulation in root of *C. papyrus* in As(III) treatment was higher than As(V) treatment, but the other harvest times were the reverse effect. The next was the leaf. Arsenic accumulation of leaf in As(III) treatment increased when harvest time increased, but leaf in As(V) treatment decreased when harvest time increased. This result was different from other organs of *C. papyrus*. In addition, it was reverse effect from Marin *et al.* (1992) and Carbonell *et al.* (1998).

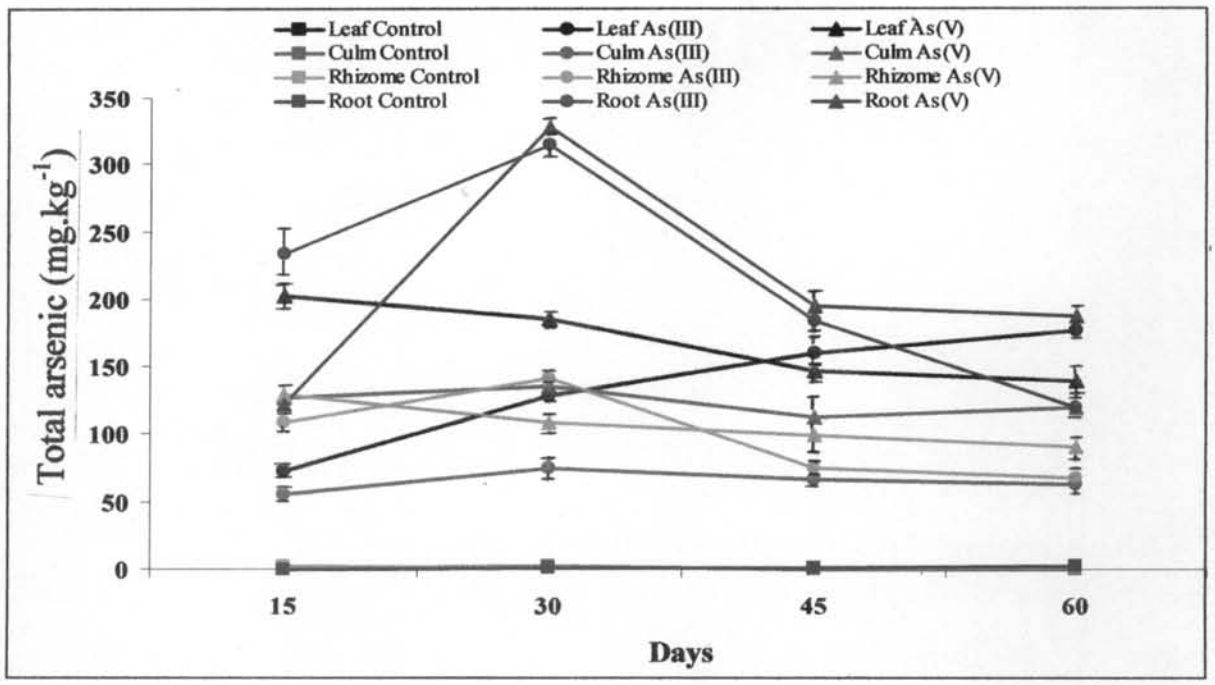

Figure 4.3 Total arsenic accumulation ($mg.kg^{-1}$) in leaf, culm, rhizome, and root of *C. papyrus* at 15, 30, 45 and 60 day

For uptake into a plant, a chemical must be in solution, either in ground water or in the soil solution (i.e., the water in the unsaturated soil zone). Water is absorbed from the soil solution into the outer tissue of the root. Contaminants in the water can move through the epidermis to and through the Casparian strip, and then through the endodermis, where they can be sorbed, bound, or metabolized. Chemicals or metabolites passing through the endodermis and reaching the xylem are then transported in the transpiration stream or sap. The compounds might react with or partition into plants tissue, be metabolized, or be released to the atmosphere through stomatal pores (Paterson *et al.*, 1990; Shimp *et al.*, 1993).

4.1.2.3 *Colocasia esculenta* (L.)

At 15 days, root contents the highest of total arsenic accumulation for both of As(III) and As(V) treatments (Table 4.5). The second was petiole in As(V) and corm in As(III) treatments, followed by leaf and petiole in As(III), and leaf and corm in As(V) contaminated soil. At 30 days, root accumulated most of arsenic accumulation when compared to every organ in all harvest times, followed by petiole in As(V) and

corm in As(III). The minimum accumulation organ was petiole in As(III) and corm in As(V) treatments. At 45 days, petiole in As(V) and corm in As(III) treatments were the best accumulation organ, followed by root in As(V) and As(III) treated soil. Leaf and petiole in As(III) were not different arsenic accumulation. In addition leaf in As(V) collected the minimum accumulation. At 60 days, corm was the best accumulation for As(III), but for As(V), petiole had the most arsenic accumulation, followed by root, petiole and leaf in As(V) treatment and root, leaf, and corm for As(III) treatment, respectively.

Table 4.5 Total arsenic accumulation ($mg.kg^{-1}$) in organs of *C. esculenta* at 15, 30, 45, and 60 days

Days	Organs	Total arsenic accumulated ($mg.kg^{-1}$)*		
		Control	As(III)	As(V)
15	leaf	1^{g}	100^{c}	91^{e}
	petiole	1^{g}	119^{d}	70^{f}
	corm	1^{g}	129^{d}	152^{c}
	root	1^{g}	174^{b}	344^{a}
	mean	1	130	165
30	leaf	1^{g}	120^{e}	128^{e}
	petiole	2^{g}	136^{e}	87^{f}
	corm	2^{g}	166^{d}	187^{c}
	root	1^{g}	272^{b}	381^{a}
	mean	1	173	196
45	leaf	1^{f}	80^{d}	61^{e}
	petiole	1^{f}	75^{d}	59^{e}
	corm	1^{f}	126^{b}	180^{a}
	root	1^{f}	93^{d}	127^{c}
	mean	1	93	107
60	leaf	1^{g}	54^{e}	88^{d}
	petiole	1^{g}	78^{d}	40^{f}
	corm	2^{g}	118^{b}	138^{a}
	root	1^{g}	105^{c}	102^{c}
	mean	1	89	92

Note: Superscripts in each harvest time by the same letters are not significantly different ($P \leq 0.05$).
* : arsenic in organ (mg) / dry weight of organ (kg)

Figure 4.4, arsenic accumulation of root in both of As(III) and As(V) increased from 15 days to the highest at 30 days that were 272 and 381 $mg.kg^{-1}$. After that arsenic accumulation in root decreased rapidly to the lowest at 60 days.

From arsenic accumulation in *C. esculenta*, the results demonstrated that the level of arsenic accumulation when treated with As(III) and As(V) were in root > corm > petiole > leaf and root > corm > petiole, respectively. This result agreed with Tambamroong (2002) and Jampanil (2000).

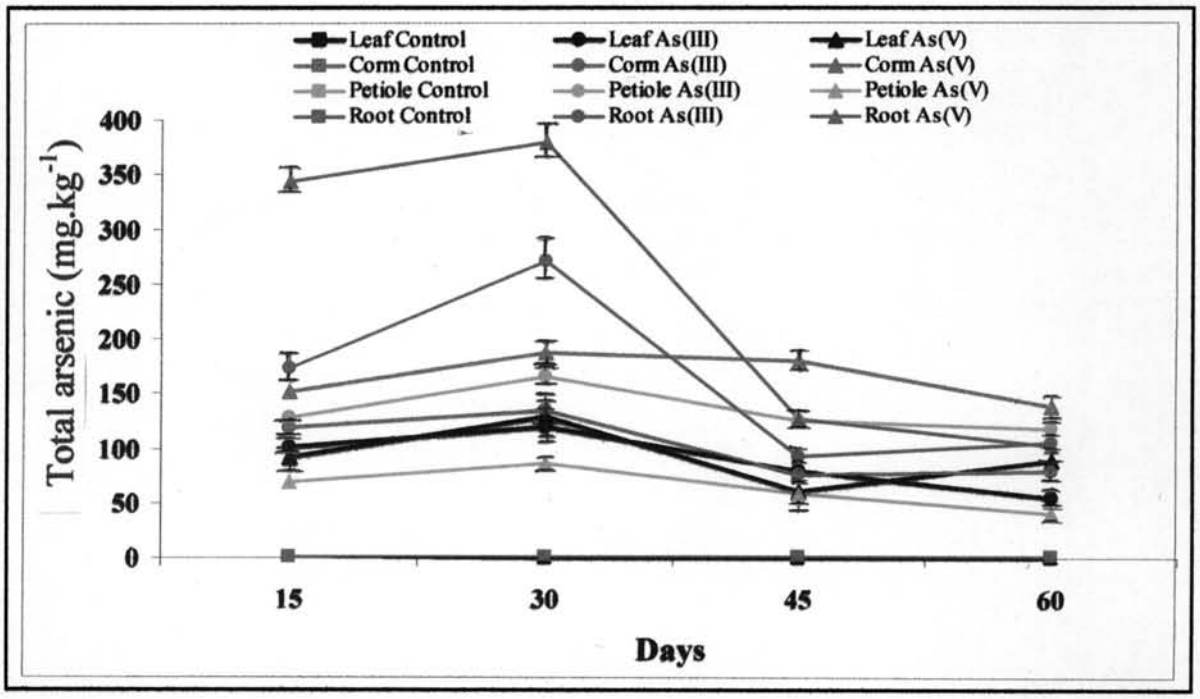

Figure 4.4 Arsenic accumulation ($mg.kg^{-1}$) in leaf, petiole, corm, and root of *C. esculenta* at 15, 30, 45 and 60 day

4.1.2.4 *Typha angustifolia* (L.)

At 15 days, rhizome in As(V) and As(III) treatment had the highest of total arsenic accumulation, followed by root (Table 4.6). The lowest of arsenic deposit was leaf in 2 arsenic species. At 30 days, the order was similar at 15 days that was rhizome, root, and leaf, respectively. At 45 days, root in As(V) treatment could collect the most arsenic accumulation, but in As(III) treatment, rhizome accumulated the best arsenic accumulation. Leaf and rhizome for As(V) contaminated soil accumulated nearly arsenic accumulation; in addition leaf and root for As(III) treated soil absorbed

similarly total arsenic. At 60 days, rhizome in As(III) treatment collected dramatically arsenic accumulation when compared with all organs for 2 arsenic species from beginning to end; although root in As(III) was the highest accumulation organ when compared with every organ in every times of As(III) contaminated soil. Leaf and rhizome in As(V) accumulated similarly arsenic deposition, and leaf and root in As(III) absorbed nearly all arsenic accumulation.

Table 4.6 Total arsenic accumulation ($mg.kg^{-1}$) in organs of *T. angustifolia* at 15, 30, 45, and 60 days

Days	Organs	Total arsenic accumulation ($mg.kg^{-1}$)*		
		Control	As(III)	As(V)
15	leaf	1^{e}	78^{d}	88^{cd}
	rhizome	2^{e}	237^{a}	108^{b}
	root	2^{e}	100^{c}	97^{c}
	mean	1	138	98
30	leaf	2^{f}	82^{e}	125^{c}
	rhizome	1^{f}	246^{a}	109^{d}
	root	1^{f}	156^{b}	155^{b}
	mean	1	161	130
45	leaf	2^{d}	128^{c}	126^{c}
	rhizome	4^{d}	265^{a}	128^{c}
	root	1^{d}	138^{c}	217^{b}
	mean	2	177	157
60	leaf	1^{f}	68^{e}	139^{c}
	rhizome	0^{f}	288^{a}	137^{c}
	root	1^{f}	85^{d}	218^{b}
	mean	1^{f}	147	165

Note: Superscripts in each harvest time by the same letters are not significantly different ($P \leq 0.05$).
* : arsenic in organ (mg) / dry weight of organ (kg)

From the result showed in Figure 4.5. arsenic accumulation in rhizome, root, leaf in As(V) treatment and rhizome in As(III) treatment increased from 15 days to 60 days, but root in As(III) treatment increased from 15 to 30 days, and leaf in As(III) treatment increased from 15 days to 45 days. After that they decreased to the lowest at 60 days. Total arsenic accumulation in different organ of *Canna* sp., *C. esculenta*, *C. papyrus*, and *T. angustifolia* indicated that all plants taken up As(V) more than As(III), excepted *T. angustifolia*. Accumulation of total arsenic in As(III) treatment of *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* were the highest accumulation at rhizome, root, corm/root, and rhizome that ranges were 183 – 196,

184 - 315, 118 – 272, and 237 – 288 $mg.kg^{-1}$, respectively. Accumulation of total arsenic in As(V) treatment of *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* were the highest accumulation at rhizome, root, corm/root, and rhizome that were 184 – 265, 188 – 328, 138 – 381, and 108 – 218 $mg.kg^{-1}$, respectively.

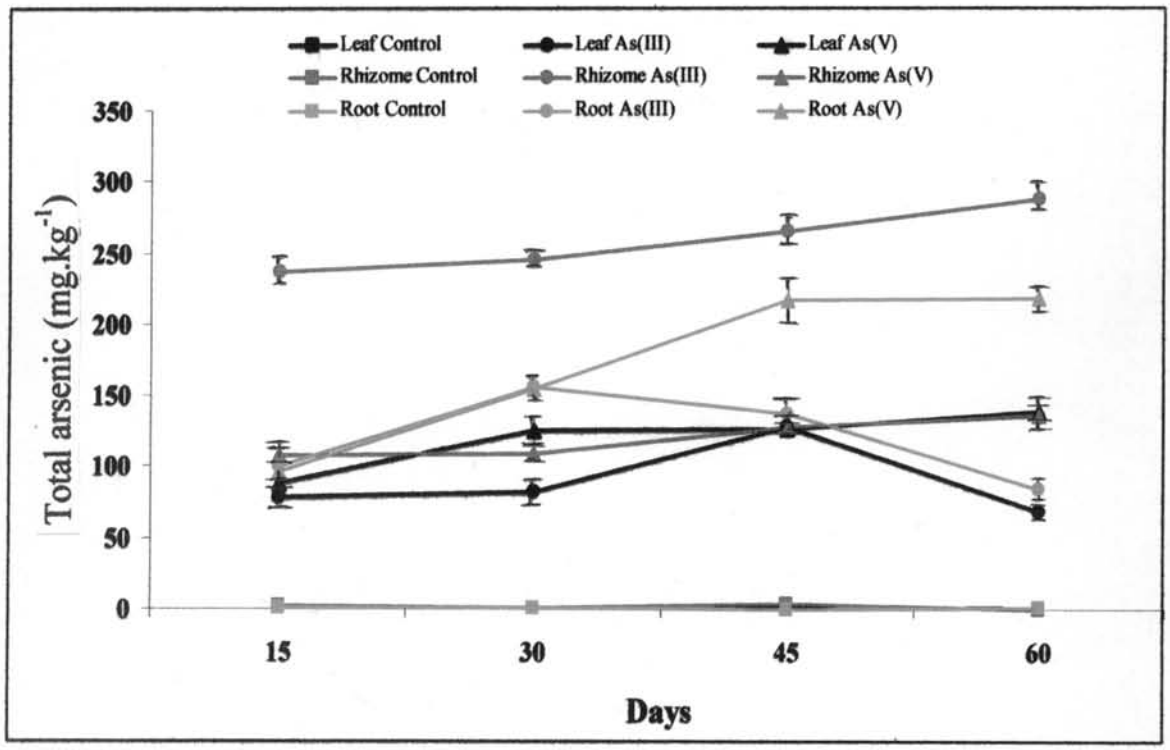

Figure 4.5 Arsenic accumulation ($mg.kg^{-1}$) in leaf, rhizome, and root of *T. angustifolia* at 15, 30, 45 and 60 day

From the result, it showed that in plant, arsenic was accumulated mainly in the root or underground system, to a lesser degree in the aboveground organs, and causes physiological changes and damages while agreed with previous work Marin *et al.*, (1992); Wells and Gilmor, (1997); Stoeva *et al.*, (2003).

Arsenic caused a reduction of the photosynthesis rate (Stoeva and Bineva, 2003). In maize, it found that the rate of CO_2 – fixation in young plants treated with arsenic decreased by about 20% and functional activity of PS II was reduced significantly. Arsenic damaged the chloroplast membrane and disorganized the membrane structure (Stoeva *et al.*, 2005). The level of arsenic in the plant correlates well with the arsenic accumulation in the soil solution. Moreover, not only the total arsenic accumulation in solution, but also the speciation of arsenic influences arsenic uptake (Quaghebeur and Rengel, 2005).

The uptake of arsenic speciation by rice in long term hydroponics culture was DMA < As(V) < MMA < As(III) (Marin *et al.*, 1992). This result agreed with accumulation of *Canna* sp., *C. esculenta*, and *C. papyrus*; however the reverse effect of *T. angustifolia* which uptake arsenic from As(III) treatment more than As(V) treatment. Moreover the highest accumulation remain in organ was lower than other plants.

It is well know that *Typha* spp. take up metals and elements from the sediment and translocation them to above sediment tissue (Sundberg *et al.*, 2006). *T. angustifolia* can commonly be found in arsenic contaminated soil (Zhang *et al.*, 2002). The observation that some plant species can grow on mine spoils that contain high accumulation of arsenic has led to the assumption that these plant species may have developed specific resistance mechanism to arsenic. Plant can achieve metal resistance by using two types of mechanism: avoidance by minimizing metal uptake across plasma membrane of root cell and tolerance to metals accumulating in the symplasm (Quaghebeur and Rengel, 2005).

4.1.3 Total arsenic accumulation *Canna* sp., *C. esculenta*, *C. papyrus*, and *T. angustifolia*

Arsenic accumulation in the plants that grown on in As(III) and As(V) contaminated soil showed that the accumulation depended on types of plants and arsenic speciation. There were also found the interaction between plants species and arsenic speciation. Arsenic accumulation in *Canna* sp., *C. esculenta,* and *C. papyrus* grew in As(V) contaminated soil seemed to be greater than that planted in As(III), except *T. angustifolia* which had reverse affects. The ability of arsenic absorption depended on plant species and types of incorporated arsenics found in all sampling periods. At 15 days after transplant, *T. angustifolia* planted in As(III) showed significantly ($p \leq 0.05$), the highest accumulation at 163 $mg.kg^{-1}$ followed by *C. esculenta*, *C. papyrus*, and *Canna* sp. which could absorb at 123, 96, and 75 $mg.kg^{-1}$, respectively. On the other hand, the plants planted in As(V) contaminated soil gave the value of accumulation as following; 150, 146, 118, and 100 $mg.kg^{-1}$in *C. papyrus*, *C. esculenta*, *Canna* sp, and *T. angustifolia*, respectively. Table 4.7 showed total arsenic accumulation ($mg.kg^{-1}$) of *Canna* sp., *C. esculenta*, *C. papyrus*, and *T. angustifolia* at 15, 30, 45, and 60 days in As(V) and As(III) treatments.

At 30 days, arsenic accumulation in *Canna* sp., *C. esculenta*, and *C. papyrus* grew up in As(V) contaminated soil seemed to be 15 days that was could grow greater than in As(III), but *T. angustifolia* which had opposite affects. *C. esculenta* in As(V) *and T. angustifolia* in As(III) and *C. papyrus* in As(V) planted showed significantly ($p \leq 0.05$), the maximum accumulation at 178, 177 and 172 $mg.kg^{-1}$, respectively. The order of plants in As(III) was *C. esculenta*, *Canna* sp., and *C. papyrus* that were 154, 138, and 138 $mg.kg^{-1}$, respectively. The accumulation of arsenic in plants in As(V) contaminated soil were 153 and 121 $mg.kg^{-1}$, in *Canna* sp. and *T. angustifolia*, respectively.

Table 4.7 Total arsenic accumulation ($mg.kg^{-1}$) of *Canna* sp., *C. esculenta*, *C. papyrus*, and *T. angustifolia* at 15, 30, 45, 60 days in As(V) and As(III) treatments

Days	Plants	Total arsenic accumulation ($mg.kg^{-1}$)*		
		Control	As(III)	As(V)
15	*Canna sp*	2 ^{f}	75 ^{ef}	118 ^{c}
	C. esculenta	1 ^{f}	123 ^{c}	146 ^{b}
	C. papyrus	1 ^{f}	96 ^{d}	150 ^{b}
	T. angustifolia	2 ^{f}	163 ^{a}	100 ^{d}
	mean	1	114	128
30	*Canna* sp	1 ^{e}	138 ^{c}	153 ^{b}
	C. esculenta	2 ^{e}	154 ^{b}	178 ^{a}
	C. papyrus	2 ^{e}	138 ^{c}	172 ^{a}
	T. angustifolia	1 ^{e}	177 ^{a}	121 ^{d}
	mean	2	152	156
45	*Canna sp*	1 ^{h}	128 ^{de}	177 ^{b}
	C. esculenta	1 ^{h}	88 ^{g}	124 ^{e}
	C. papyrus	1 ^{h}	114 ^{f}	132 ^{d}
	T. angustifolia	3 ^{h}	201 ^{a}	140 ^{c}
	mean	2	133	143
60	*Canna sp*	1 ^{f}	147 ^{b}	189 ^{a}
	C. esculenta	1 ^{f}	83 ^{e}	104 ^{d}
	C. papyrus	1 ^{f}	107 ^{d}	130 ^{c}
	T. angustifolia	1 ^{f}	185 ^{a}	149 ^{b}
	mean	1	131	143

Note: Superscripts in each harvest time by the same letters are not significantly different ($P \leq 0.05$).
* : total arsenic in plant (mg) / dry weight of plant (kg)

At 45 days, *T. angustifolia* in As(III) displayed significantly ($p \leq 0.05$), the maximum accumulation of arsenic at 201 $mg.kg^{-1}$ followed by *Canna* sp., *C. papyrus*, and *C. esculenta* which could accumulated arsenic at 128, 114, and 88 $mg.kg^{-1}$,

respectively. The plants in As(V) contaminated soil gave the value of arsenic accumulation as following; 177, 140, 132, and 124 $mg.kg^{-1}$, in *Canna* sp., *T. angustifolia, C. papyrus*, and *C. esculenta*, respectively.

At 60 days, the order of arsenic accumulation was similarly with these at 45 days showed that *T. angustifolia* planted in As(V) contaminated expressed significantly ($p \leq 0.05$), the maximum accumulation at 185 $mg.kg^{-1}$ followed by *Canna* sp., *C. papyrus*, and *C. esculent* which could collect at 147, 107, and 83 $mg.kg^{-1}$, respectively. The plants in As(V) contaminated soil gave the value of accumulation as following; 189, 149, 130, and 104 $mg.kg^{-1}$ in *Canna* sp., *T. angustifolia, C. papyrus*, and *C. esculenta*, respectively.

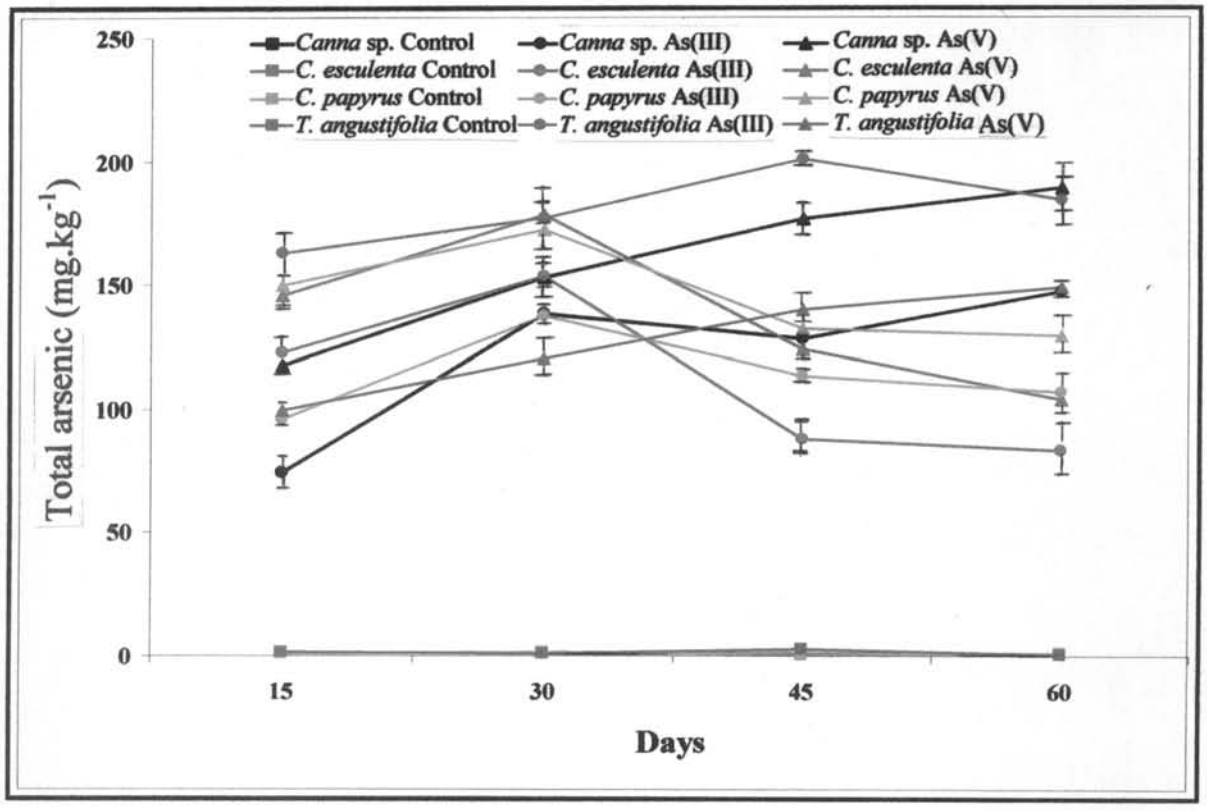

Figure 4.6 Total arsenic accumulation ($mg.kg^{-1}$) in *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* planted in As(V) and As(III) treatments

The arsenic accumulation concluded in Figure 4.6 that showed *T. angustifolia* in As(III) treatment accumulated a total level of arsenic higher than those in As(V) treatment at every harvest period, but *Canna* sp., *C. esculenta*, and *C. papyrus* had

reverse effect. *T. angustifolia* in As(III) contaminated soil increased continuously from beginning to end, and it was the maximum of arsenic accumulation, followed *C. esculenta* at 15 and 30 days, but at 45 and 60 days, the next was *Canna* sp. In As(V) incorporated soil, at 15 and 30 days *C. papyrus* and *C. esculenta* could accumulated the highest of arsenic accumulation, but at 45 and 60 days *Canna* sp. was the maximum arsenic accumulation.

Arsenic accumulation in plant shoots depend mainly on the root activity (Carbonell-Barrachina *et al.*, 1999a). Upward arsenic transport from the roots to shoots is often limited by the high toxicity of arsenic to the radicular membranes. The uptake of arsenic by rice in long term hydroponics culture was DMA < As(V) < MMA < As(III) (Marin *et al.*, 1992). Plants take up As(V) and As(III) through phosphate transporters and aquaglyceroporins respectively (Tripathi *et al.*, 2007; Quaghebeur and Rengel, 2005). Arsenic distribution in plant tissues differed with arsenic accumulation, exposure duration as well as plant species (Wei *et al.*, 2006).

4.1.4 Arsenic accumulated translocation factor

Arsenic accumulated translocation factor (ATF) were calculated from arsenic accumulation in aboveground organs divided by underground organs (Tu and Ma, 2002; Wei *et al.*, 2006; Singh and Ma, 2006; Tu *et al.*, 2004). It means the capacity of plant to translocation arsenic. If ATF is high value, the plant will be a suitable plant to phytoremediation. From the result, it found that *C. papyrus* was the highest ATF, the ranging from 0.78-2.54 (Table 4.8)

One of the characteristics of an arsenic hyperaccumulator is its ability to accumulate arsenic in the aboveground biomass (Marin *et al.*, 2005). From the result of arsenic accumulation in different organs of plants showed that *Canna* sp., *C. esculenta*, and *T. angustifolia* accumulated arsenic accumulation more than 70% in underground organs, but *C. papyrus* accumulated arsenic accumulation in aboveground such culm and leaf.

Table 4.8 Arsenic accumulated translocation factor (ATF) of *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia*

plants	Treatment	As accumulated translocation factor *			
		15 days	30 days	45 days	60 days
Canna sp.	As(III)	0.17	0.2	0.22	0.34
	As(V)	0.18	0.36	0.32	0.29
C. esculenta	As(III)	0.61	0.6	0.89	0.69
	As(V)	0.3	0.34	0.25	0.36
C. papyrus	As(III)	0.78	0.92	1.82	2.54
	As(V)	2.54	1.57	1.81	1.96
T. angustifolia	As(III)	0.2	0.19	0.28	0.14
	As(V)	0.43	0.55	0.44	0.47

*: arsenic accumulation in aboveground organs($mg.kg^{-1}$) / underground organs($mg.kg^{-1}$)

Several studies have demonstrated that arsenic reduction from As(V) to As(III) is an important mechanism for arsenic tolerance and accumulation (Zhang *et al.*, 2002). Final steps in detoxification involve arsenic sequestration in the vacuoles of root and shoot tissue (Tripathi *et al.*, 2006). Koch *et al.* (1999 referred by Schmidt 2005) assumed strong binding of non-exchangeable arsenic to lipid or to cell wall constituents such as cellulose, calcium and magnesium pectates and lignin. Arsenic compounds bound to insoluble cell components cannot be found in extracellular or intracellular fluids. The nature of such binding has not been elucidated Arsenoribodies could bind at cell surfaces, like other sugars. Arsenic analogues of lecithin can possibly be assembled in cell membranes (Kuhnelt, 2001 referred by Schmidt, 2005). In higher plants, hydrophobic, lipid-soluble arsenic compounds have not yet been found. In brown algae, lipid-soluble arsenic amounted to 3% to 4% of total arsenic only, whereas in special macro-algae, arsenolipids accounted for 50% of total arsenic. The accumulated translocation factor of *C. papyrus* suggested that plant can actively uptake arsenic from soil and store them in its aboveground ports, which make *C. papyrus* a remarkable phytoremediator (Wei and Chen, 2005).

4.1.5 Arsenic accumulation efficiency

From arsenic accumulation in *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* at every harvested time, it was considered that the arsenic accumulation efficiency of plants could be assessed from bioaccumulation factor (BF) which was the ratio of arsenic accumulation in the plant and soil (Zhang *et al.*, 2002; Tu *et al.*, 2004; Tu and Ma, 2002). A hyper-accumulation plant had a BF more than 1 (Zhang *et al.*, 2002). Table 4.9 expressed bioaccumulation factor, BF of *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* in As(III) and As(V) contaminated soil at 15, 30, 45 and 60 days. From the Table 4.9, it can be seen was hyper-accumulation plants, because of BF>1 from the beginning to end. *T. angustifolia* in As(V) treatment at 45 days had the highest BF (1.1475). It was well know that *Typha* spp. took up metals and elements from the sediment and translocation them to above-sediment issue (Shardendu *et al.*, 2003 refer by Sundberg *et al.*, 2006).

Table 4.9 Bioaccumulation factor, BF, of *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* in As(III) and As(V) treatments at 15, 30, 45 and 60 days

plant	treatments	Bioaccumulation factor (BF)*			
		15 days	30 days	45 days	60 days
Canna sp.	control	0.0105 ^{f}	0.0069 ^{e}	0.0079 ^{h}	0.0036 ^{g}
	As(III)	0.4265 ^{e}	0.7906 ^{c}	0.7322 ^{de}	0.8424 ^{b}
	As(V)	0.6717 ^{c}	0.8757 ^{b}	1.0106 ^{b}	1.0807 ^{a}
C. esculenta	control	0.0055 ^{f}	0.0087 ^{e}	0.0065 ^{h}	0.0069 ^{f}
	As(III)	0.7034 ^{c}	0.8792 ^{b}	0.5018 ^{g}	0.4766 ^{e}
	As(V)	0.8347 ^{b}	1.0186 ^{a}	0.7089 ^{e}	0.5961 ^{d}
C. papyrus	control	0.0065 ^{f}	0.0099 ^{e}	0.0044 ^{h}	0.0054 ^{f}
	As(III)	0.5494 ^{d}	0.7885 ^{c}	0.6483 ^{f}	0.6104 ^{d}
	As(V)	0.8592 ^{b}	0.9851 ^{a}	0.7552 ^{d}	0.7410 ^{c}
T. angustifolia	control	0.0100 ^{f}	0.0077 ^{e}	0.0157 ^{h}	0.0035 ^{f}
	As(III)	0.9316 ^{a}	1.0131 ^{a}	1.1475 ^{a}	1.0542 ^{a}
	As(V)	0.5701 ^{d}	0.6906 ^{d}	0.8007 ^{c}	0.8498 ^{b}

Note: Superscripts in each harvest time by the same letters are not significantly different ($P \leq 0.05$).

* : arsenic accumulation in the plant ($mg.kg^{-1}$) / arsenic concentration in soil($mg.kg^{-1}$)

At 15 days, *T. angustifolia* planted in As(III) soil gave significantly ($p \leq 0.05$), the highest bioaccumulation factor at 0.9316, followed by *C. esculenta, C. papyrus*, and *Canna* sp., that were 0.7034, 0.5494, and 0.4265. The order bioaccumulation factor of plants in As(V) was *C. papyrus, C. esculenta, Canna* sp. and *T. angustifolia.* Their Superscrip were 0.8592, 0.8347, 0.6717 and 0.5701, respectively.

At 30 days, *T. angustifolia* in As(III) soil and *C. esculenta* and *T. angustifolia* in As(V) soil and displayed significantly ($p \leq 0.05$), the maximum bioaccumulation factor at 1.0186 and 1.0131, respectively. In As(III) treatment soil, the plants offered the value of bioaccumulation factor following 0.8792, 0.7906, and 0.7885 in *C. esculenta, C. papyrus,* and *Canna* sp., respectively. On the hand, the plants in As(V) soil ranked the bioaccumulation factor value as following; 0.9851, 0.8757, and 0.6906 in *C. papyrus, Canna* sp. and *T. angustifolia*, respectively.

At 45 days, *T. angustifolia* in As(III) treatment soil expressed significantly ($p \leq 0.05$), the maximum bioaccumulation factor at 1.1475, followed by *Canna* sp., *C. papyrus*, and *C. esculenta* being 0.7322, 0.6483 and 0.5018, respectively.

For As(V) incorporated soil, the order of bioaccumulation factor was *Canna* sp., *T. angustifolia, C. papyrus*, and *C. esculenta* that were 1.0106, 0.8007, 0.7552, and 0.7089, respectively.

At 60 days, the highest bioaccumulation factor was *Canna* sp. in As(V) and *T. angustifolia* in As(III) contaminated soil which showed significantly ($p \leq 0.05$) at 1.0807 and 1.0542, respectively, followed by *Canna* sp. (0.8424), *C. papyrus* (0.6104), and *C. esculenta* (0.4766); However the bioaccumulation factor value of plants in As(V) contaminated soil were 0.8498, 0.7410, and 0.5961 in *T. angustifolia, C. papyrus*, and *C. esculenta*, respectively.

4.1.6 Total arsenic in soil

Deposition of arsenic in submerged soils was evaluated at the same period of that accumulation in the plants. Results found that accumulation of arsenic in the soil were continuously decreased from beginning to the end of experiment, especially in plant growing treatments. However, in the soil without plant there were not changed in the amount of arsenic. This finding indicated that arsenic was taken up by plants. Among plant species, all of them had similar absorption ability which was shown

similar quantity of arsenic left in the soil, except *C. papyrus* and *T. angustifolia* planted in As(III) contaminated soil. (Figure 4.7 and Table 4.10)

Total arsenic of soil in As(III) and As(V) treatments at 15, 30, 45, and 60 days showed at Table 4.10. From the Table 4.10, total arsenic of soil in As(III) and As(V) treatments was not different in control pots, which hadn't plants and every treatment pots. Soil of every plant in As(III) treatment had total arsenic more than As(V) treatment, at every harvest time.

Table 4.10 Total arsenic accumulation ($mg.kg^{-1}$) in tested soil at 15, 30, 45 and 60 days

Types of plants	Treatments	Total arsenic in soil ($mg.kg^{-1}$)*			
		15 days	30 days	45 days	60 days
No plant	Control	1^{f}	0^{j}	0^{k}	0^{j}
	As(III)	175^{a}	174^{a}	174^{a}	174^{a}
	As(V)	173^{c}	172^{b}	173^{b}	173^{b}
Canna sp.	Control	0^{g}	0^{j}	0^{k}	0 j
	As(III)	171^{d}	155^{e}	140^{e}	125^{f}
	As(V)	160^{e}	148^{g}	136^{g}	121^{g}
C. esculenta	Control	0^{g}	0^{j}	0^{k}	0^{j}
	As(III)	173^{c}	156^{d}	133^{i}	121^{h}
	As(V)	160^{e}	145^{i}	131^{j}	116^{i}
C. papyrus	Control	1^{f}	0^{j}	0^{k}	0^{j}
	As(III)	174^{b}	159^{c}	153^{d}	139^{d}
	As(V)	160^{e}	147^{h}	135^{h}	126^{e}
T. angustifolia	Control	1^{f}	0^{j}	0^{k}	0^{j}
	As(III)	171^{d}	159^{c}	155^{c}	147^{c}
	As(V)	160^{e}	149^{f}	137^{f}	126^{e}

Note: Superscripts in each harvest time by the same letters are not significantly different ($P \leq 0.05$).
* : arsenic in soil (mg) / soil dry weight (kg)

Figure 4.7 showed total arsenic of control and treatment pots. From Figure 4.7 showed that total arsenic accumulation in control pots (No plant). Every plant absorbed arsenic from soil; therefore total arsenic accumulation in soil decreased continuously from beginning to the lowest at 60 days. This result agreed with other researchers ((Bruce. (2001), Robinson *et al.* (2003), and Brooks.(1998)). Arsenic is commonly occurring toxic metal in the environment. Addition of arsenic compounds to soils may be toxic to plants directly or may accumulate in plants.

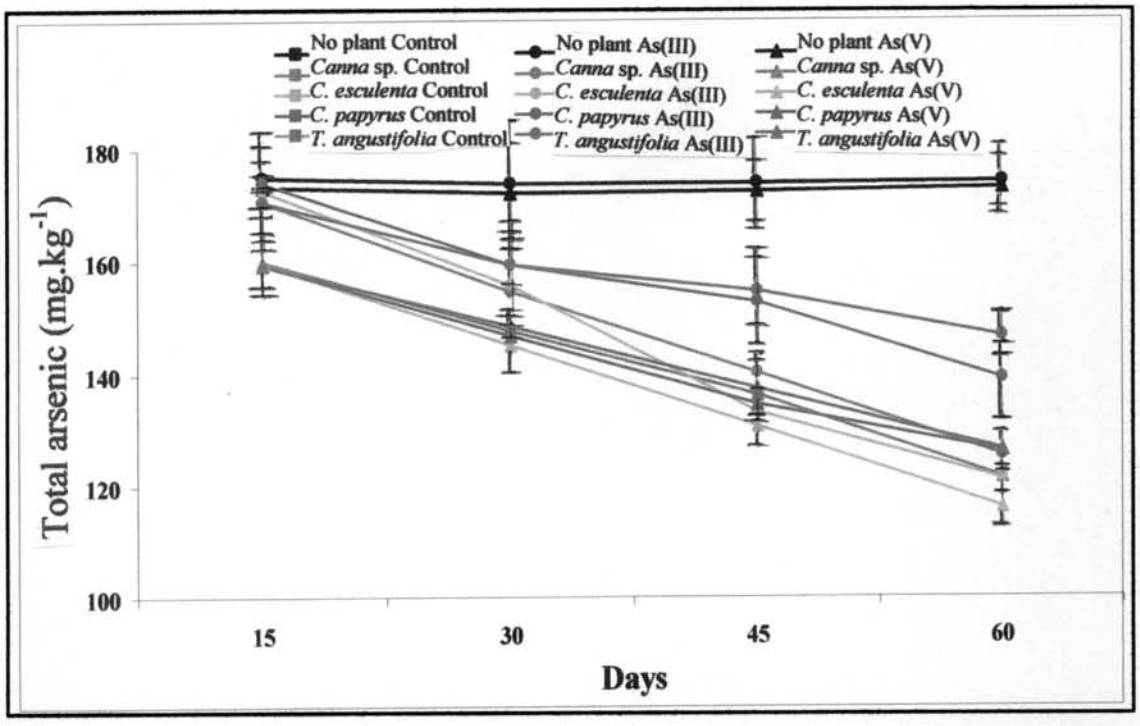

Figure 4.7 Total arsenic accumulation ($mg.kg^{-1}$) in tested soil at 15, 30, 45 and 60 days

Contaminated soil, sediment, or sludge can be treated using phytoextraction, phytostabilization, rhizodegradation, phytodegradation, and phytovolatilization, or through vegetative cap applications. Phytoremediation is most appropriate for large areas of a relatively thin surface layer of contaminated soil, within the root depth of the selected plant. Deeper soil contamination, high contaminant accumulation, or small soil volumes might be more effectively treated using conventional technologies, although though future phytoremediation might be increased. Soil characteristics, such as texture and water accumulation (degree of saturation), should be conductive to plant growth (Brooks *et al.*, 1998).

4.2 Total arsenic removal efficiency from soil by the four species viz; *C. esculenta*, *Canna* sp., *C. papyrus*, and *T. angustifolia*.

All raw data were tabulated in table A.15

Arsenic removal efficiency calculated from the ratio of total arsenic accumulation in plants (mg) per total arsenic accumulation in soil (mg) by calculation in percentage form (Dhitivara, 2000; Jampanil, 2000). The Table 4.11 showed arsenic

removal efficiency (%) of *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* in As(V) and As(III) treatments at 15, 30, 45 and 60 days.

At 15 days, the highest of arsenic removal efficiency in As(V) and As(III) was *C. papyrus* followed by *T. angustifolia* in both of arsenic species. At 30 days, the maximum of arsenic removal efficiency was *C. papyrus* in As(V) and As(III) which was similarly at 15 days, followed by *T. angustifolia*, *C. esculenta*, and *Canna* sp. in both of arsenic treatments.

Table 4.11 Arsenic removal efficiency (%) of *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* planted in As(V) and As(III) treatments at 15, 30, 45 and 60 days

Days	Plants	Removal efficiency (%)*		
		Control	**As(III)**	**As(V)**
15	*Canna sp*	0.00 ^{f}	0.06 ^{ef}	0.10 ^{de}
	C. esculenta	0.00 ^{f}	0.11 ^{de}	0.17 ^{cd}
	C. papyrus	0.01 ^{f}	0.36 ^{b}	0.67 ^{a}
	T. angustifolia	0.00 ^{f}	0.33 ^{b}	0.22 ^{c}
	mean	0.00	0.22	0.29
30	*Canna* sp	0.00 ^{g}	0.12 ^{f}	0.19 ^{e}
	C. esculenta	0.00 ^{g}	0.12 ^{f}	0.2$^{4\ de}$
	C. papyrus	0.00 ^{g}	0.56 ^{b}	0.80 ^{a}
	T. angustifolia	0.00 ^{g}	0.35 ^{c}	0.29 ^{d}
	mean	0.00	0.29	0.38
45	*Canna sp*	0.00 ^{h}	0.15 ^{fg}	0.28 ^{de}
	C. esculenta	0.00 ^{f}	0.14 ^{g}	0.25 ^{ef}
	C. papyrus	0.01 ^{h}	0.66 ^{b}	0.87 ^{a}
	T. angustifolia	0.01 ^{h}	0.49 ^{c}	0.37 ^{d}
	mean	0.00	0.36	0.44
60	*Canna sp*	0.00 ^{e}	0.18 ^{d}	0.43 ^{c}
	C. esculenta	0.00 ^{e}	0.19 ^{d}	0.26 ^{d}
	C. papyrus	0.01 ^{e}	0.72 ^{b}	0.93 ^{a}
	T. angustifolia	0.00 ^{e}	0.50 ^{c}	0.41 ^{c}
	mean	0.00	0.40	0.51

Note: Superscripts in each harvest time by the same letters are not significantly different ($P \leq 0.05$).

:[total As accumulation in plants (mg) / total As accumulation in soil (mg)] x 100

At 45 days, *C. papyrus* in As(V) had the best of arsenic removal efficiency, but in As(III) *C. papyrus* and *T. angustifolia* expressed nearly arsenic removal efficiency, which was the second. At 60 days, the maximum of arsenic removal

efficiency was *C. papyrus* in As(V) followed by *T. angustifolia*, *Canna* sp., and *C. esculent.* On the other hand, in As(III) contaminated soil was *C. papyrus* and *T. angustifolia.*

The research conducted on arsenic uptake and metabolism in arsenic resistant and nonresistant plant species. Elevation of arsenic levels in soils causes considerable concern with respect to plant uptake and subsequent entry into wildlife and human food chains. Arsenic speciation in the environment is complex, existing in both inorganic and organic forms, with inter-conversion between species regulated by biotic and abiotic processes (Andrew and Whitaker, 2003).

From Dhitivara (2000) research found that amount of arsenic accumulation in *Vetiveria zizanioides* (L.) Nash was more than in *Vetiveria nemoralis* (Balansa) A. Camus. Accumulaiton of arsenic in root was higher than in leaves. The highest efficiency of *Vetiveria zizanioides* (L.) Nash was 0.0488% at experimental time of 90 days in treatment of 75 mg.As. kg^{-1} soil dry weight, and the highest efficiency of *Vetiveria nemoralis* (Balansa) *A.Camus.* was 0.0398% at experimental time of 90 days in treatment of 125 mg.As. kg^{-1} soil dry weight. Another research was Jampanil (2000) found that the efficiency of both *Colocasia esculenta* (L.) Schott was not different; in addition maximum efficiency of arsenic removal was 0.06% in 125 mg.As. kg^{-1} soil dry weight and its efficiency increased by time of growth as well.

4.3 The possibility of As(III) and As(V) transformation in four aquatic plants.

All raw data were tabulated in table A.16 to table A.39.

4.3.1 The arsenic behavior in submerged soil

Consideration of arsenic speciation accumulated in the soils it was found that all of arsenic was accumulated in the form of As(V) occurred in As(V) incorporated soil and it was not found in As(III) incorporated soils, in all sampling periods. This showed that As(V) in the soil could not change to be As(III) in the submerged soil both with and without plants. Moreover, the quantity of As(III) deposition decreased with time elapsed. Rapidly decreased of As(III) was found at 30 days and lower decrease rate after that (Figure 4.8).

4.3.1.1 As(III) accumulation in soil

The result showed that As(V) treatment did not find As(III) accumulation at 15, 30, 45, and 60; however As(III) accumulation was found only at As(III) treatment. The result showed in Table 4.12. At 15 days, As(III) accumulation in control pots were 159 $mg.kg^{-1}$, and it was not different with As(III) accumulation in *T. angustifolia* in As(III) treated soil that was 124 $mg.kg^{-1}$.The next was *C. papyrus*, *C. esculenta,,* and *Canna* sp in As(III) treatment that were 95, 87, and 83 $mg.kg^{-1}$, respectively.

Table 4.12 As(III) accumulation ($mg.kg^{-1}$) in tested soil at 15, 30, 45 and 60 days

Days	Plants	As(III) accumulation ($mg.kg^{-1}$)		
		Control	**As(III)**	**As(V)**
15	No plant	0^{f}	159^{a}	0^{f}
	Canna sp	0^{f}	83^{e}	0^{f}
	C. esculenta	0^{f}	87^{d}	1^{f}
	C. papyrus	0^{f}	95^{c}	0^{f}
	T. angustifolia	0^{f}	124^{b}	0^{f}
	mean	0	110	0
30	No plant	0^{f}	105^{a}	1^{f}
	Canna sp	0^{f}	74^{c}	0^{f}
	C. esculenta	0^{f}	59^{d}	0^{f}
	C. papyrus	0^{f}	80^{b}	0^{f}
	T. angustifolia	0^{f}	48^{e}	0^{f}
	mean	0	73	0
45	No plant	0^{e}	94^{a}	1^{e}
	Canna sp	0^{e}	13^{c}	0^{e}
	C. esculenta	0^{e}	9^{d}	0^{e}
	C. papyrus	0^{e}	13^{c}	0^{e}
	T. angustifolia	0^{e}	25^{b}	0^{e}
	mean	0	31	0
60	No plant	0^{d}	9^{c}	0.0^{d}
	Canna sp	0^{d}	8^{a}	0.0^{d}
	C. esculenta	0^{d}	9^{bc}	0.0^{d}
	C. papyrus	0^{d}	12^{b}	0.0^{d}
	T. angustifolia	0^{d}	19^{bc}	0.0^{d}
	mean	0	11	0.0

Note: Superscripts in each harvest time by the same letters are not significantly different ($P \leq 0.05$). Detection limit 0.05 $mg.kg^{-1}$

At 30 days, arsenic accumulation in control case was the highest, and the range of arsenic accumulation in soil in treatment cases was 48 – 80 $mg.kg^{-1}$. At 45 days, As(III) accumulation in control and treatment cases decreased continuously. The As(III) accumulation in control case was 94 $mg.kg^{-1}$, and the range of As(III) accumulation in As(III) treatment cases was 9 – 25 $mg.kg^{-1}$. At 60 days, the As(III) accumulation in control and treatment cases was similarly, that range was 8 – 9 $mg.kg^{-1}$. As(III) accumulation in As(V) treatment ranged 0 - 1 $mg.kg^{-1}$.

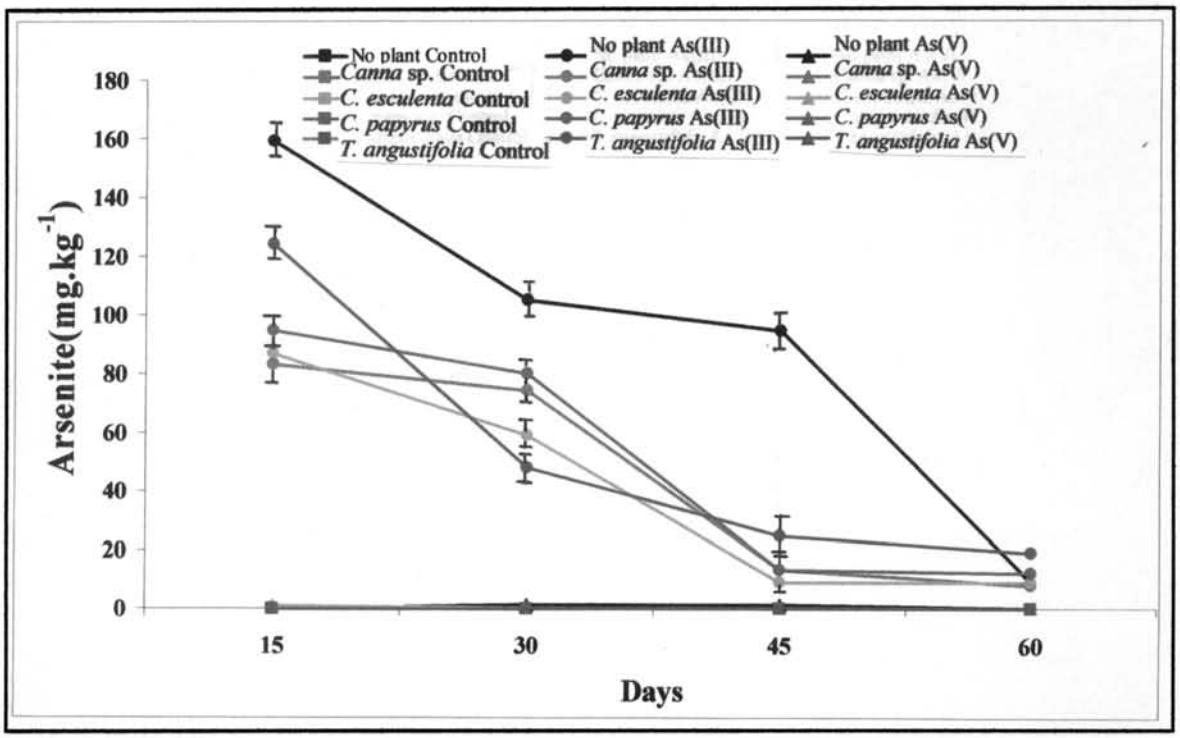

Figure 4.8 As(III) accumulation ($mg.kg^{-1}$) in tested soil at 15, 30, 45 and 60 days

Figure 4.8 showed the As(III) accumulation in control and treatment cases at 15, 30, 45, and 60 days. The As(III) accumulation of control case was higher than treatment cases at 15 and 45 days. After that the As(III) accumulation in treatment cases was not different, at 60 days. The As(III) accumulation was the highest at 15 days and then decreased continuously to the lowest at 60 days. Soil of *Canna* sp. had the lowest As(III) accumulation.

There are several arsenic species that can be present in the environment. Inorganic compounds in different oxidation states (As(III) and As(V)) are especially found in natural waters, soils and sediments(Dousova *et al.*, 2003). Under aerobic conditions, arsenic occurs in soils in the form of arsenate (Grossl *et al.*, 1997), bound

to clay minerals, Fe and Mn-oxides (oxyhydroxide), and to organic substances (Gomez-Caminero *et al.*, 2001). This result related with Eh of submerged soil that was above -220 mV (Table 4.14); therefore As(III) was oxidized to As(V) (Carbonell-Barrachina *et al.*, 1999).

4.3.1.2 As(V) accumulation in soil

Other arsenic speciation, As(III) was interesting rather than As(V) because it had ability to transform to be As(V) which could be seen in the treatments of As(III) incorporated soil (Table 4.13).

Table 4.13 As(V) concentration ($mg.kg^{-1}$) in tested soil at 15, 30, 45 and 60 days

Days	Plants	Treatments		
		Control	As(III)	As(V)
15	No plant	0^{g}	14^{f}	162^{a}
	Canna sp	0^{g}	75^{c}	150^{b}
	C. esculenta	0^{g}	72^{c}	149^{b}
	C. papyrus	0^{g}	65^{d}	152^{b}
	T. angustifolia	0^{g}	36^{e}	152^{b}
	mean	0	52	153
30	No plant	0^{i}	66^{h}	165^{a}
	Canna sp	0^{i}	70^{fg}	134^{d}
	C. esculenta	0^{i}	87^{e}	136^{d}
	C. papyrus	0^{i}	67^{gh}	140^{c}
	T. angustifolia	0^{i}	72^{f}	147^{b}
	mean	0	73	144
45	No plant	0^{f}	79^{e}	168^{a}
	Canna sp	0^{f}	115^{d}	126^{b}
	C. esculenta	0^{f}	113^{d}	123^{bc}
	C. papyrus	0^{f}	127^{b}	124^{bc}
	T. angustifolia	0^{f}	117^{cd}	128^{b}
	mean	0	110	134
60	No plant	0^{f}	164^{a}	166^{a}
	Canna sp	0^{f}	106^{de}	110^{cd}
	C. esculenta	0^{f}	102^{e}	106^{de}
	C. papyrus	0^{f}	116^{b}	115^{b}
	T. angustifolia	0^{f}	117^{b}	115^{bc}
	mean	0	120	123

Note: Superscripts in each harvest time by the same letters are not significantly different ($P \leq 0.05$).
Detection limit 0.03 $mg.kg^{-1}$

As(V) accumulation could find in As(III) and As(V) treatments. As(V) accumulation depended on arsenic speciation, types of plants, and interaction of arsenic speciation, types of plants. At 15 days, soil of As(V) treatment had As(V) accumulation higher than As(III) treatment. The result showed at Table 4.13.

Control pots, which had not plants, had 162 $mg.kg^{-1}$ of As(V) accumulation. The pots of As(III) treatment found that the lowest As(V) accumulation that was 14 $mg.kg^{-1}$. As(V) treatment treated As(V) to soil; therefore As(V) accumulation in soil was higher than As(III) treatment. The soil of As(V) treatment had 149-162 $mg.kg^{-1}$ of As(V) accumulation, and the soil of As(III) treatment had 14 – 75 $mg.kg^{-1}$of As(V) accumulation

At 30 days, the result was similarly at 15 days. The As(V) accumulations in control pots, which treated As(III) and As(V), but no plants, were 66 and 165 $mg.kg^{-1}$, respectively. The result showed at Table 4.13. The ranges of As(V) accumulation in As(V) and As(III) treatment were 134 – 165 $mg.kg^{-1}$and 66–87 $mg.kg^{-1}$, respectively.

At 45 and 60 days, the average of As(V) accumulation of As(V) treatment was higher than As(III) treatment. At 45 days, the As(V) accumulation of control pots, which was no plants in As(V) treatment, was higher than As(III) treatment, which were 168 and 79 $mg.kg^{-1}$, respectively. At 60 days, the As(V) accumulations in As(V) and As(III) treatment of control pots weren't different that were 166 and 164 $mg.kg^{-1}$, respectively. The ranges of As(V) accumulation in As(III) contaminated soil were 102 - 117 $mg.kg^{-1}$, and in As(V) incorporated soil was 106-115 $mg.kg^{-1}$.

Figure 4.10 showed variation of As(V) accumulation in the soil at 15, 30, 45 and 60 days. From the graph showed that the range of As(V) accumulation in soil of As(V) treatment was 106 – 168 $mg.kg^{-1}$. The As(V) accumulation of As(III) treatment was the lowest at 15 days, and then increased to the highest at 60 days, that was 164 $mg.kg^{-1}$. The As(V) accumulation in As(V) treatment and vary of As(V) accumulation found that treatment pots had the As(V) accumulation lower than control pots , which had not plants, in As(V) treatment. Every plant produced the As(V) accumulation in soil of As(III) treatment that was higher than control, which hadn't plants, except at 60 days. The variation of As(V) accumulation in treatment pots found that plants absorbed As(V) from As(V) treatment that decreased to the lowest at 60 days.

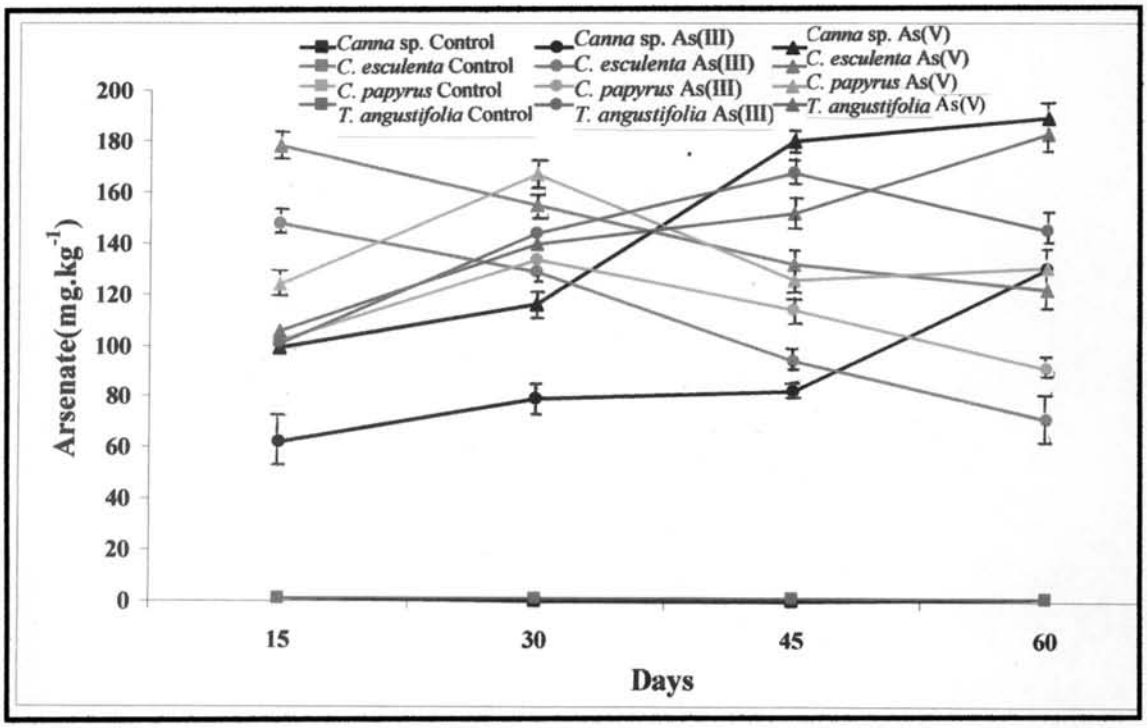

Figure 4.9 As(V) accumulation ($mg.kg^{-1}$) in tested soil at 15, 30, 45 and 60 days

The two major soluble species of inorganic arsenic are As(V) and As(III) (Masscheleyn *et al.*, 1991). As(V) is the stable oxidation state in oxidizing environments, whereas As(III) is mainly formed in soils under reducing conditions (Bhumbla and Keefer, 1994). In aqueous solutions at neutral pH, As(V) is present predominantly as $H_2AsO_4^-$, whereas As(III) is present as H_3AsO_3 (Keon *et al.*, 2001; Fernandez, 2005). The distribution of these arsenic species is of considerable environmental concern, since As(III) is the most toxic of the water-soluble species and is more mobile than As(V) (Sheppard *et al.*, 1992; Fernandez, 2005).). It is possible that As(III) may have been immobilized due to oxidation to As(V) and subsequent sorption onto Fe-oxyhydroxides to coat the root (Quaghebeur and Rengel, 2005).

4.3.1.3 Arsenic transformation efficiency in submerged soil

After soil was treated with As(III) and As(V) in submerged soil and grew plants. pH of soil was 6.2-8.0, which was the normal range of pH submerged soil (Kumaresan, 2001). Eh was -30 to -167 mV (Table 4.14). In case of As(III)

treatments, Eh decreased more than As(V) treatments. Water in As(III) treatment pots decomposed more than As(V) treatment. Eh average of *Canna sp.* in As(III) and As(V) treatments were -126 mV and -113 mV. Eh average of *C. esculenta* in As(III) and As(V) treatments were -136 and -126 mV. Eh average of *Canna sp.* in As(III) and As(V) treatments were -128 and -118 mV and Eh average of *T. angustifolia* in As(III) and As(V) treatments were -121 and -113 mV.

Level of arsenic toxicity in As(III) from is higher than As(V); therefore As(III) transformed to As(V) which is detoxification. Since arsenic was similarly properties with phosphorus (Elvira *et. al.*, 2003); therefore properties and behaviors of arsenic and phosphorus are similar in soil and water. The redox state and pH of the soil has a major influence on arsenic speciation and solubility (Carbonell-Barrachina *et al.*, 1999b). Microbial activity is know to directly and indirectly affect diagenetic reactions in sediments by controlling the redox conditions in shallow sediments (Masscheleyn *et al.*, 1991b).

Table 4.14 pH and Eh of soil in As(III) and As(V) treatments at 15, 30, 45, and 60 days

Plant	Day	pH			Eh (mV)		
		Control	As(III)	As(V)	Control	As(III)	As(V)
No plant	15	6.5	7.0	7.4	-85	-77	-145
	30	7.3	7.5	8.0	-80	-110	-90
	45	7.1	7.3	7.2	-93	-133	-87
	60	7.7	7.7	8.2	-80	-87	-93
Canna sp	15	6.9	6.8	6.9	-99	-147	-105
	30	6.3	7.1	7.4	-30	-90	-120
	45	6.3	7.0	7.0	-133	-175	-130
	60	7.1	7.9	7.9	-33	-93	-98
C. esculenta	15	6.7	6.5	6.9	-110	-137	-153
	30	6.6	7.0	7.5	-50	-68	-110
	45	6.4	7.0	7.0	-93	-167	-160
	60	7.5	8.0	7.8	-75	-143	-80
C. papyrus	15	6.7	6.9	6.9	-75	-127	-123
	30	6.6	7.2	7.4	-35	-100	-80
	45	6.2	6.7	6.8	-138	-170	-153
	60	7.0	7.9	7.7	-60	-117	-117
T. angustifolia	15	7.0	6.7	7.2	-147	-113	-105
	30	6.8	7.6	8.1	-62	-100	-45
	45	6.9	6.9	6.7	-73	-145	-163
	60	7.5	7.9	7.8	-42	-97	-137

It is therefore not surprising that soil parameters influence the toxicity of arsenic species due to altered availability (solubility or mobility) (Meharg and Hartley-Whitaler, 2002). In aquatic system, pH of submerged soil is nearly 7, which arsenic solubility is the highest. Factors effects to arsenic transformation that is redox potential, Eh is below –220 mV. That state occurs reduce sulfate process too (Carbonell-Barrachina, 1998). This result related with Eh of submerged soil that was above -220 mV; therefore As(V) was not reduced to As(III). Table 4.14 showed pH and Eh of soil in As(III) and As(V) treatments at 15, 30, 45, and 60 days.

From preliminary data, transformation efficiency of As(III) to As(V) assessed from ratio of As(V) accumulation in soil per summation of As(V) and As(III) accumulation in soil. It was calculated in percentage form. Arsenic transformation efficiency depended on types of plants, harvest times, and interaction of types of plants and harvest times. The result showed that ratio of transformation efficiency As(III) to As(V) increased until beginning to 60 days (Table 4.15 and Figure 4.11).

Table 4.15 Transformation efficiency (%) of soil at 15, 30, 45 and 60 days

Plants	Transformation efficiency of As(V) in soil (%)*				Mean
	15 days	30 days	45 days	60 days	
No plant	8 ^{o}	39 ^{m}	46 ^{k}	95 ^{a}	47
Canna sp.	48 ^{j}	49 ^{i}	90 ^{e}	93 ^{b}	70
C. esculenta	45 ^{k}	60 ^{h}	93 ^{b}	92 ^{bc}	72
C. papyrus	41 ^{l}	46 ^{k}	91 ^{de}	91 ^{cd}	67
T. angustifolia	22 ^{n}	60 ^{h}	82 ^{g}	86 ^{f}	63
mean	33	50	80	91	

Note: Superscripts by the same letters are not significantly different ($P \leq 0.05$).
* : As(III) transformed to As(V)

From the result found that the averages of arsenic transformation efficiency in soil at 15, 30, 45, and 60 days were 33%, 50%, 80%, and 91%, respectively. The treatment pots had arsenic transformation efficiency higher than control pots. The average of arsenic transformation efficiency was 64%. *C. esculenta* was the highest of arsenic transformation efficiency that 72%. The next was *Canna sp.*, *C. papyrus*, and *T. angustifolia*, Their averages were 70%, 67%, and 63%, respectively.

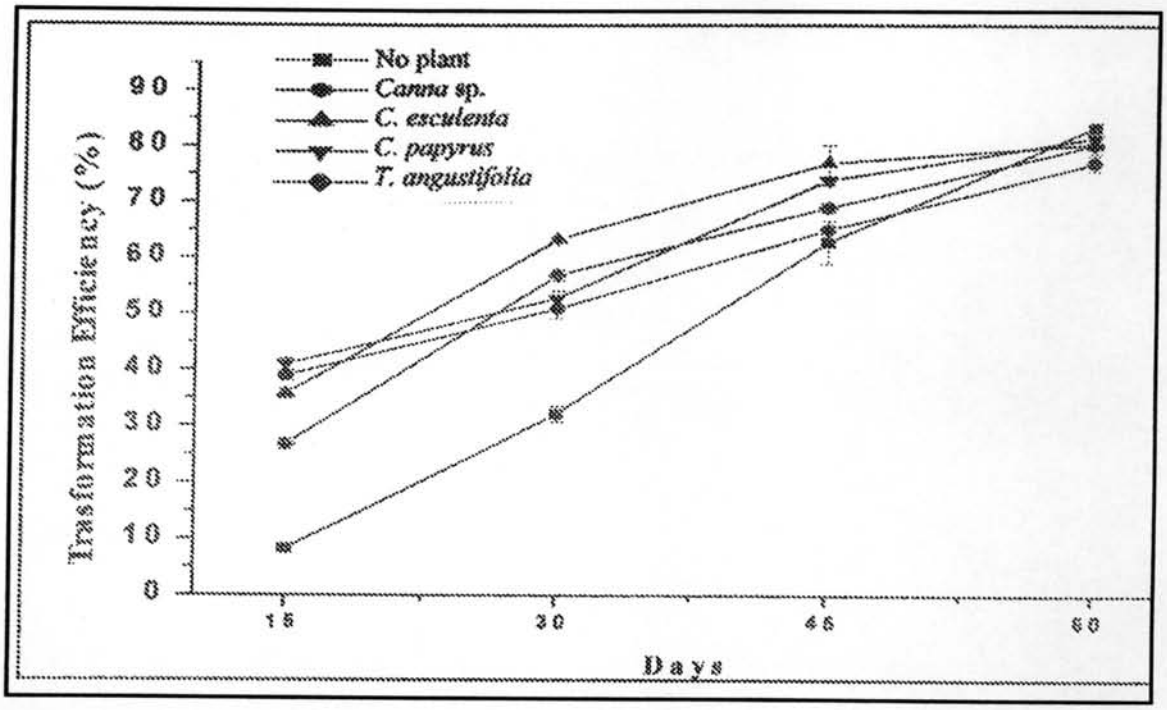

Figure 4.10 As(V) transformation efficiency (%) of soil at 15, 30, 45 and 60 days

Iron oxides in rhizosphere are generally considered to have great adsorption capacity for inorganic anions, especially for As(V) (Meng *et al.*, 2002). Root coating with brownish precipitate, indicating the formation of an iron plaque due to the oxidizing activity of root, was observe on these plants that grew up under reducing conditions (Otte *et al.*, 1991). It is possible that As(III) may have been immobilized due to oxidation to As(V) and subsequent sorption onto Fe-oxyhydroxides to coat the root (Quaghebeur and Rengel, 2005). The most common wetland plants, iron plaque is commonly formed on root surfaces and may subsequently affect arsenic dynamics in the rhizosphere and arsenic accumulation by plants (Liu *et al.*, 2005). The formation of iron plaque on plant roots is thought to be facilitated by the release of oxygen and oxidants into the rhizoaphere (Taylor *et al.*, 1984).

The formation of iron plaque may contribute to the plant genotypic difference in arsenic uptake and translocation (Liu *et al.*, 2004). Iron plague may act as a buffer in the rhizosphere for arsenic uptake into rice roots. A number of reports have shown that iron plaque could act as a barrier for the uptake of other toxic metals (Otte and Dekkers, 1991; Zhang *et al.*, 1998; Geng, 2005). In the wetland plants Hansel *et al.*,(2002 referred by Chen *et al.*, 2005) found that arsenic existed as a combination of two species in the iron plaque, being comprised predominantly of As(V) with lesser

amounts of As(III). In addition, X-ray flouresence microtomography showed that arsenic bound to iron plaque on root surface of the aquatic plants *Phalaris arundinacea* and *Typha latifolia* was largely As(V) (Hansel *et al.*, 2002). Therefore, iron plague may also play a role in reducing the toxicity of arsenic contamination in solid-plant system (Liu *et al.*, 2004)

4.3.2 Accumulation of arsenic speciation by aquatic plants

4.3.2.1 As(III) accumulation in plants

There were significant differences on accumulation of arsenic speciation in the form of As(III) in different plant species planted on both As(III) and As(V) contaminated soil. Averagely, accumulation of As(III) was mainly found in As(III) treatment throughout the experimental period. However, the ability of As(III) accumulation depended on plant species and sources of arsenic in the growing soils. At early growth stage (15 days) *C. esculenta* planted in As(III) soil could absorb at the highest quantity of As(III) (36 $mg.kg^{-1}$) followed by *C. papyrus* in As(V) treated soil (32 $mg.kg^{-1}$) (Table 4.16).

At 30 days, *C. esculenta* in As(III) treatment could absorb at the maximum quantity of As(III) (69 $mg.kg^{-1}$) followed by *C. esculenta* in As(V) that was 55 $mg.kg^{-1}$. The lowest was *T. angustifolia* in As(V) and *C. papyrus* in As(V) treatment 17 $mg.kg^{-1}$. The *Canna* sp. could not find As(III) accumulation in As(V) treatment.

At 45 days, the highest of As(III) accumulation was *C. esculenta* (38 $mg.kg^{-1}$) for As(III) treatment while in As(V) it was *T. angustifolia* (28 $mg.kg^{-1}$) followed by *T. angustifolia* in As(V) (27 $mg.kg^{-1}$) and *C. esculenta* in As(V) treatment (16 $mg.kg^{-1}$); in addition the next was *C. papyrus* in As(III) and As(V) treatment (14 and 16 $mg.kg^{-1}$). The minimum deposit of As(III) accumulation at this stage of growth was *Canna* sp. in As(V) (4 $mg.kg^{-1}$) which did not absorb arsenic in As(III) treatment.

Table 4.16 Total As(III) accumulation (mg.kg^{-1}) of *Canna* sp., *C. esculenta*, *C. papyrus* , and *T. angustifolia* at 15 days in As(V) and As(III) treatments at 15, 30, 45, and 60 days

Days	Plants	Total As(III) accumulation (mg.kg^{-1})		
		Control	As(III)	As(V)
15	*Canna* sp	0 ^{g}	4 ^{f}	0 ^{g}
	C. esculenta	0 ^{g}	36 ^{a}	19 ^{d}
	C. papyrus	0 ^{g}	19 ^{e}	17 ^{b}
	T. angustifolia	0 ^{g}	25 ^{c}	15 ^{de}
	mean	0	21	18
30	*Canna* sp	0 ^{f}	29 ^{c}	0 ^{f}
	C. esculenta	0 ^{f}	69 ^{a}	55 ^{b}
	C. papyrus	0 ^{f}	17 ^{e}	32 ^{c}
	T. angustifolia	0 ^{f}	25 ^{d}	17 ^{e}
	mean	0	35	26
45	*Canna* sp	0 ^{d}	4 ^{d}	0 ^{d}
	C. esculenta	0 ^{d}	38 ^{a}	16 ^{c}
	C. papyrus	0 ^{d}	14 ^{c}	12 ^{c}
	T. angustifolia	0 ^{d}	27 ^{b}	28 ^{b}
	mean	0	21	14
60	*Canna* sp	0 ^{f}	2 ^{e}	0 ^{f}
	C. esculenta	0 ^{f}	48 ^{a}	25 ^{b}
	C. papyrus	0 ^{f}	0 ^{f}	15 ^{c}
	T. angustifolia	0 ^{f}	16 ^{c}	10 ^{d}
	mean	0	17	12

Note: Superscripts in each harvest time by the same letters are not significantly different ($P \leq 0.05$).
Detection limit 0.05 mg.kg^{-1}

At 60 days, in As(III) treatment, *C. esculenta* had the highest of As(III) accumulation of 48 mg.kg^{-1}, and in As(V) treatment, *C. esculenta* was the highest of As(III) accumulation, at 25 mg.kg^{-1}, followed *T. angustifolia* in As(V) treatment that was 16 mg.kg-1 and *C. papyrus* and *T. angustifolia* in As(V) being 15 and 10 mg.kg^{-1}. The minimum was *Canna* sp. in As(V) treatments; moreover *Canna* sp. in As(V) soil could not concentrate As(III) at this harvest time.

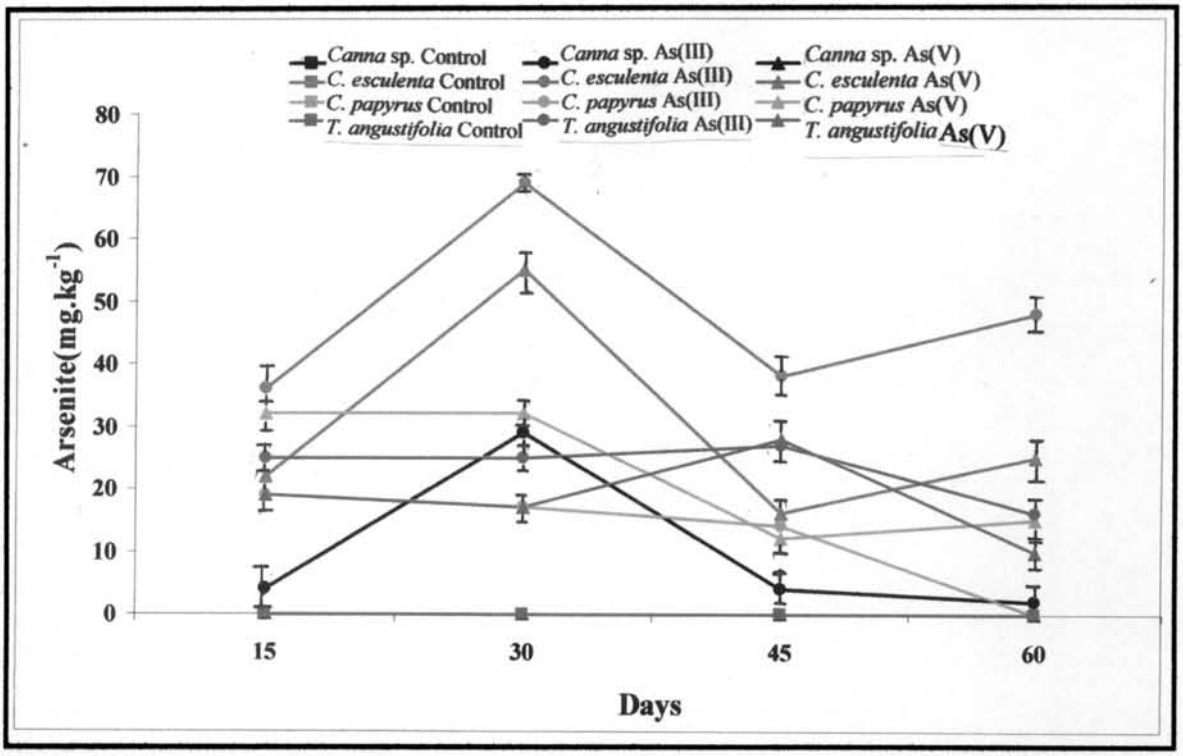

Figure 4.11 Total As(III) accumulation ($mg.kg^{-1}$) of *Canna* sp., *C. esculenta*, *C. papyrus*, and *T. angustifolia* in As(V) and As(III) treatments at 15, 30, 45, and 60 days

From Figure 4.12 shows that *Canna* sp. concentrated As(III) in As(III) treatment, but it did not concentrate As(III) in As(V) treatment. From beginning to end, *C. esculenta* in As(V) could absorb the maximum of As(III) accumulation. The analysis of As(III) accumulation in plants found that *Canna* sp. concentrated only As(III) from As(III) treatment; therefore *Canna* sp. didn't transform As(V) to As(III). From this analysis, *Canna* sp. could not reduced As(V) to As(III) by using a reduction enzyme (Tripathi *et al.*, 2007); however *C. esculenta*, *C. papyrus*, and *T. angustifolia*, when it up took the As(V) form, could reduce As(V) to As(III).

Factors which can influence the arsenic species present in a plant are arsenic species present in the soil; the ability of the compounds to enter the plant, activity or passively; the ability of the plant to synthesis arsenic species; and the presence of arsenic species adsorbed to the outside surface of the plant roots (Meharg and Hartley-Whitake, 2002). The importance of iron plaque in arsenic attenuation in the rhizosphere has been demonstrated in wetland plants (Hansel *et al.*, 2002). Chen *et al.* (2005) demonstrated that the presence of iron plaque enhanced As(III) and decreased As(V) uptake by aquatic plants.

Phytoplankton, macroalgae and fungi contain large amounts of organic arsenic species, whereas terrestrial plants contain mainly inorganic arsenic such as As(III) and As(V). Small amounts of organic arsenic species have also been detected in plant tissue (Quaghebeur and Rengel, 2005).

4.3.2.2 As(V) accumulation in plants

There were significant difference on accumulation of arsenic speciation in the form of As(V) in different plant species planted on both As(III) and As(V) treated soil. The capacity of As(V) accumulation depended on plant species and arsenic speciation in the growing soils.

At 15 days, *C. esculenta* planted in As(III) shown significantly ($p \leq 0.05$), the maximum accumulation at 178 $mg.kg^{-1}$ while in As(III) was *C. esculenta* that was 207.5 $mg.kg^{-1}$ followed by *C. papyrus*, *T. angustifolia*, and *Canna* sp. which could absorb at 124, 106, and 99 $mg.kg^{-1}$, respectively. On the other hand, the plants that grew in As(V) contaminated soil gave the value of accumulation as following; 102, 101, and 62 $mg.kg^{-1}$ in *C. papyrus, T. angustifolia*, and *Canna* sp., respectively. The Table 4.17 showed total As(V) accumulation ($mg.kg^{-1}$) of *Canna* sp. *C. esculenta, C. papyrus*, and *T. angustifolia* in As(V) and As(III) treatments at 15, 30, 45, and 60 days.

At 30 days, *C. papyrus* planted in As(V) displayed significantly ($p \leq 0.05$), the maximum accumulation at 167 $mg.kg^{-1}$, followed by *C. esculenta, T. angustifolia,* and *Canna* sp. which could accumulated 155, 140, and 116 $mg.kg^{-1}$, respectively. The plant that grew in As(V) incorporated soil gave the value of accumulation as following 144, 134, 129, and 79 $mg.kg^{-1}$ in *T. angustifolia, C. papyrus, C. esculenta,* and *Canna* sp., respectively.

At 45 days, *Canna* sp. planted in As(V) expressed significantly ($p \leq 0.05$), the highest accumulation at 180 $mg.kg^{-1}$, followed by *T. angustifolia, C. esculenta,* and *C. papyrus*, which could absorb at 152, 132, and 126 $mg.kg^{-1}$, respectively. At the third harvest, *Canna* sp. was the best absorption plant in As(V) treatments. The order of As(III) accumulation was *T. angustifolia, C. papyrus, C. esculenta* and *Canna* sp., that were 168, 114, 94, and 82 $mg.kg^{-1}$.

Table 4.17 Total As(V) accumulation ($mg.kg^{-1}$) of *Canna* sp. *C. esculenta*, *C. papyrus*, and *T. angustifolia* in As(V) and As(III) treatments at 15, 30, 45, and 60 days

Days	Plants	Total As(V) accumulation ($mg.kg^{-1}$)		
		Control	As(III)	As(V)
15	*Canna sp*	1^{f}	62^{e}	99^{d}
	C. esculenta	1^{f}	148^{b}	178^{a}
	C. papyrus	1^{f}	102^{d}	124^{c}
	T. angustifolia	0^{f}	101^{d}	106^{d}
	mean	1	103	127
30	*Canna* sp	0^{g}	79^{f}	116^{e}
	C. esculenta	1^{g}	129^{d}	155^{b}
	C. papyrus	1^{g}	134^{cd}	167^{a}
	T. angustifolia	1^{g}	144^{bc}	140^{cd}
	mean	1	122	145
45	*Canna sp*	0^{h}	82^{g}	180^{a}
	C. esculenta	1^{h}	94^{f}	132^{d}
	C. papyrus	1^{h}	114^{e}	126^{d}
	T. angustifolia	1^{h}	168^{b}	152^{c}
	mean	1	114	147
60	*Canna sp*	1^{f}	130^{c}	189^{a}
	C. esculenta	1^{f}	71^{e}	122^{c}
	C. papyrus	1^{f}	91^{d}	131^{c}
	T. angustifolia	1^{f}	145^{b}	183^{a}
	mean	1	109	156

Note: Superscripts in each harvest time by the same letters are not significantly different ($P \leq 0.05$). Detection limit 0.03 $mg.kg^{-1}$

At 60 days, *Canna* sp. increased As(V) accumulation to the highest value, which was the maximum accumulation among plants and harvest times, As(V) treatment that was 189 $mg.kg^{-1}$; moreover in As(V) followed by *T. angustifolia*, *C. papyrus* and *C. esculenta* 183, 131, and 122 $mg.kg^{-1}$, respectively. Other plants that grew in As(III) contaminated soil gave the value of accumulated accumulationas following *T. angustifolia*, *Canna* sp., *C. papyrus*, and *C. esculenta* which could collect at 145, 130, 91, and 71 $mg.kg^{-1}$, respectively.

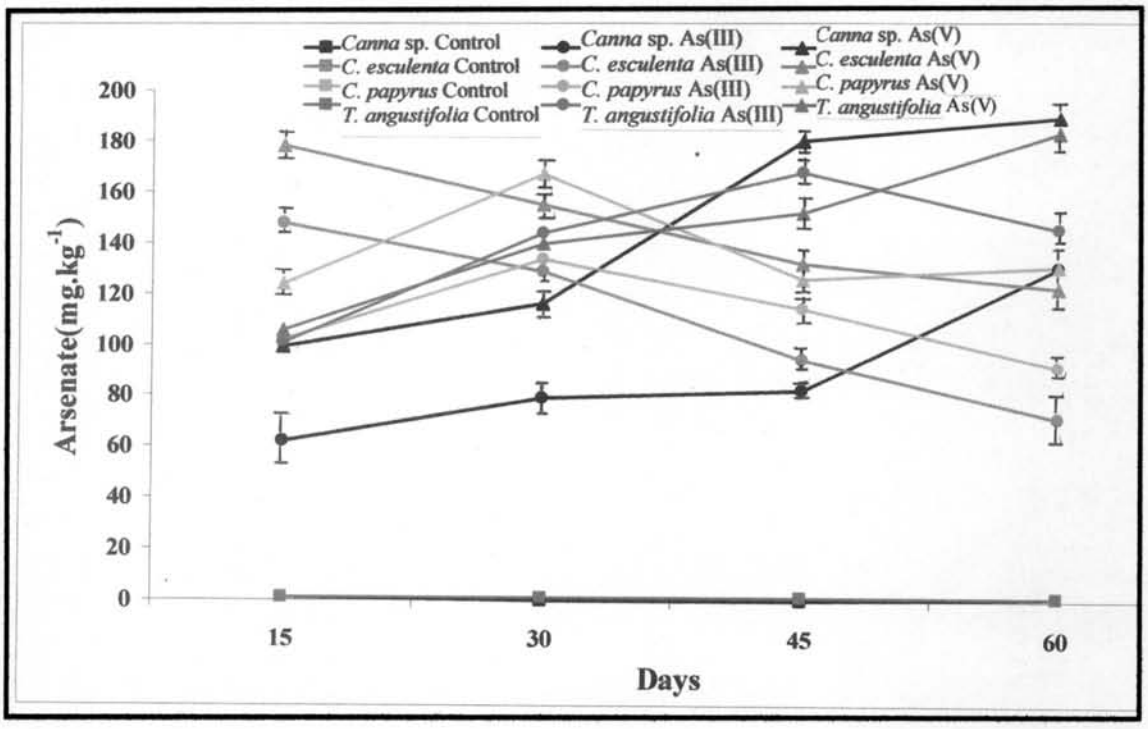

Figure 4.12 Total As(V) accumulation (mg.kg^{-1}) in *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* in As(V) and As(III) treatments at 15, 30, 45, and 60 days

Figure 4.13 expressed that *C. esculenta* in As(V) treatment was the highest As(V) accumulation at 15 days. *C. papyrus* that grew in As(V) incorporated soil had the best capacity of As(V) absorption at 30 days; however, after that *Canna* sp. planted in As(V) contaminated soil had the highest ability of As(V) absorption until 45 to 60 days.

Determination of the As(III) and As(V) accumulation in plant found that the highest accumulation of As(III) in As(III) and As(V) treatment was 99.9 and 61.5 mg.kg^{-1}; moreover the maximum As(V) accumulation in As(III) and As(V) treatment was 233.6 and 245.3 mg.kg^{-1}, respectively. As(V) accumulation of *C. papyrus* and *T. angustifolia* in As(III) and As(V) treatment soil absorbed nearly the same level, however their arsenic accumulations in As(V) treated soil was higher than As(III) incorporated soil. *Canna* sp. and *C. esculenta* in As(III) treatment had arsenic accumulation more than As(V) treatment. For As(V) accumulation of *C. esculenta* and *T. angustifolia* in As(III) treatment was higher arsenic accumulation than in As(V) treatment. From the result showed that every plant uptaked As(V) species more

than As(III) species. *Canna* sp. and *C. esculenta* accumulated arsenic species in the same as arsenic species in soil. On the other hand, *C. papyrus* and *T. angustifolia* in As(III) treatment was more than As(V) accumulation As(V) accumulation higher than As(III) accumulation, and in As(V) treatment, As(III) accumulation was higher than As(V) accumulation.

A part of arsenic detoxification, the majority of As(V) is reduced to As(III) by the enzyme arsenate reductase. Three is debate on the form in which arsenic id transported from root-to-shoot: X-ray and high-performance liquid chromatography-inductively coupled plasma mass spectrometery studies on sporophytes of *P. vittata* have shown thet arsenic is translocated to the shoot mainly as As(V) and is stored in the fronds as inorganic As(III). By contrast, Duan (2005 refered by Tripathi *et al.*, 2007) showed evidence that arsenate reductase activity was found exclusively in the roots of *P. vittata* and because most arsenic exists as As(III) in the fronds, concluded that the majority of arsenic is translocated in its reduced form.

4.3.3 As(III) and As(V) transformation efficiency by plants

The transformation efficiency of As(III) to As(V) is called the As(V) transformation efficiency. Transformation efficiency of As(V) to As(III) is called the As(III) transformation efficiency (Quaghebeur and Rengel, 2005).

Analysis of the As(III) transformation efficiency of the 4 plants at 15, 30, 45, and 60 days found that the 4 plants had 0–22% As(III) transformation efficiency (Table 4.18). *C. esculenta* had the highest As(III) transformation efficiency and the next was *C. papyrus*; however *Canna* sp. didn't transform As(V) to As(III).

At harvest, it was found that the plants could transform the highest levels of As(III) at 30 days (at 12%). The order of As(III) transformation was 8%, 8%, and 7% at 45, 60, and 15 days, respectively. The relationship between harvest periods and types of plants to As(III) transformation efficiency showed that *C. papyrus* was the highest As(III) transformation efficiency at 15 days, and *C. esculenta* at 30 days, followed by *T. angustifolia* at 45 and *C. papyrus* at 60 days.

Table 4.18 As(III) transformation efficiency (%) of *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* at 15, 30, 45 and 60 days

Plants	% Transformation efficiency of As(III)*			
	15 days	30 days	45 days	60 days
Canna sp.	0^{g}	0^{g}	0^{g}	0^{g}
C. esculenta	0^{g}	22^{a}	4^{f}	6^{f}
C. papyrus	16^{b}	14^{cd}	13^{d}	16^{bc}
T. angustifolia	11^{e}	10^{e}	15^{bcd}	10^{e}
mean	7	11	8	8

Note: Superscripts by the same letters are not significantly different ($P \leq 0.05$).
* : As(V) transformed to As(III)

Figure 4.14 shows the As(III) transformation efficiency. Organs of the plants could transform As(V) to As(III), which depended on the organs of plants, harvest period, and interaction of the organs of the plants and harvest periods. The order of As(III) transformation efficiency was: *C. papyrus*, *T. angustifolia*, and *C. esculenta*

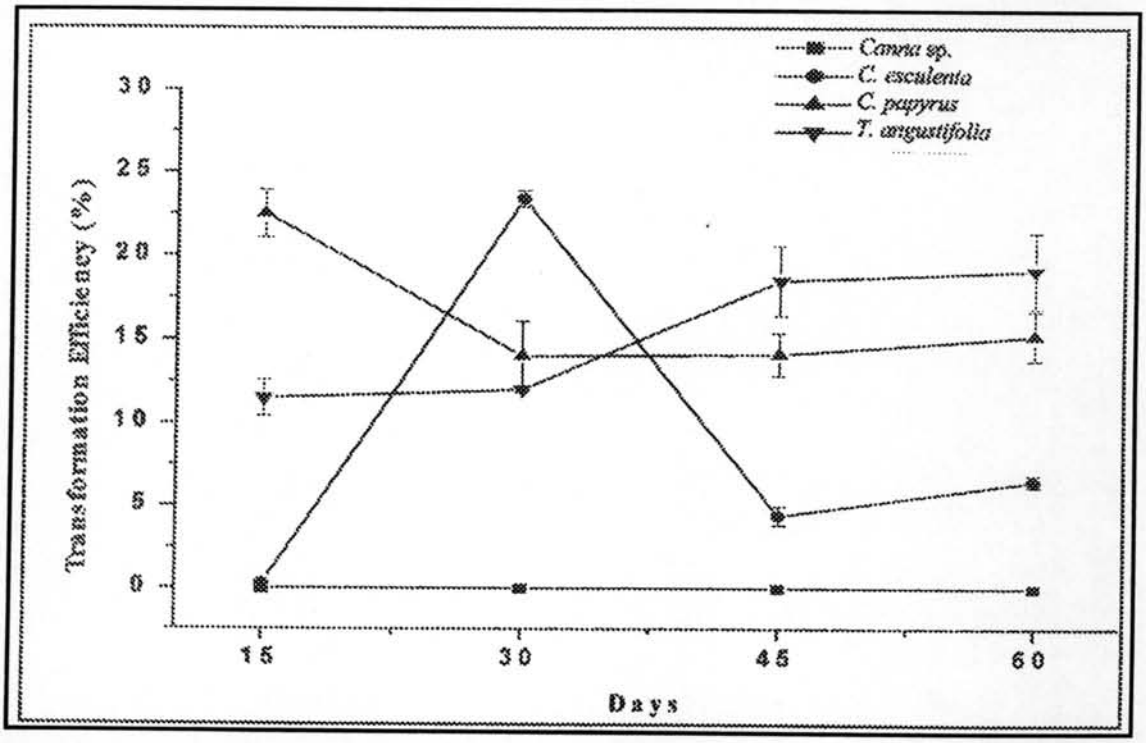

Figure 4.13 As(III) transformation efficiency (%) of *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* at 15, 30, 45 and 60 days

The transformation efficiency of As(V) showed that the types of plants, harvest periods, and interaction of 2 factors affected the As(V) transformation efficiency of the plants. The range of As(V) transformation efficiency of the 4 plants

was 0 – 52% (Table 4.19 and Figure 4.15). The As(V) transformation efficiency decreased continuously when harvest periods increased. When the harvest period was considered, the range of As(V) transformation efficiency in every plant was 2–46%.

Table 4.19 As(V) transformation efficiency (%) of *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* at 15, 30, 45 and 60 days

plants	% Transformation efficiency of As(V)*			
	15 days	30 days	45 days	60 days
Canna sp.	46 ^{b}	31 ^{e}	5 ^{hij}	3 ^{jk}
C. esculenta	43 ^{c}	7 ^{gh}	0 ^{k}	0 ^{0}
C. papyrus	41 ^{cd}	40 ^{d}	0 ^{k}	9 ^{g}
T. angustifolia	52 ^{a}	27 ^{f}	4 ^{ij}	6 ^{hi}
mean	45	26	2	4

Note: Superscripts by the same letters are not significantly different ($P \leq 0.05$).
* : As(III) transformed to As(V)

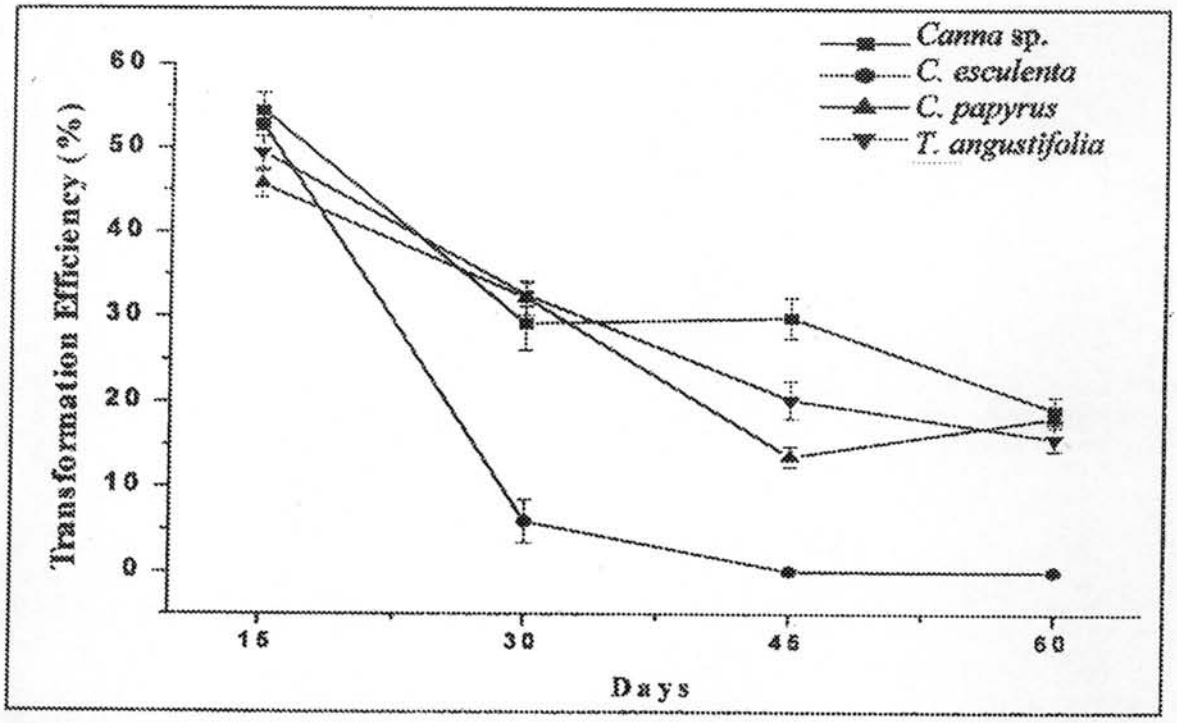

Figure 4.14 As(V) transformation efficiency (%) of *Canna* sp., *C. papyrus*, *C. esculenta*, and *T. angustifolia* at 15, 30, 45 and 60 days

The interaction of types of plants and harvest periods to As(V) transformation efficiency are shown in Figure 4.15. From Figure 4.15, we can see that every plant had the highest As(V) transformation efficiency at 15 days. *T. angustifolia* had the

highest average As(V) transformation efficiency at 52%, and the second was *Canna* sp. at 46%. The next were *C. esculenta* and *C. papyrus* (43% and 41%, respectively).

At 30 days, the order of As(V) transformation efficiency in plants was 40%, 31%, 27% and 7% for *C. papyrus*, *Canna* sp., *T. angustifolia*, and *C. esculenta*, respectively. As(V) transformation efficiency of *C. esculenta* decreased dramatically from 15 to 30 days; moreover it didn't transform As(V) at 45 and 60 days. At 45 days, the As(V) transformation efficiency of *Canna* sp, and *T. angustifolia* were 5% and 4%. The lowest was *C. esculenta* and *C. papyrus* being 0%. At 60 days, *Canna* sp., and *C. esculenta* decreased to the minimum efficiency of As(V) transformation. The As(V) transformation efficiency of *Canna* sp., *C. papyrus*, and *T. angustifolia* was 3%, 9%, and 6%, respectively.

From As(III) and As(V) transformation efficiency of plants (Table 4.18 and 4.19) showed that every plant could transform As(V) to As(III) more than As(III) to As(V). *Canna* sp. was the best As(V) transformation, but it could not As(III) transformation. *T. angustifolia* was the only plant species which increased As(III) transformation. Factors which can influence the arsenic species present in a plant are arsenic species present in the soil. Activity or passively; the ability of the plant to synthesis arsenic species; and the presence of arsenic species absorbed to the outside surface of the plant roots (Meharg and Hartley-Whitake, 2000). Chen *et al.*(2005) demonstrated that the presence of iron plaque enhanced arsenite and decreased arsenate uptake by aquatic plants. Phytoplankton, macroalgae and fungi contain large amounts of organic arsenic species, whereas terrestrial plants contain mainly inorganic such as arsenite and arsenate. Small amounts of organic arsenic species have also been detected in plant tissue (Quaghebeur and Rengel, 2005; Hansel *et al.*, 2002). Efficient uptake and translocation from root-to-shoot contribute greatly to hyperaccumulation of arsenic in *P. vittata* (Singh and Ma, 2006). Not only is far more arsenic talen up but an exceedingly high proportion of arsenic is translocated to shoot tissue. This fact emphasizes the importance of the transporters involved in arsenic uptake, root-to-shoot translocation and vacuolar sequestration during hyperaccumulation. In general, the constitutive expression of genes that encode various transporters, and the biosyntyesis of chelators, is higher in hyperaccumulator plants compared with non-accumulators (Kramer, 2005).

4.3.4 As(V) transformation efficiency by *Canna* sp.

Organs of the plants, harvest period, and the interaction of the organs of the plants and harvest periods affected to As(V) transformation efficiency. The As(V) transformation efficiency of the organs of the plants and harvest periods are shown at Table 4.20 and Figure 4.16.

At 15 days, *Canna* sp. had the highest As(V) transformation efficiency. The order of As(V) transformation efficiency of rhizome, root, leaf, and pseudostem were 52%, 52%, 49%, and 27%. The As(V) transformation efficiency of leaf, rhizome, and root decreased continuously to the lowest at 60 days.

Table 4.20 As(V) transformation efficiency (%) of *Canna* sp. at 15, 30, 45 and 60 days

Organs	**% Transformation efficiency of As(V)***			
	15 days	**30 days**	**45 days**	**60 days**
Leaf	49 ^{a}	28 ^{b}	10 ^{cd}	7 ^{d}
Pseudostem	27 ^{b}	27 ^{b}	0 ^{e}	7 ^{d}
Rhizome	52 ^{a}	15 ^{c}	9 ^{d}	7 ^{d}
Root	52 ^{a}	51 ^{a}	10 ^{cd}	0 ^{e}
mean	45	30	8	5

Note: Superscripts by the same letters are not significantly different ($P \leq 0.05$).
* : As(III) transformed to As(V)

At 30 days, the maximum organ of As(V) transformation was root that was 51%, followed by leaf, pseudostem, and rhizome that were 28%, 27%, and 15%, respectively. At 45 days, the order of As(V) transformation efficiency in organs of *Canna* sp. was offered that 16%, 10%, 9% and 0% for leaf, root, rhizome, and pseudostem, respectively.

At 60 days, three organs could transform As(III) to As(V) equally at 7% that were leaf, pseudostem, and rhizome. However the lowest of As(V) transformation efficiency in every organ all of harvest times were root. It stood at 0%.

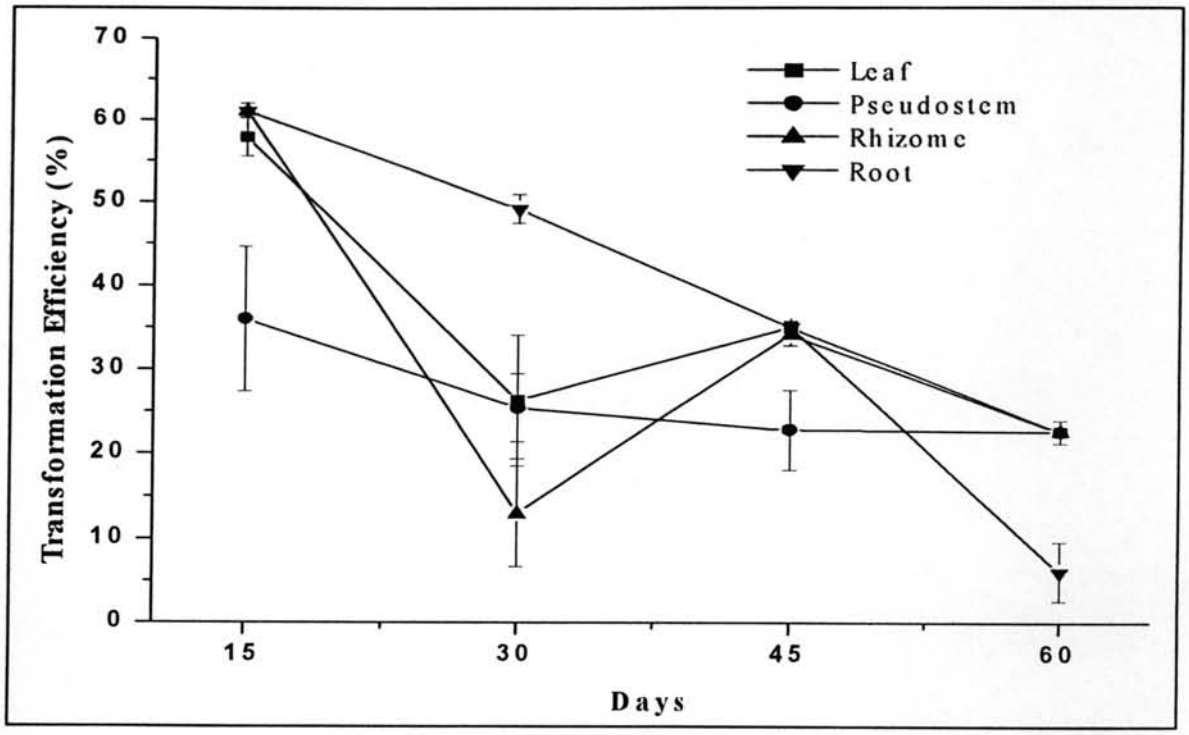

Figure 4.15 As(V) transformation efficiency (%) of *Canna* sp. at 15, 30, 45 and 60 days

Root of *Canna* sp. was the best As(V) transformation from beginning to 45 days, but at 60 days, rhizome, pseudostem, and leaf transformed higher than root. Phytoplankton, macroalgae and fungi contain large amounts of organic arsenic species, whereas terrestrial plants contain mainly inorganic arsenic (As(III) and As(V)) (Quaghebeur and Rengel, 2005). Small amounts of organic arsenic species have also been detected in plant tissues, but it is unclear whether these organic arsenic species are produced in plant metabolism from inorganic arsenic taken up, or whether they are actually taken up from soil as organic arsenic arsenic species (Meharg and Hartley-Whitaker, 2002). Most plants supplied with As(V) in the root medium reduce a large proportion of As(V) taken up to As(III) in roots, and contain mainly As(III) in roots (Quaghebeur and Rengel, 2005). In contrast, arsenic contain mostly As(V) in *Canna sp.* root. Hence, it is likely that the arsenic hyperaccumulating plants do not use the reduction of As(V) to As(III) and subsequent complexation of As(III) to phytochelatins in roots as the arsenic-detoxidication strategy in contrast to other plant species (Wang *et al.*, 2002 refered by Quaghebeur and Rengel, 2005).

4.3.5 As(III) and As(V) transformation efficiency by *C. esculenta*

The As(III) transformation efficiency of *C. esculenta* was 0 – 37%. The results are shown in Table 4.21 and Figure 4.17. The As(V) transformation efficiency of the leaf, petiole, corm and root were 0–31%, 0–37%, 1–9%, and 0– 9%, respectively. Every organ of *C. esculenta* showed the highest As(III) transformation efficiency at 30 days, (37%, 31%, 9%, and 9% at petiole, leaf, root and corm, respectively). After that the As(III) transformation efficiency decreased continuously until 60 days.

Table 4.21 As(III) transformation efficiency (%) of *C. esculenta* in difference organs at 15, 30, 45 and 60 days

Organs	% Transformation efficiency of As(III)*			
	15 days	30 days	45 days	60 days
Leaf	0^{h}	31^{b}	24^{c}	0^{h}
Petiole	0^{h}	37^{a}	2^{gh}	16^{d}
Corm	1^{gh}	9^{e}	2^{gh}	3^{g}
Root	0^{h}	9^{e}	0^{h}	6^{f}
mean	0	22	7	6

Note: Superscripts by the same letters are not significantly different ($P \leq 0.05$).
* : As(V) transformed to As(III)

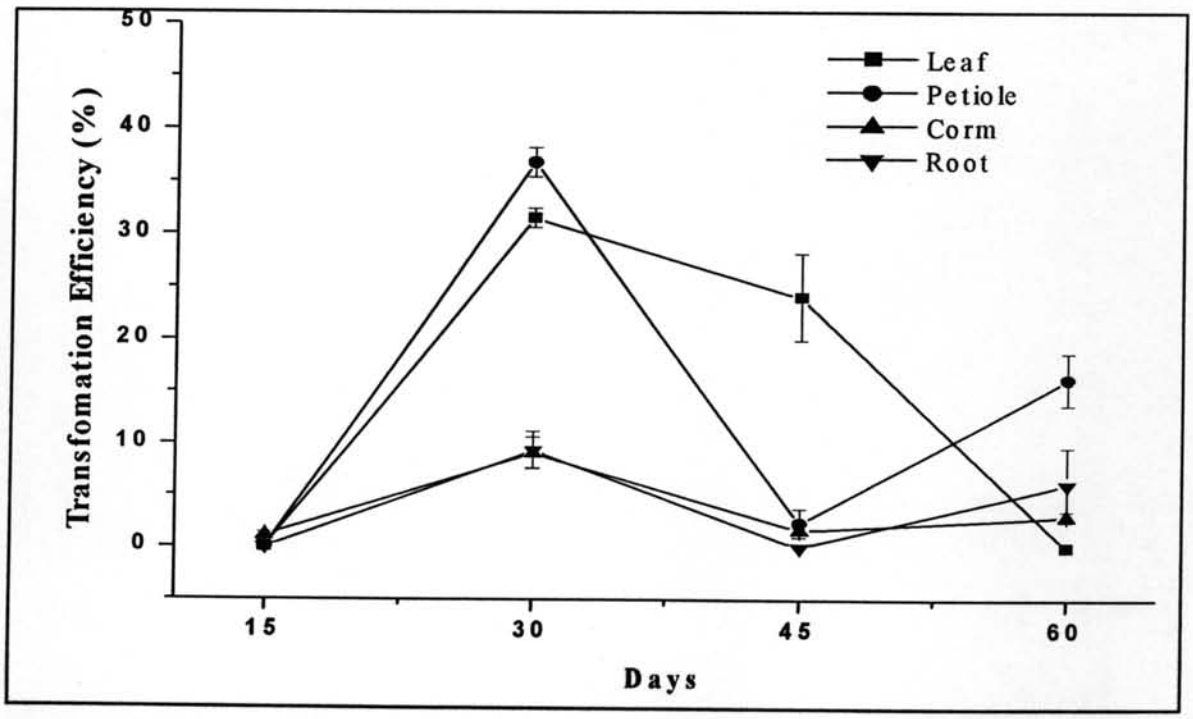

Figure 4.16 As(III) transformation efficiency (%) of *C. esculenta* in difference organs at 15, 30, 45 and 60 days

Every organ of *C. esculenta*, not including the petiole, had the As(V) transformation efficiency at 0–59% (Table 4.29 and Figure 4.18).

Table 4.22 As(V) transformation efficiency (%) of *C. esculenta* at in difference organs 15, 30, 45 and 60 days

Organs	% Transformation efficiency of As(V)*			
	15 days	**30 days**	**45 days**	**60 days**
Leaf	55 ^{b}	23 ^{d}	0 ^{h}	8 ^{f}
Petiole	14 ^{e}	0 ^{h}	0 ^{h}	0 ^{h}
Corm	59 ^{a}	39 ^{c}	9 ^{f}	0 ^{h}
Root	55 ^{b}	13 ^{e}	7 ^{f}	3 ^{g}
mean	46	19	4	3

Note: Superscripts by the same letters are not significantly different ($P \leq 0.05$).
* : As(III) transformed to As(V)

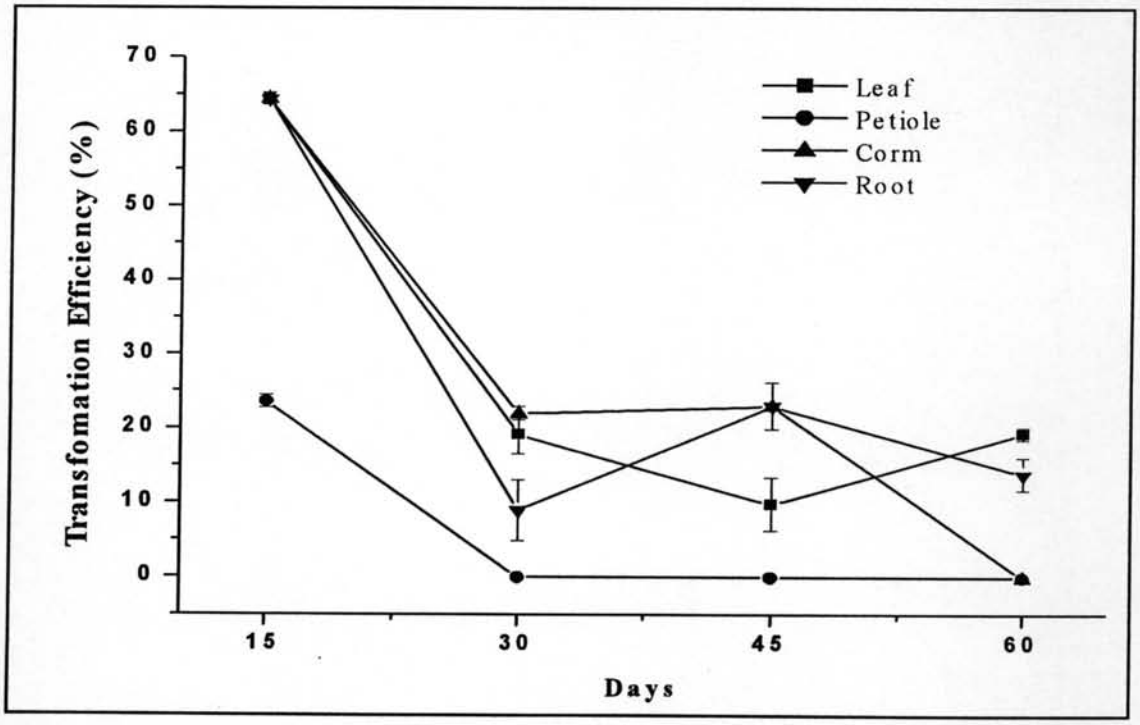

Figure 4.17 As(V) transformation efficiency (%) *C. esculenta* at 15, 30, 45 and 60 days

At 15 days, the As(V) transformation efficiency was the highest at corm that was at 59%. The lowest was petiole being 14%. At 30 days, the best efficiency of As(V) transformation was corm (39%), followed by leaf and root that were 23%, and 13%. Petiole could not transform As(III) to As(V) from this stage to 60 days.

At 45 days, corm and root transformed As(III) to As(V) nearly at 9% and 7%, but leaf and petiole didn't transform As(III) to As(V). At 60 days, the maximum efficiency of As(V) transformation was leaf (8%), and the second was root that was 3%. However petiole and corm didn't transform As(III) to As(V). Table 4.22 and Figure 4.18 expressed As(V) transformation efficiency (%) of *C. esculenta* at in difference organs 15, 30, 45 and 60 days.

Leaf and petiole of *C. esculenta* was the highest As(III) transformation beginning at 30 days, but As(V) transformation began at 15 days which was the maximum As(V) transformation. Corm and root was the highest As(V) transformation organs. From the result found that if petiole transformed As(V) to As(III), it didn't transform As(III) to As(V). In addition, if petiole transformed As(III) to As(V), it didn't transform As(V) to As(III). This result agreed with arsenic hyperaccumulating plants that contain mostly As(V) in roots (Quaghebeur and Rengel, 2005).

4.3.6 As(III) and As(V) transformation efficiency by *C. papyrus*

In the *C. papyrus* it was found that the root had the highest As(III) transformation efficiency (Table 4.23). Next were the culm, rhizome, and leaf, respectively. *C. papyrus* could transform 16% at 60 days, 15% at 15 days, 15% at 30 days, and 14% at 45 days. The interaction of 2 factors for the As(III) transformation efficiency of *C. papyrus* is shown in Figure 4.19.

Table 4.23 As(III) transformation efficiency (%) of *C. papyrus* in difference organs at 15, 30, 45 and 60 days

Organs	% Transformation efficiency of As(III)*			
	15 days	30 days	45 days	60 days
Leaf	20^{d}	6^{g}	0^{h}	0^{h}
Culm	42^{b}	33^{c}	1^{h}	0^{h}
Rhizome	0^{h}	8^{fg}	12^{ef}	15^{e}
Root	0^{h}	13^{e}	42^{b}	49^{a}
mean	15	14.97	14	16

Note: Superscripts by the same letters are not significantly different ($P \leq 0.05$).
* : As(V) transformed to As(III)

At 15 days, the culm had the highest As(III) transformation efficiency (42%) and the leaf had 20%. After that the As(III) transformation efficiency decreased to

33% in the culm and 6% in the leaf, and didn't transform at all at 45 days. In the root and rhizome of the plants transformed 13% and 8% at 30 days; moreover the As(III) transformation efficiency increased continuously until the highest transformation efficiency at 60 days (49% in the root and 15% in the rhizome).

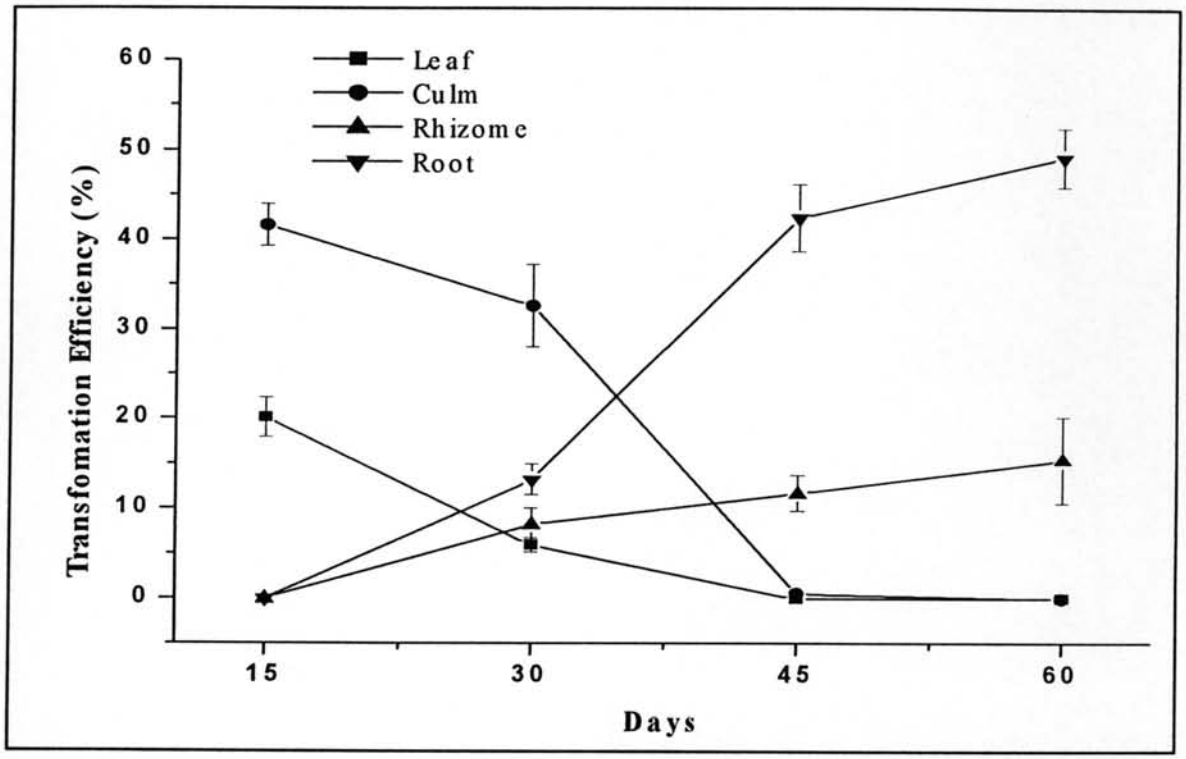

Figure 4.18 As(III) transformation efficiency (%) in organs of *C. papyrus* at 15, 30, 45 and 60 days

Organs of the *C. papyrus* could transform As(V) in a range of 0–59% (Table 4.24 and Figure 4.20). At 15 days, leaf was the best efficiency of As(V) transformation that was 59%. The next was culm and root, being 48% and 35%, as well as rhizome was the lowest transformed organ that was 30%. At 30 days, the order of As(V) transformation efficiency was culm, leaf, rhizome, and root that were 49%, 48%, 41%, and 23%, respectively. At 45 days, culm was the best transformation efficiency that stayed at 5%, followed by leaf at 4%. Root and rhizome decreased As(V) transformation efficiency to 0%. At 60 days, every organ could transform similarly at 9%

Table 4.24 As(V) transformation efficiency (%) of *C. papyrus* in difference organs at 15, 30, 45 and 60 days

Organs	% Transformation efficiency of As(V)*			
	15 days	**30 days**	**45 days**	**60 days**
Leaf	59 [a]	48 [b]	4 [h]	9 [g]
Culm	48 [b]	49 [b]	5 [h]	9 [g]
Rhizome	30 [e]	41 [c]	0 [i]	9 [g]
Root	35 [d]	23 [f]	0 [i]	9 [g]
mean	43	40	2	9

Note: Superscripts by the same letters are not significantly different ($P \leq 0.05$).
* : As(III) transformed to As(V)

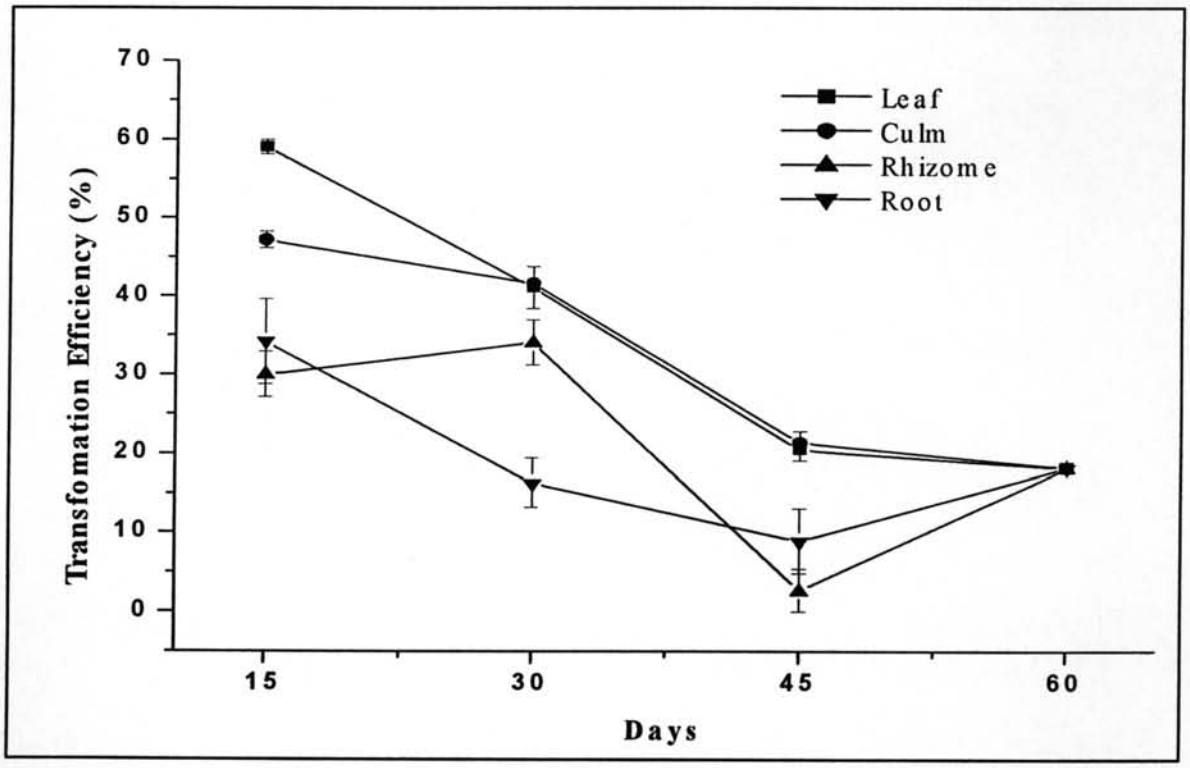

Figure 4.19 As(V) transformation efficiency (%) of *C. papyrus* in difference organs at 15, 30, 45 and 60 days

In *C. papyrus*, at 30 days culm transformed the maximum reduction organ that transformed to As(III). At 45 and 60 days, root was the greatest As(III) transformation, and at 15 days, root and rhizome could transform As(V) to As(III) for oxidized As(III) to As(V) form occurred in every organ of *C. papyrus* from beginning to end. Leaf and culm were the highest transformation organs. As part of arsenic detoxification, the majority of As(V) is reduced to As(III) by the enzyme arsenate

reductase. *P. vittata* have shown that arsenic is translocated inorganic As(III) (Tripathi, 2007). By contrast, Duan *et al.*, (2005) showed evidence that arsenate reductase activity was found exclusively in the in the fronds, concluded that the majority of arsenic is translocated in its reduced form.

4.3.7 As(III) and As(V) transformation efficiency by *T. angustifolia*

The rhizome of *T. angustifolia* had the highest transformation efficiency(Table 4.25). The next was leaf and root. The order of As(III) transformation efficiency was 15%, 11%, 9% and 9% at 45, 60, 30, and 15 days, respectively. The interaction of the organs of the plants and harvest periods showed that at 15 days, the rhizome and leaf had the highest percentage of As(III) transformation efficiency (26%), as seen in Figure 4.21. After that, the As(III) transformation efficiency of the rhizome decreased continuously until it reached the lowest transformation efficiency at 60 days. The As(III) transformation efficiency of the leaf was the maximum at 45 days, being 21% at 45 days, and dncreased to 7% at 60 days. The As(III) transformation efficiency in the root increased continuously to highest at 60 days. That was 27%.

Table 4.25 As(III) transformation efficiency (%) of *T. angustifolia* in difference organs at 15, 30, 45 and 60 days

Organs	As(III) transformation efficiency (%)*			
	15 days	30 days	45 days	60 days
Leaf	0 ^{g}	18 ^{c}	21 ^{b}	7 ^{f}
Rhizome	26 ^{a}	10 ^{e}	14 ^{d}	0 ^{g}
Root	0 ^{g}	0 ^{g}	10 ^{e}	27 ^{a}
mean	9	9	15	11

Note: Superscripts by the same letters are not significantly different ($P \leq 0.05$).
* : As(V) transformed to As(III)

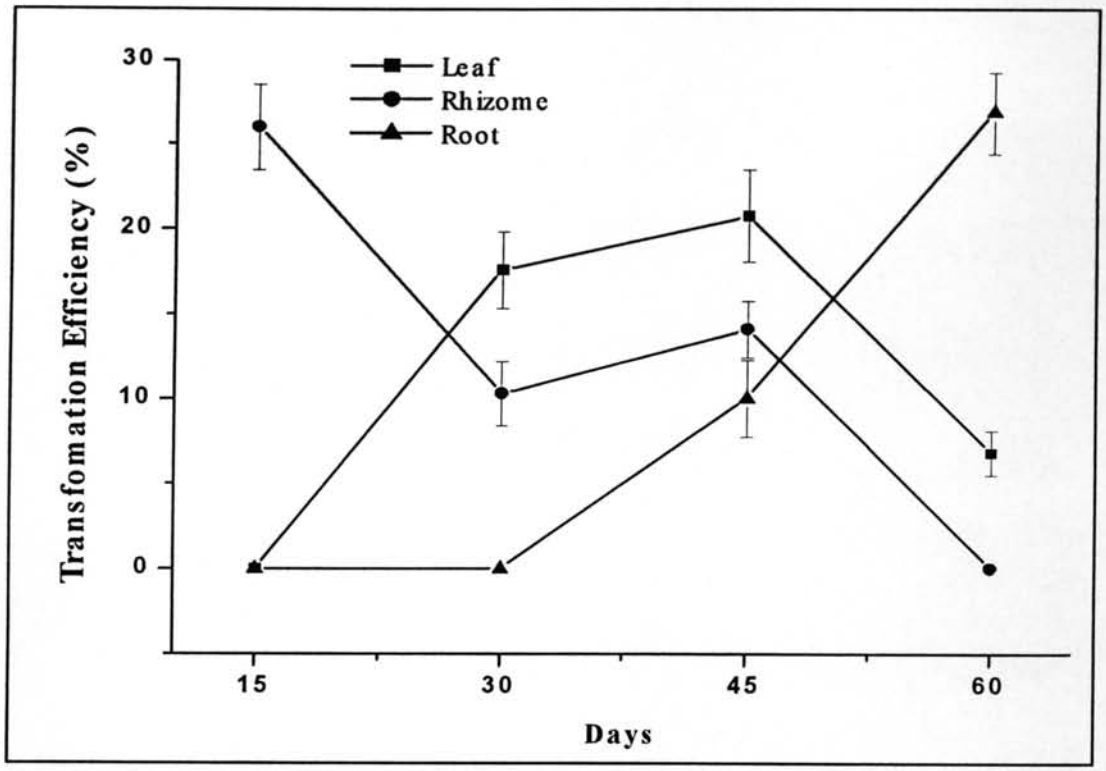

Figure 4.20 As(III) transformation efficiency (%) of *T. angustifolia* in difference organs at 15, 30, 45 and 60 days

Organs of *T. angustifolia* could transform As(V) a range of 0-66%. In addition As(V) transformation efficiency decreased continuously from beginning to end that was 50% to 9%. At 15 days, the rhizome of *T. angustifolia* had the highest As(V) transformation efficiency (66%). The next was the leaf and the root (56% and 29%, respectively) as shown in Table 4.26 and Figure 4.22.

At 30 days, rhizome efficiency of As(V) transformation decreased to 32%. Root was the best organs to transformation efficiency. The lowest As(V) transformation efficiency was leaf, being 12%. At 45 days, rhizome and root transformed As(III) to As(V) nearly at 18% and 12% in root and rhizome, respectively. At 60 days, root and leaf transformed similarly at 14%. The minimum organ of As(V) transformation efficiency was rhizome that was 0%.

Table 4.26 As(V) transformation efficiency (%) of *T. angustifolia* in difference organs at 15, 30, 45 and 60 days

Organs	% Transformation efficiency of As(V)*			
	15 days	**30 days**	**45 days**	**60 days**
Leaf	56 [b]	12 [f]	0 [g]	14 [f]
Rhizome	66 [a]	32 [d]	12 [f]	0 [g]
Root	29 [d]	40 [c]	18 [e]	14 [f]
mean	50	28	10	9

Note: Superscripts by the same letters are not significantly different ($P \leq 0.05$).
: As(III) transformed to As(V)

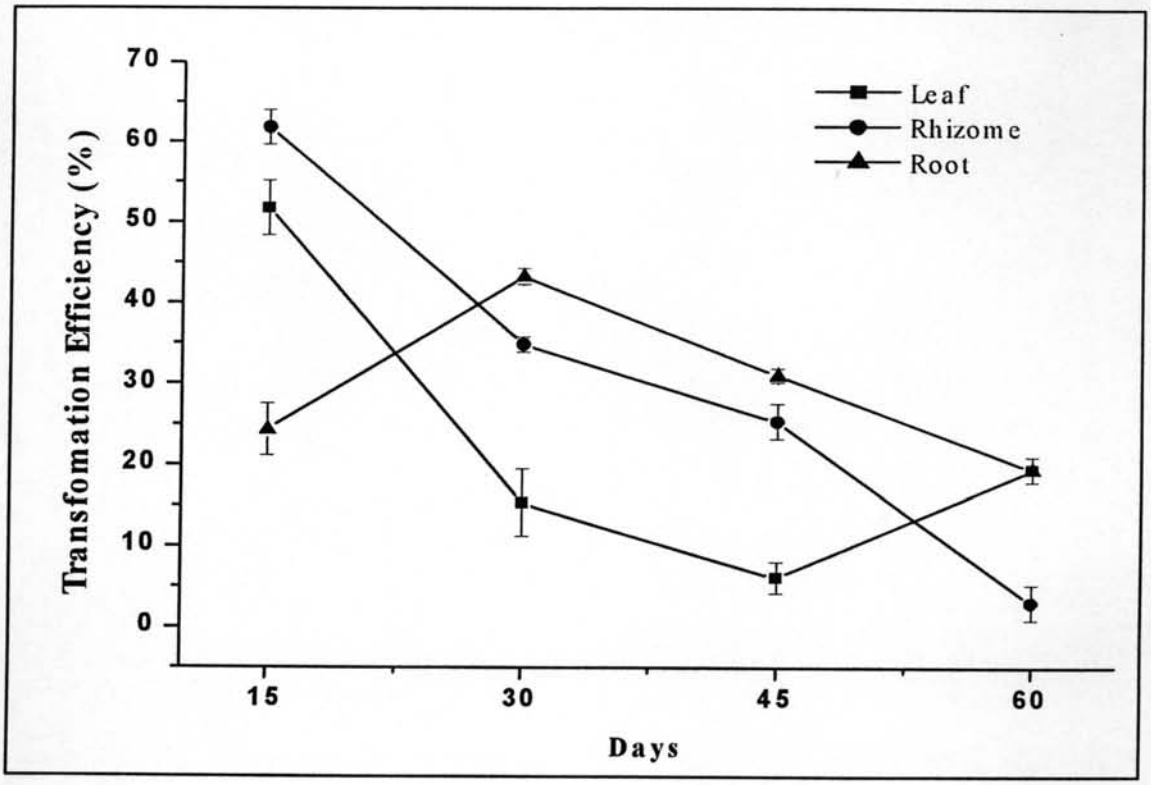

Figure 4.21 As(V) transformation efficiency (%) of *T. angustifolia* in difference organs at 15, 30, 45 and 60 days

In *T. angustifolia*, at 15 days root and leaf didn't transform As(V) to As(III), but rhizome could reduce As(V) to As(III). At 60 days, root was the highest As(III) transformation organ. Every organ could transform As(III) to As(V). At 15 days, rhizome and leaf were the maximum transformation, and then root was the maximum transformed organ.

In conclusion, *Canna* sp., *C. esculenta*, *C. papyrus*, and *T. angustifolia* in As(III) treatment could oxidize As(III) to As(V) in every organ. Moreover root could transform As(III) to As(V). Other organs were different As(III) transformation, and plants translocated in both of arsenic species.

Different plant species distributed arsenic in different parts, with mobility or translocation of arsenic in plant being influenced by form of arsenic available (Quaghebeur and Rengel, 2005). Plants in As(V) treatment did not reduce As(V) to As(III). At 15 days, root translocated As(V) form to other organs which transformed to other arsenic species, excepted *Canna* sp. After that reduction reaction occurred at root to transform As(V) to As(III). From these results displayed every plant translocated in both of arsenic species.

From the result agreed with the study of Pickering *et al.*, (2000) and Raab *et al.*, (2005) identified unbound As(V) and As(III) in xylem sap of *Brassica juncea* and *Helianthus annuus*, thus As(V) and As(III) are the main species that are transported from root to shoot. Most terrestrial plants supplied with As(V) in the root medium reduce a large proportion of As(V) taken up to As(III) in roots (57-100%), with As(III) most likely then being complex to phytochelatins (Quaghebeur and Rengel, 2005). In contract, arsenic- hyperaccumulating plants contain mostly As(III) in root (>90% of total arsenic) and translocate to shoots most of arsenic taken up (50 to 78%). Hence, it is likely that the arsenic hyperaccumulating plants do not use the reduction of As(V) to As(III) and subsequent complexation of As(III) to phytochelations on roots as the arsenic-detoxification strategy in contrast to terrestrial plant species but similar with aquatic plant.

4.4 Relation of arsenic accumulation in plant and soil factors

All raw data were tabulated in table A.40 to table A.44.

The properties of soil to use in the experiment was soil texture that was silty clay loam and pH stayed at 6.5. Electrical conductivity (EC) was 2.21 $dS.m^{-1}$ and % organic matter (%OM) was 1.07 %. Cation exchange capacity was (CEC) 11.5 $me.100\ g^{-1}$. The primary elements for plant included inorganic N; 17.5 $mg.kg^{-1}$ and available P; 10.5 $mg.kg^{-1}$. The other elements was detected that were extractable Ca 923 $mg.kg^{-1}$ and extractable Mg 80 $mg.kg^{-1}$. The metal elements were determined extractable Al; 0.0025 $mg.kg^{-1}$ and extractable Fe 460 $mg.kg^{-1}$. For arsenic

accumulation in soil for experiment included total arsenic accumulation; 0.05 $mg.kg^{-1}$, As(III) accumulation; 0.00 $mg.kg^{-1}$, and As(V) accumulation; 0.05 $mg.kg^{-1}$.

From the Table 4.27 showed the range of extractable Fe in control, As(III) and As(V) treatment were 302 – 640 $mg.kg^{-1}$, 348 – 678 $mg.kg^{-1}$, 338 – 673 $mg.kg^{-1}$, respectively. From the Table 4.28 showed the range of extractable Ca in control, As(III) and As(V) treatment were 819 – 1264 $mg.kg^{-1}$, 665 – 1386 $mg.kg^{-1}$, 675 – 1151 $mg.kg^{-1}$, respectively. From the Table 4.29 showed the range of extractable Mg in control, As(III) and As(V) treatment were 13 – 40 $mg.kg^{-1}$, 16 – 46 $mg.kg^{-1}$, 14 – 38 $mg.kg^{-1}$, respectively. From the Table 4.30 showed the range of available P in control, As(III) and As(V) treatment were 10 – 16 $mg.kg^{-1}$, 7 – 17 $mg.kg^{-1}$, 10 – 16 $mg.kg^{-1}$, respectively. From the Table 4.31 showed the range of Extractable Al in control, As(III) and As(V) treatment were 0.01 – 0.04 $mg.kg^{-1}$, 0.01 – 0.05 $mg.kg^{-1}$, 0.01 – 0.05 $mg.kg^{-1}$, respectively.

Table 4.27 Extractable Fe ($mg.kg^{-1}$) in submerged soil at 15, 30, 45 and 60 days

Types of plants	Treatments	Extractable Fe ($mg.kg^{-1}$)			
		15 days	30 days	45 days	60 days
No plant	Control	640	463	477	499
	As(III)	678	477	413	416
	As(V)	673	484	432	428
Canna sp.	Control	557	556	466	334
	As(III)	597	534	538	446
	As(V)	583	573	455	424
C. esculenta	Control	432	425	305	320
	As(III)	427	388	348	357
	As(V)	365	353	341	338
C. papyrus	Control	558	513	506	309
	As(III)	532	515	370	342
	As(V)	639	637	495	481
T. angustifolia	Control	561	495	409	302
	As(III)	675	633	530	438
	As(V)	604	530	478	425

Detection limit 0.02 $mg.kg^{-1}$

The relation of total arsenic in the soil with other soil factors that are As(III) and As(V) accumulation in soil, Eh, Al, Ca, Fe, K, Mg, K and Na in extractable form, the arsenic accumulation in each plant and As(III) accumulation in the plants, the As(V) accumulation in the plants, As(III) accumulation in soil and As(V)

accumulation in soil, the total amount of arsenic in soil, and harvest periods showed that each plant responded differently to the total amount of arsenic in the soil and the plants and soil factors.

Table 4.28 Extractable Ca ($mg.kg^{-1}$) in submerged soil at 15, 30, 45 and 60 days

Types of plants	Treatments	Extractable Ca ($mg.kg^{-1}$)			
		15 days	30 days	45 days	60 days
No plant	Control	924	984	1015	937
	As(III)	1325	1386	1173	665
	As(V)	871	869	1151	675
Canna sp.	Control	1204	1264	845	951
	As(III)	710	713	755	763
	As(V)	884	811	880	820
C. esculenta	Control	1226	1029	884	828
	As(III)	903	919	925	880
	As(V)	704	819	790	738
C. papyrus	Control	956	973	1059	860
	As(III)	710	918	892	923
	As(V)	1123	875	880	824
T. angustifolia	Control	819	1002	1160	876
	As(III)	829	907	808	843
	As(V)	990	1040	971	1057

Detection limit 0.03 $mg.kg^{-1}$

Table 4.29 Extractable Mg ($mg.kg^{-1}$) in submerged soil at 15, 30, 45 and 60 days

Types of plants	Treatments	Extractable Mg ($mg.kg^{-1}$)			
		15 days	30 days	45 days	60 days
No plant	Control	21	33	40	21
	As(III)	53	38	46	16
	As(V)	19	27	38	14
Canna sp.	Control	30	21	17	41
	As(III)	26	19	24	36
	As(V)	26	28	24	22
C. esculenta	Control	37	33	26	21
	As(III)	25	19	35	22
	As(V)	29	30	19	38
C. papyrus	Control	23	23	28	29
	As(III)	16	30	32	34
	As(V)	27	27	26	33
T. angustifolia	Control	13	35	40	25
	As(III)	18	28	27	25
	As(V)	27	36	34	34

Detection limit 0.01 $mg.kg^{-1}$

Table 4.30 Available P ($mg.kg^{-1}$) in submerged soil at 15, 30, 45 and 60 days

Types of plants	Treatments	Available P ($mg.kg^{-1}$)			
		15 days	30 days	45 days	60 days
No plant	Control	12	12	11	13
	As(III)	16	16	16	17
	As(V)	14	16	15	15
Canna sp.	Control	16	15	13	12
	As(III)	13	13	13	15
	As(V)	15	13	13	12
C. esculenta	Control	14	13	12	11
	As(III)	11	15	15	16
	As(V)	14	16	16	15
C. papyrus	Control	14	10	12	10
	As(III)	10	14	13	12
	As(V)	11	11	13	13
T. angustifolia	Control	12	10	10	10
	As(III)	10	7	10	13
	As(V)	12	10	10	11

Detection limit 0.06 $mg.kg^{-1}$

Table 4.31 Extractable Al ($mg.kg^{-1}$) in submerged soil at 15, 30, 45 and 60 days

Types of plants	Treatments	Extractable Al ($mg.kg^{-1}$)			
		15 days	30 days	45 days	60 days
No plant	Control	< 0.05	< 0.05	< 0.05	< 0.05
	As(III)	< 0.05	< 0.05	< 0.05	< 0.05
	As(V)	0.05	< 0.05	< 0.05	< 0.05
Canna sp.	Control	< 0.05	< 0.05	< 0.05	< 0.05
	As(III)	< 0.05	< 0.05	< 0.05	< 0.05
	As(V)	< 0.05	< 0.05	< 0.05	< 0.05
C. esculenta	Control	< 0.05	< 0.05	< 0.05	< 0.05
	As(III)	< 0.05	< 0.05	< 0.05	< 0.05
	As(V)	< 0.05	< 0.05	< 0.05	< 0.05
C. papyrus	Control	< 0.05	< 0.05	< 0.05	< 0.05
	As(III)	< 0.05	< 0.05	< 0.05	< 0.05
	As(V)	< 0.05	< 0.05	< 0.05	< 0.05
T. angustifolia	Control	< 0.05	< 0.05	< 0.05	< 0.05
	As(III)	< 0.05	0.05	< 0.05	< 0.05
	As(V)	< 0.05	< 0.05	< 0.05	< 0.05

Detection limit 0.05 $mg.kg^{-1}$

In the soil, the As(III) and As(V) accumulation showed a positive correlation (Table 4.32). Total arsenic in soil of *Canna* sp. showed a significantly positive correlation; As(III) in soil, As(V) in soil, and redox potential (Eh); however significantly negative correlation; day, and extractable Ca. Accumulation of *Canna* sp. expressed a significantly positive correlation; total arsenic in plant.

Total arsenic in soil of *C. esculenta* showed a significantly positive correlation; As(III) and As(V) in soil. Accumulation of *C. esculenta* expressed a significantly positive correlation; total arsenic in plant and day. Total arsenic in soil of *C. papyrus* displayed a significantly positive correlation; As(III) and As(V) in soil and extractable Fe. Accumulation of *C. papyrus* expressed a significantly positive correlation; As(V) in plant; however significantly negative correlation; As(III) in plant. Total arsenic in soil of *T. angustifolia* showed a significantly positive correlation; As(III) in soil, As(V) in soil, day, and extractable Fe. Accumulation of *T. angustifolia* showed a significantly positive correlation; total arsenic in plant and As(V) in soil, but significantly negative correlation; total arsenic in soil.

Adsorption of arsenic onto soil is of paramount importance because these processes regulate mobility of arsenic in soil, which further influences the bioavailability and toxicity of arsenic (Jiang *et al.*, 2005). Many researches have show that As(V) adsorption is related significantly to Al and Fe oxides and clay concentration of soil (Wauchope, 1975; Elkhatib *et al.*,1984). It is found that Fe oxide was the most important mineral influencing adsorption of As(V) (Manning and Goldberg,1997). In addition, organic matter, dissolved organic carbon and phosphate in soils have all been demonstrated As(V) form soil (Grafe *et al.*,2001; Liu *et al.*,2004).

Some studies have also examined the influence of pH on arsenic absorption by soil and adsorption of As(V) by amorphous iron hydroxides was substantially pH-dependent (Jiang *et al.*,2005). Under near-neutral conditions, the influence of redox on arsenic solubility in soils wad found to be governed by reduction of As(V) to As(III) followed by desorption and the dissolution of Fe-oxyhydroxides (Carbonell-Barrachian *et al.*, 1999). The reduction and decomposition of iron oxyhydroxides/ xides and arsenic can occur inorganically in certain subsurface conditions. However, these processes will be directly related to anaerobic bacteria activity in the present sediments. Arsenic is mobilized in the sediment pore-water as a result of the

microbially reductive dissolution of iron without arsenic reduction (Cumming *et al.*, 1999; Bose and Sharma, 2002; Masuda *et al.*, 2005).

Table 4.32 multiple regression equation of total arsenic in soil and arsenic accumulation of plants

Total As	Regression equation	MES	R^2
***Canna* sp.**			
Soil	61.316+0.493(As(III)S)***+1.051(As(V)S)***-0.569(Day)*+0.144(Eh)* +8.879(pH)+392.159(Al)-0.048(Ca)*-0.118(Fe)*-0.296(Mg)+1.225(P)	17085.9	0.9896**
Plant	109.728+16.494(TAsP)*-24.930(As(III)P)+9.854(As(V)P)-9.418(TAsS) +4.136(As(III)S) -4.664(As(V)S)-3.104(Day)	5942415	0.9362**
C. esculenta			
Soil	-23.153+1.122(As(III)S)***+1.006(As(V)S)***-0.018(Day)-0.031(Eh) +2.228(pH)-14.669(Al)-0.008(Ca)+0.004(Fe)*+0.037(Mg)+1.023(P)	16795.3	0.9926**
Plant	-519.627*+9.137(TAsP)*-17.084(As(III)P)+21.843(As(V)P)-8.264(TAsS) +4.576(As(III)S)+11.531(As(V)S)+15.101(Day)**	3474703	0.8708**
C. Papyrus			
Soil	-14.354+1.150(As(III)S)***+1.002(As(V)S)***+0.115(Day)+0.029(Eh) -0.269(pH)-155.060(Al)+0.008(Ca)+0.052(Fe)*-0.179(Mg)-0.835(P)	16780.7	0.9917**
Plant	-143.626+7.938(TAsP)-115.641(As(III)P)**+43.901(As(V)P)*+20.911(TAsS) -36.594(As(III)S)-3.497(As(V)S)+4.273(Day)	4.882E+07	0.9375**
T. angustifolia			
Soil	-129.144*+0.932(As(III)S)***+0.961(As(V)S)***+0.839(Day)*-0.031(Eh) +4.717(pH)+120.180(Al)+0.005(Ca)+0.169(Fe)*-0.123(Mg)-1.596(P)	18289.7	0.9900**
Plant	-178.137+26.913(TAsP)***-13.816(As(III)P)-0.493(As(V)P)-14.178(TAsS) +6.880(As(III)S)+12.602(As(V)S)+4.682(Day)	1.391E+07	0.9634**

As(III)S: As(III) in soil, As(V)S: As(V) in soil, Day: harvest times, Eh: soil redox potential, pH: pH of soil, Al: extractable Al, Ca: extractable Ca, Fe: extractable Fe, Mg: extractable Mg, P: available P, TAsP: total arsenic in plant, As(III)P: As(III) in plant tissue, As(V)P: As(V) in plant tissue, TAsS: Total arsenic in soil, As(III)S: As(III) in soil, As(V)S: As(V) in soil, Day: harvest day

Plants require macronutrients (N, P, K, Ca, Mg, S) and micronutrients (B, Cl, Cu, Fe, Mn, Mo, Zn and possibly Co, Ni, Se, Si, V and may be others). Lack of chlorophyll due to stresses on the plant, such as lack of nutrients, can result in chlorosis (the yellowing of normally green plant leaves). Nutrient uptake pathways can take up contaminants that are similar in chemical form or behavior to the nutrients (Pierzynski *et al.*, 1994).

High accumulation arsenic becomes toxic for all plants, causing chlorosis, necrosis and finally inhibition of plant growth. Uptake of arsenic by plants occurs primarily through the root system; because arsenic is not readily translocated to the shoots. Crop damage or even failure is usually assumed to occur before arsenic levels in shoots (O'Nell, 1995; Peterson *et al.*, 1981). Jacobs and Keeney (1970 refered by Patel *et al.*, 2005) concluded that the arsenic contamination of soils primarily affects productivity, rather than presenting a health risk for consumers of crops grown on these soils. But some plants may accumulate high levels of arsenic even at soil accumulation. Although many researchers have studied arsenic accumulation by plants, e.g., Otte and Ernst (1994), Sheppard (1992), Xu and Thornton (1985) and Warren *et al.* (2003) the relationship between arsenic in the soil and plant uptake is still not well understood. Texture and chemical composition of the soils are important factors that govern the availability of arsenic to plants. Woolson (1971) reported that arsenic was not toxic to vegetable crops on loamy sand and of low toxicity on a silty clay loam. Jacobs and Keeney (1970 refered by Patel *et al.*, 2005) reported that arsenic was more phytotoxic to corn on a sandy than on a silt loam soil. Smith *et al.* (1998 refered by Patel *et al.*, 2005) found that inorganic arsenic was five times more toxic to plants grown on a sand soil with a mean of 40 mg $As.kg^{-1}$ than on a clay soil with a mean of 200 mg As kg^{-1} at the same rate of application. Arsenic uptake by plants and hence phytotoxicity is expected to be greater in sandy soils than in other soils, because of their low contents of Fe and Al oxides, clay minerals and organic matter, which are strong sorbent of arsenic (Sadiq, 1997). There are numerous cations in the soil with which arsenate can react to form insoluble compounds. The purpose of this paper is to delineate some of the arsenate compounds that may form in the soil, and to use this information as a basis for developing an Eh-pH diagram to predict the relative stability of various arsenates in soil. Because of their importance in the soil system, Fe, Ca, Al, and Mg were examined for their relationships with arsenate (Hess and Blanchar, 1976). There, for a given arsenic application rate the soluble arsenic accumulation is lower in loamy than in sandy soils. In acid soils, iron and aluminum oxides are the primary sorbents of arsenate, which is the predominant arsenic species in agricultural soils (Pongratz, 1998). In alkaline soils, arsenate is sorbed by calcium oxides, but this adsorption is less intense than that at lower pH on iron and aluminum oxides (Gulz *et al.*, 2005).

Although Woolson *et al.*(1971) observed a significant linear correlation between the logarithm of the total soil arsenic accumulation and growth reduction in corn, the water soluble arsenic accumulation was better correlated with plant growth than was the total soil arsenic. Sadiq (1986) found that the arsenic uptake by maize was correlated with the water-extractable arsenic accumulation, but not with the total arsenic accumulation in calcareous soils. In most studies focusing on the arsenic uptake by plants, however, only the effects of the total doses of applied arsenic to soils have been compared, mostly without consideration of its solubility.

Few studies compared arsenic uptake by different plant species. Wauchope (1983) reported that the arsenic accumulation in plant shoots was proportional to the soluble soil arsenic accumulation and was similar in plants of different species grown in the same solution. On the other hand, Otte and Wrnst (1994) found that the arsenic uptake from soil may be quite different between plants species. A factor of primary importance influencing the binding of arsenate in soils is phosphate (Darland and Inskeep, 1997). Due to the chemical similarity of arsenate and phosphate, these two anions compete strongly not only in unspecific anion exchange reactions, but also in specific binding by surface complications e.g., on iron and aluminium hydroxides surfaces.