Effects of lead concentrations on germination and development of common vegetables in Thailand

By

Mr. Surat Piemyoo

A special project submitted to the faculty of Biotechnology,
Assumption University in part of fulfillment of the requirements
For the degree of Bachelor of Science

2005

Faculty of Biotechnology พว.ชาต.

Special Project

Effects of lead concentrations on germination and development of common vegetables in Thailand

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By

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By	: Mr. Surat Piemyoo
Advisor	: A. Trilert Chaicherdsakul
Co-Advisor	: Dr. Pahol Kosiyachinda
Level of study	: Bachelor of Science
Department	: Agro-Industry
Faculty	: Biotechnology
Academic year	: 2005

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Abstract

Heavy metal contamination is one of limiting factors in agricultural practice. This study was to provide us a tool to plan and decide which vegetables would grow better and be less affected by lead contamination in agriculture. The experiment was conducted to study effects of lead on germination and physiological changes and to identify level of tolerance of lead in vegetables. The study was carried out on ten species of vegetables. Seeds were planted in tissue culture media with lead; 0 ppm (control), 5 ppm, 15 ppm, and 30 ppm. Average length as plant growth was measured. Ten species showed no significant difference ($P>0.05$) on germination when cultured in treatments. Average length of mung bean, tomato, holy basil, and bird pepper had significant difference ($P<0.05$) to control after one, two, three, and four week exposure to lead onward, respectively. Morning glory, cucumber, lettuce, sweet basil, kale, and cabbage had no significant difference ($P>0.05$) on average length to control. Effect of lead on physiology changes was found in all ten species as shown in their root development. Lead did not seriously affect on seed germination in this study. However, lead showed effect on average growth by length of four species and effect on root elongation of all ten vegetables.

Acknowledgements

This project would not have been successful with the cooperation of many people. I would like to take this opportunity to express my sincere gratitude and appreciation to the following people.

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I would also like to thank my highly respected Dean, Dr. Churdchai Cheowtirakul, the faculty members and the technicians of Biotechnology Faculty, Assumption University for all the support and inspiration in this field of study. Special thanks to Dr. Viyada Kunathigan and A. Tatsawan C. for their knowledge and help.

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Finally, sincere thanks to my friends and my family, for their support and understanding. I also like to extend this thanks to all my seniors and juniors of Biotechnology Faculty, Assumption University.

Mr. Surat Piemyoo

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List of abbreviations

1. cm	centimeter (s)
2. CRD	completely randomized design
3. EDTA	ethylenediaminetetraacetic acid
4. g	gram (s)
5. LSD	least significant difference
6. M	molar (s)
7. mg	milligram(s)
8. ml	milliliter (s)
9. pH	the logarithm of the reciprocal of hydrogen-ion concentration in gram atoms per liter
10. ppm	parts per million
11. rpm	round per minute
12. w/w	weight in weight
13. SD	standard deviation
14. μl	microliter (s)

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Chapter 1
Introduction

1.1 Rationale

Human activity has led to high levels of heavy metals being accumulated from the metal related industries, the premises of old mines, and also rural areas where the soil along highways and roads is polluted by automotive exhausts and in fields contaminated with fertilizers containing heavy metal ingredients (Antosiewicz, 1992). Lead is the most dangerous heavy metal because of its elevated level in the environment in certain areas. These areas include urban regions polluted by wastes that are beginning to reach thresholds able to evoke the first signs of toxicity in humans. Plants are an important link in the pathway by which excessive amounts of heavy metals are channeled into the food chain and biological cycles (Todd et al., 1996). This is because plants are able to accumulate lead in their tissues. Lead is toxic to many organ systems of human body, such as the central and peripheral nervous system, the red blood cells, the kidneys, the cardiovascular systems, and the male and female reproductive organs. Lead can decrease sperm counts and increase prevalence of morphologically abnormal sperm in male, and increase risk of miscarriage in female (Mengel et al., 1980).

The levels of lead in soils that are toxic to plant are not easy to evaluate. However, it is generally agreed that soil lead concentration ranging from 100 to 500 ppm are considered to be excessive (Pendias et al., 1984). The toxic symptoms of lead in plant are not very specific. There is much evidence that lead toxicity resulted in retardation of plant growth.

The inhibitory effects may be due to interference with enzymes essential for normal metabolic and development, photosynthetic processes, water and mineral nutrients absorption, and changes in cell ultrastructure (Van et al., 1990).

Plants are an important link in the pathway by which excessive amounts of heavy metals are channeled into the food chain and biological cycles (Todd et al., 1996). This is because plants are able to accumulate lead in their tissue. Lead from the soil enters plants through their root system, while lead from dusts and automotive exhaust aerosols deposits directly on their overground parts (Zimdahl, 1976). The localization of lead in root cells and tissues effects on cell division, only a small part of the lead taken up by the roots from the soil is transported via the xylem to the above-ground parts of the plant (Jones et al., 1973). There still remains the problem, however, of the degree to which exogenous lead, as that from direct atmospheric pollution or soil solutions in contact with seeds, is able to pass through the seed coat into the seed and consequently affect germination (Małgorzata et al., 1998).

In this study, we conducted our experiment mainly in a plant tissue culture laboratory. The objectives of this project were to study effects of lead at different concentrations on germination of common vegetables and to identify level of tolerance to lead in common vegetables and to study effects of lead at different concentration on physiological changes during plant development.

1.2 Collaboration

This research work is a collaboration of:

Faculty of Biotechnology, Assumption University

Department of Biology, Faculty of Science, Mahidol University

1.3 Problem statement

Contamination of lead may impair growth and development of plant in agriculture. Lead is one of the prevalent heavy metals present naturally in the soil. Contamination of lead in soil can be from the natural event itself, e.g. volcanic activities, mineral decomposition, and from human activities such as mining and related activities. For the natural source, the indigenous plant species may have well adapted to the concentration and be able to regulate heavy metal to provide protection from phytotoxicity. Nevertheless, introduced species may suffer from lead at different levels. These species often include plants and vegetables of economic importance.

Thailand and Thai people rely heavily on agriculture for their everyday life. The fundamental problems to be tackled in this research could provide us a tool to plan and decide which plant species would grow better and be less affected by lead contamination in agricultural. The data obtained from this study may elucidate the tolerance of common vegetables to lead concentrations.

1.4 Objectives

1. To study effects of lead at different concentrations on germination of common vegetables.

2. To identify level of tolerance of common vegetables to different lead concentrations.

3. To study effects of lead at different concentrations on physiological changes during plant development.

1.5 Scope

In this study, we will conduct our experiment mainly in a plant tissue culture laboratory. Plant tissue culture techniques have become important to both research and development field and agriculture industry. It allows us to understand metal regulation and strategies that plants use to survive under stress from the heavy metal. This experiment is to find out the effects of lead at various concentrations on germination and development of common vegetables in Thailand.

1.6 Hypothesis

I hypothesize that each species or variety of common vegetables would carry different tolerance to lead; thus, enabling us to characterize vegetables of economic importance of which inherent tolerance to lead will be challenged for their limits.

1.7 Expected outcomes

This experiment is to find out the effects of lead at various concentrations on germination and development of common vegetables in Thailand. At the end of the experiment we will know that which of the ten common vegetables are affected by lead at different concentrations on germination and development of common vegetables. We can also identify level of tolerance of common vegetables to lead concentrations

1.8 Support

At this point, no external funding had been provided for this research. We do aim, however, at submitting this work to potential organizations to gain future support and collaboration. In order to do so, the following are the support we would like to request from the university.

1.8.1 Manpower

- Mr. Trilert Chaicherdsakul (Full-time lecturer, Faculty of Biotechnology, Assumption University)
- Dr. Pahol Kosiyachinda (Full-time lecturer, Department of Biology, Faculty of Science, Mahidol University)
- Mr. Surat Piemyoo (senior student, Faculty of Biotechnology, Assumption University)

1.8.2 Equipments

- **Plant culture**

The equipments for plant culture were supported from Faculty of Biotechnology, Assumption University and Department of Biology, Faculty of Science, Mahidol University.

- **Data collection and analysis**

The equipments for data collection and analysis were supported from Department of Biology, Faculty of Science, Mahidol University.

- **Dry weight collection**

The equipments for dry weight collection were supported from Faculty of Biotechnology, Assumption University.

1.8.3 Financial support

- Finances were supported from Faculty of Biotechnology, Assumption University.
- Department of Biology, Faculty of Science, Mahidol University

Chapter 2
Literature Review

2.1 *In vitro* study of plant physiology

Plants require elements and minerals to maintain proper growth and development. However, nutrient in the planting substrate at different location may naturally contain those elements and minerals in different forms and concentration. Study on plant physiology can be conducted either *in vivo* or *in vitro*, which attempts to provide answers to different questions. Experiment in natural setting could also provide answers to a real world situation. Nevertheless, due to its complexity and numerous uncontrollable parameters, *in vitro* study often gives us preliminary information and hints to look at the problem in a clearer direction.

2.2 Phytoremediation, plant-based strategies for cleaning up contaminated soils

The use of such plants to cleanup soils and water contaminated with pollutants, a technique known as phytoremediation, is emerging as a new tool for *in situ* remediation. Phytoremediation takes advantage of the fact that a living plant acts as a solar-driven pump, which can extract and concentrate certain heavy metals from the environment (Raskin et al., 1997). Plants that take up heavy metals (Figure 1) from the soil offer an alternative and less expensive method to strip heavy metals directly from the soil. Plants have constitutive and adaptive mechanisms for accumulating or tolerating high contaminant concentrations. This remediation method maintains the biological properties and physical structure of the soil. The technique is environmentally friendly, potentially cheap, and offers the possibility of bio-recovery of the heavy metals.

Phytoremediation strategies can offer suitable approaches for decontaminating polluted soil, water, and air by trace metals as well as organic substances (Table 1).

Table 1: Lists of phytoremediation strategies (Xiaoe et al., 2005)

Phytoremediation techniques	Action mechanism	Medium treated
Phytoextraction	Direct accumulation of contaminants into plant shoots with subsequent removal of the plant shoots	Soil
Rhizofiltration (phytofiltration)	Absorb and adsorb pollutants in plant Roots	Surface water and water pumped through roots
Phytostabilization	Root exudates cause metals to precipitate and biomass becomes less bioavailable	Groundwater, soil, mine tailings
Phytovolatilization	Plants evaporate certain metal ions and volatile organics	Soil, groundwater
Phytodegradation (plant-assisted bioremediation)	Microbial degradation in the rhizosphere region	Groundwater within the rhizosphere and soil
Phytotransformation	Plant uptake of organic contaminants and degradation	Surface- and groundwater
Removal of aerial contaminants	Uptake of various volatile organics by leaves	Air

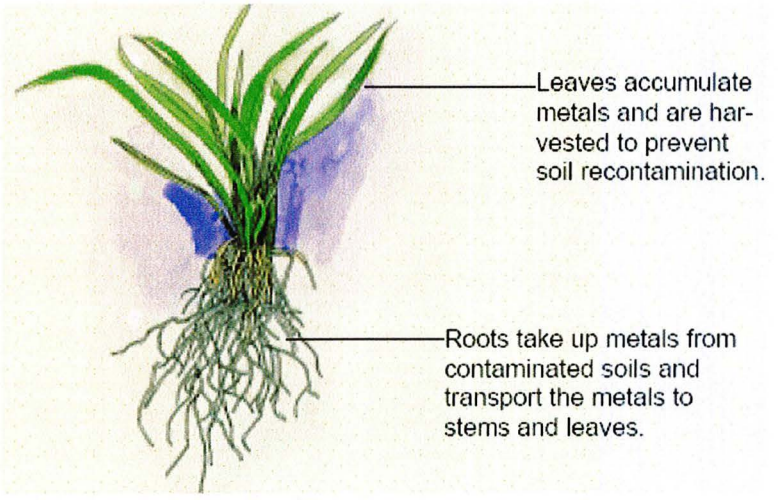

Figure 1: Phytoremediation: Using plants to clean up soil (Leon, 2000)

Phytoextraction is a specific type of phytoremediation that refers to the uptake of metal contaminants by plant roots in plant stems and leaves. In mechanisms (Figure 2) that require translocation of metals through plant tissues, there may be steps involving such as: (a) transport of metals across the plasma membrane of root cells; (b) xylem loading and translocation; and (c) detoxification and sequestration of metals at the cellular and the whole plant levels (Rupali et al., 2004).

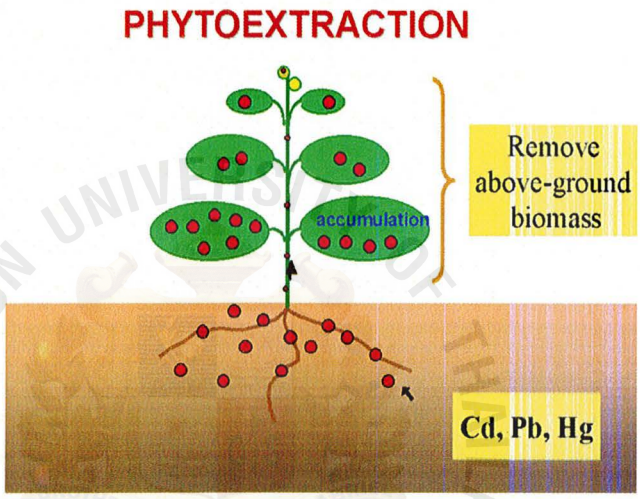

Figure 2: Mechanisms of phytoextraction in plants

2.3 Hyperaccumulation of heavy metals by plants

Hyperaccumulation of heavy metals by higher plants is a complex phenomenon. These plants are called hyperaccumulators, absorbing high levels of contaminants concentrated either in their roots, shoots, and/or leaves. Plants show different levels of tolerance and accumulation to different metals. The first characterized hyperaccumulators were members of Family Brassicaceae and Family Fabaceae. More than 400 plant species have been reported so far that hyperaccumulate metals (McIntyre, 2003). The accumulation ability of a given metal is determined by the uptake capacity and intracellular transportation of plant. The major processes that are assumed to be influencing metal accumulation rates in plant (Xiaoe et al., 2005) are illustrated in Figure 3.

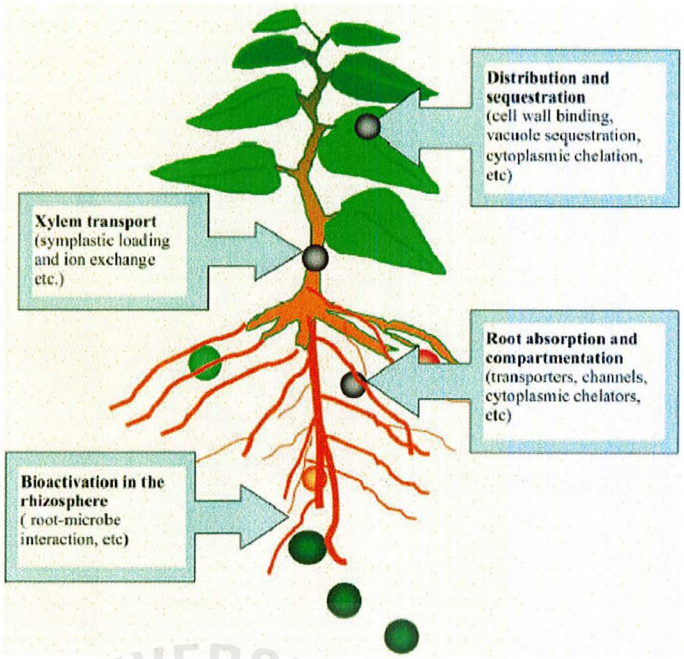

Figure 3: Major processes proposed to be involved in heavy metal hyperaccumulation by plants.

2.4 Type of phytoextraction

2.4.1 Natural phytoextraction

Natural phytoextraction is the removal of metal depends on the natural ability of the plant to remediate contamination. At least 45 families have been identified to have hyperaccumulate plants; some of the families are Brassicaceae, Fabaceae, Euphorbiaceae, Asteraceae, Lamiaceae, and Scrophulariaceae (Dushenkov, 2003; Salt et al., 1998). The best-known hyperaccumulators is *Brassica juncea,* has been found to have a good ability to transport lead from the roots to the shoots. Aquatic plants such as the floating *Eichhornia crassipes* (water hyacinth), *Lemna minor* (duckweed), and *Azolla pinnata* (water velvet) have been investigated for use in rhizofiltration, phytodegradation, and phytoextraction (Salt et al., 1997). Recently, a fern *Pteris vitatta* has been shown to accumulate as much as 14,500 mg kg^{-1}arsenic in fronds without showing symptoms of toxicity (Ma et al., 2001).

2.4.2 Induced phytoextraction

Induced phytoextraction or chelate assisted phytoextraction is the method in which artificial chelates are added to increase the mobility and uptake of metal contamination. Chelators have been isolated from plants that are strongly involved in the uptake of heavy metals and their detoxification. Chelating agents like ethylenediaminetetraacetic acid (EDTA) are applied to lead-contaminated soils that increases the amount of bioavailability lead in the soil and a greater accumulation in plants is observed (Huang et al., 1997).

2.5 Limitations of phytoextraction

Plants express an incomplete set of remediating features. For example, most of the metal hyperaccumulators are small and slow growing (Mitch, 2002). Phytoextraction and plant-assisted bioremediation is most effective if soil contamination is limited to within 3 feet of the surface, and if groundwater is within 10 feet of the surface (Raskin et al., 1994). It is applicable to sites with low to moderate soil contamination over large areas, and to sites with large volumes of groundwater with low levels of contamination that have to be cleaned to low (strict) standards (Salt et. al., 1995). Since chemical chelators have additional toxicity to plants, thus they may increase the uptake of metals but decrease plant growth thus proving to be of limited benefit.

Enhanced root-to-shoot transport is another key component of metal/metalloid hyperaccumulation. This may be achieved by a reduced sequestration of the metal in the root vacuoles or by enhanced xylem loading, although there has been little progress in research on this aspect (Steve et al., 2003).

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2.6 Effects of lead on plant

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Although lead is not an essential element for plants, it gets easily absorbed and accumulated in different plant parts. Excess lead causes a number of toxicity symptoms in plants e.g. stunted growth, chlorosis and blackening of root system. Lead inhibits photosynthesis, upsets mineral nutrition and water balance, changes hormonal status and affects membrane structure and permeability (Pallavi et al., 2005). The uptake, transport, and accumulation of lead by plants are strongly governed by soil and plant factors, and they differ significantly with plant species (Eltrop et al., 1991).

2.7 Role of EDTA in lead transport and accumulation

The synthetic chelate EDTA forms a soluble complex with many metals, including lead and can solubilize lead. Recently, application of EDTA to lead contaminated soils has been shown to induce the uptake of lead by plants (Huang et al., 1997). The synthetic chelates including EDTA destroy the physiological barrier(s) in roots that normally function to control uptake and translocation of solutes. The plasma membrane surrounding root cells is thought to play a major role in forming this barrier. Both Zn^{2+} and Ca^{2+} are involved in stabilizing plasma membranes. Therefore, synthetic chelates may induce metal-chelate uptake and accumulation by removal of stabilizing Zn^{2+} and Ca^{2+} from the plasma membrane. Lead is known to be effective at displacing various cationic metals from roots, suggesting that lead may also play a role in destabilizing the physiological barrier to solute movement in roots (Andrew et al., 1998).

2.8 Frequently asked questions about lead contamination

2.8.1 How much lead is there in our soil?

The natural background level of lead in soil is less than 100 parts per million (ppm). Lead in surface soil in residential communities is commonly higher than 200 ppm. In older, urban residential areas lead in soil on some properties may range from 500 to 1000 ppm, even when there is no local industrial source.

2.8.2 Can I eat vegetables from the garden?

Lead enters and is stored in vegetables grown in lead-contaminated garden soils. The amount of lead taken up and stored in these vegetables will vary depending on the type of vegetable, the type of soil, your gardening practices and the amount of lead in the soil. Although lead normally increases in plants as they age, it is taken up and stored differently in roots and in plant leaves. For example, lettuce leaves can store seven times more lead than the roots of carrots. Beet leaves contain more lead than beetroots. Therefore, it is not always safe to assume that root vegetables will contain more lead than leafy vegetables. Fruit crops such as tomatoes, berries, apples and cucumbers, present a much lower risk because they take up and store very little lead.

2.8.3 Is lead in soil harmful?

Children take in an average of 80 milligrams of soil and dust (equal to the size of a grain of rice) each day while they play. Depending on the concentration of lead in the soil, they may develop elevated levels of lead in their blood. Soil and dust are considered a major route of exposure for children. The Ministry of the Environment advises that there is minimal risk from exposure to soil with lead levels below 200 ppm.

There is minimal risk in consuming homegrown vegetables grown in soil containing less than 200 ppm of lead. However, this is only a guide and it should be remembered that eating vegetables grown in soil contaminated with lead will always increase your exposure to lead and the risk to your health, especially for infants and young children if they are used in baby food recipes. You should not eat any vegetables out of your garden if lead levels are above 1000 ppm (http://www.ene., 2006).

2.9 Names of common vegetables in Thailand

Ten species of common vegetable seeds were chosen (Table 2). Name of each species was classified in term of family, species, common name and Thai name.

Table 2: Names of common vegetables used in this study

Family	Species	Common name	Thai name
Fabaceae	*Vigna radiate* (L.) R.wilczek	Mung bean	ถั่วเขียว
Cucurbitaceae	*Cucumis sativus* L.	Cucumber	แตงกวา
Convolvulaceae	*Ipomoea reptans* Poir.	Morning glory	ผักบุ้ง
Asteraceae	*Lactuca sativa* L.	Lettuce	ผักกาดหอม
Lamiaceae	*Ocimum basilicum* L.	Sweet basil	โหระพา
	Ocimum tenuiflorum L.	Holy basil	กระเพา
Brassicaceae	*Brassica alboglabra* L.H. Bailey	Chinese kale	คะน้า
	Brassica oleracea L.var. *capitata* L.	Cabbage	กะหล่ำปลี
Solanaceae	*Lycopersicum esculentum* Mill.	Tomato	มะเขือเทศ
	Capsicum annuum L.	Bird pepper	พริกขี้หนู

Chapter 3
Research and Methodology

3.1 Experimental locations

3.1.1 Plant culture and experimental design were performed at Department of Biology, Faculty of Science, Mahidol University.

3.1.2 Measuring dry weight was performed at faculty of Biotechnology, Assumption University.

3.2 Chemical reagents and equipments

3.2.1 Chemical reagents

All chemical reagents were prepared at Department of Biology, Faculty of Science, Mahidol University.

1) Modified White (1963) medium-see appendix A
2) Lead standard solution –Pb $(NO_3)_2$ in HNO_3 0.5 mol/l, 1000mg/l Pb-CertiPUR
3) Agarose, Bacto™Agar-Becton, Dickinson and company
4) Sucrose
5) Distilled water
6) Sodium hypochlorite 8 %
7) Detergents 0.5%
8) EDTA 0.5 M
9) NaOH
10) HCl

3.2.2 Equipments

1) Analytical balance- Mettler PJ300
2) pH meter- Suntex
3) Laminar air-flow cabinet- Issco Model
4) Stirrer-Ikamag®Rce-G
5) Oven-Electrolux
6) Magnetic bar
7) Forcep
8) Autoclave
9) Pipette
10) Erlenmeyer flask
11) Beaker

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3.3 Vegetable seeds

The common vegetable seeds were bought from The Mall, Ramkhamhaeng, Bangkok, Thailand. Chia Tai Company produced nine species of vegetable seeds but mung bean was produced by Thai-Ha Company as shown in Table 3.

Table 3: Sources of vegetable seeds

Common name	Product from
1. Mung bean	Thai-Ha, Thailand
2. Cucumber	Chia Tai, Thailand
3. Morning glory	Chia Tai, Thailand
4. Lettuce	Chia Tai, Thailand
5. Sweet basil	Chia Tai, Thailand
6. Holy basil	Chia Tai, Thailand
7. Chinese kale	Chia Tai, Thailand
8. Cabbage	Chia Tai, Thailand
9. Tomato	Chia Tai, Thailand
10. Bird pepper	Chia Tai, Thailand

3.4 Experimental procedure

This experimental procedure was divided into four steps; the first step was media preparation where both the control and the media treated with lead were prepared. The second steps were surface sterilization of vegetable seeds. The third steps were plant culture. The fourth steps were data collection and analysis.

3.4.1 Preparation of media

The culture medium was modified from White (1963) and was designed for lead experiment. The solutions of modified White's medium were prepared from stocks ranging from 200-600 times the final concentrations. A series of solutions was prepared as Appendix A.

The media were prepared

Place a volume of deionized water, equal to approximately half the total volume of media to be prepared, in a beaker. Stock solutions numbers 1-6 were added into the beaker and the volume was adjusted to the final desired amount with deionized water.

Table 4: Preparation of media with lead

Media concentration (ppm)	Nutrient solution (ml)	Lead standard solution (ml)	Final volume (ml)
0	1000	0	1000
5	995	5	1000
15	985	15	1000
30	970	30	1000

The media with lead were prepared:

Media with lead were prepared in 0 ppm (control), 5 ppm, 15 ppm and 30 ppm of lead standard solution –Pb $(NO_3)_2$ in HNO_3 0.5 mol/l, 1000mg/l. The media with lead were prepared as in Table 4. The pH was adjusted to 5.5-5.7 with HCl, NaOH and 0.5 M EDTA, as known, nitrates are soluble in water. However, adding Pb $(NO_3)_2$ into the stock solutions will cause precipitation. This is due to the reactions between Na_2SO_4, KCl, and KI. The results of white precipitates were not desirable for agar solution. 0.5 M of EDTA, a chelating agent was applied to completely dissolve Pb $(NO_3)_2$ in the stock solution. One ml of 0.5 M EDTA was used in four treatments. The amount of EDTA used was determined by dissolving the highest concentration (30 ppm) of Pb $(NO_3)_2$ in the stock solution and was applied to other treatments, 0 ppm (control), 5 ppm and 15 ppm. 8 g of agar was added in each concentration. Placing into the oven until the agar is dissolved. 20 g of sucrose was added into the media and let dissolved by stirring. Melted media were poured into the bottles and bottles were covered. Culture media were autoclaved sterilization for 15 min at 121°C. After sterilization the media were kept in the tissue culture room.

3.4.2 Surface sterilization of vegetable seeds

200 seeds of each vegetable were counted and put into 250 ml of Erlenmeyer flask. The surface sterilization of vegetable seeds was performed as following sequence: 8% bleach and 0.5 % detergents, shaken at 150 rpm. for 10 min, washed with sterilized water for 10 min, shaken at 150 rpm. for 10 min, repeated washing again.

3.4.3 Plant culture

Four treatments at concentrations of 0 ppm (control), 5 ppm, 15 ppm and 30 ppm of lead, supplied in the form of Pb $(NO_3)_2$ were set up. 32 bottles were used for each plant species and 8 bottles were used for each treatment. After the seeds were sterilized, seeds were planted into the media with each medium containing 5 seeds as replication. The plants were cultured under 12-12 lights & dark at 25°C.

3.4.4 Data collection and analysis

Each replicate was assigned to a specific treatment. When assigning replicates to treatments, it was important to make assignments in a manner such that all have an equal chance of receiving a given treatment. This is called randomization. The data were collected weekly by each bottle of each treatment was randomized collecting.

The seedlings were harvested and the germination rate, length were recorded. The germination rate was determined in percentages; seeds were scored as germinated when the breakage of seed coat was visible. Dry weight was measured after drying at 60°C for 2 days.

The data were analyzed to determine the effects of the treatments, and least significant difference (LSD) tests were performed to determine the statistical significance of differences between means of treatments.

A completely randomized design (CRD) was used to analyze the results. A majority of plant cell and tissues culture studied employ a CRD because cell cultures are generally grown in environmental chambers that accurately control light, temperature and humidity. In the CRD, treatments are assigned to experimental units at random. The numbers of treatments and replicates per treatment that can be tested are not limited by CRD.

Chapter 4

Results and Discussion

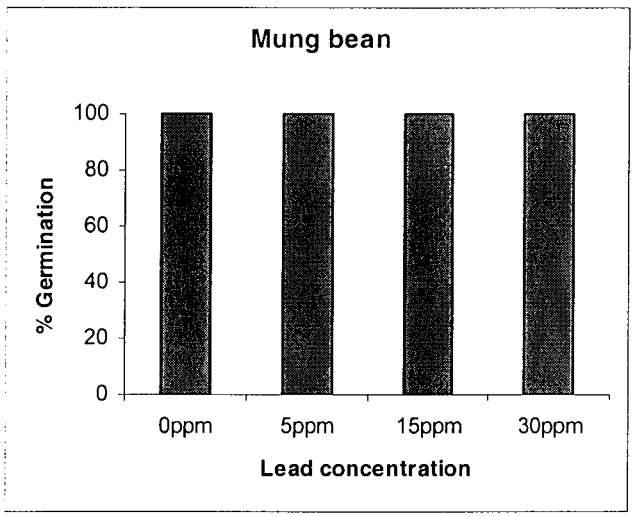
4.1 Percentage of seed germination

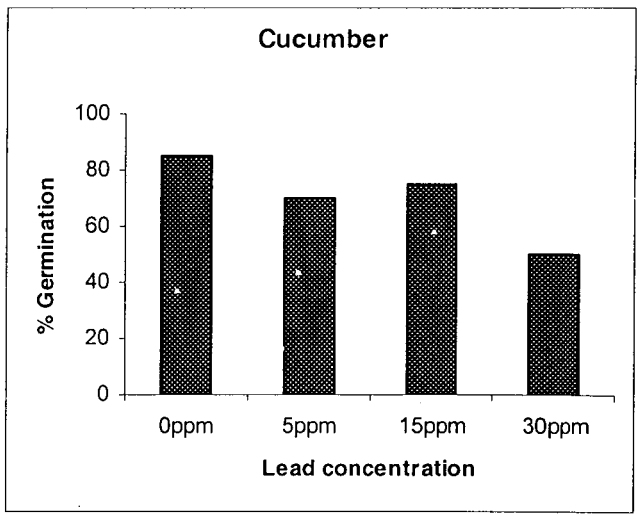
In this study required observation of germination in each bottle. The number of germination seeds was counted in four week cultures. Seeds were considered to germinate when the breakage of seed coat was visible. Figure 4, the different lead concentrations (0 ppm, 5 ppm, 15 ppm and 30 ppm) did not affect seed on germination in the ten species of common vegetables.

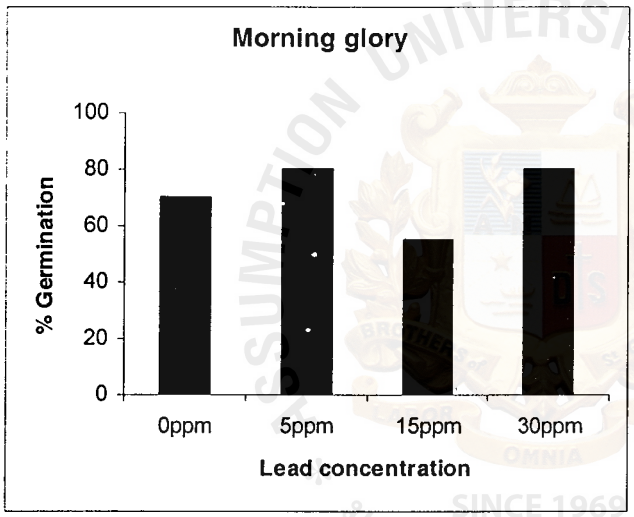
Mung bean (100%) was germination at 0 ppm to 30 ppm of lead concentrations. It showed that lead did not affect mung bean on germination. Cucumber, morning glory, sweet basil, lettuce, kale, tomato, cabbage, holy basil, and bird pepper were germination less than 100 percentages. However, there were no significant difference in percent germination (P>0.05), see Appendix B.

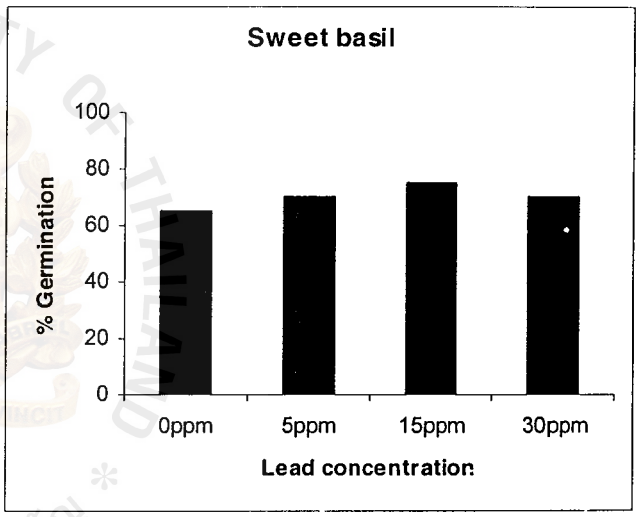
All the ten species of common vegetables have seed coat. Presence of the seed coats plays a role in the selective penetration of different lead concentration into the seeds. In this study, only very low amounts of lead may be able to penetrate through even with a high lead concentration. Hence, no significant effect was observed in the seed germination.

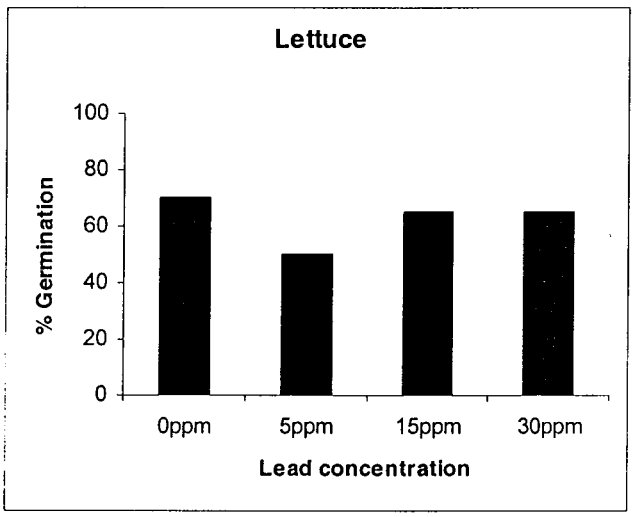
Mung bean, cucumber, morning glory, sweet basil, lettuce, kale, tomato, cabbage, holy basil, and bird pepper had not seriously affected on seed germination by the different concentrations of lead. This was supported by the fact that seeds are still able to germinate in the presence of high concentrations of lead.

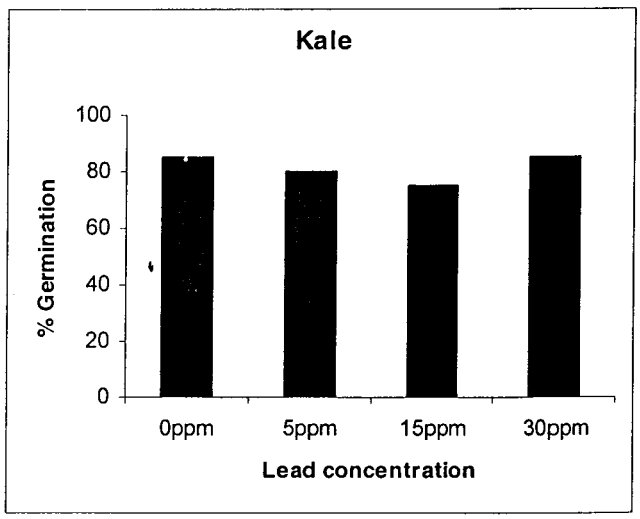

Mung bean
% Germination
100
80
60
40
20
0
0ppm
5ppm
15ppm
30ppm
Lead concentration


Cucumber
% Germination
100
80
60
40
20
0
0ppm
5ppm
15ppm
30ppm
Lead concentration


Morning glory
% Germination
100
80
60
40
20
0
0ppm
5ppm
15ppm
30ppm
Lead concentration


Sweet basil
% Germination
100
80
60
40
20
0
0ppm
5ppm
15ppm
30ppm
Lead concentration


Lettuce
% Germination
100
80
60
40
20
0
0ppm
5ppm
15ppm
30ppm
Lead concentration


Kale
% Germination
100
80
60
40
20
0
0ppm
5ppm
15ppm
30ppm
Lead concentration

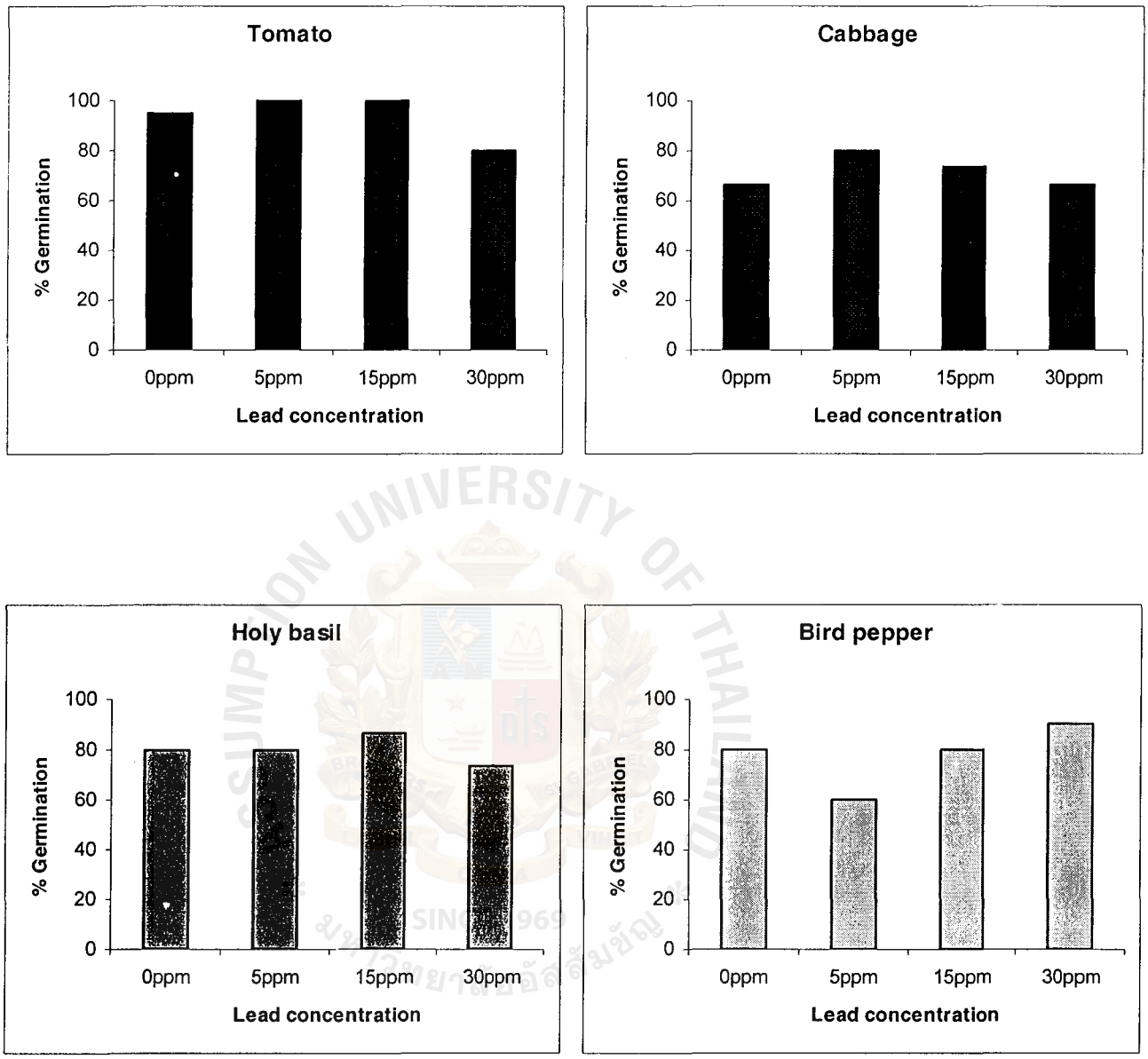


Figure 4: Percentage of seed germination in four week cultures. Mung bean had 100% germination. Cucumber, morning glory, sweet basil, lettuce, kale, tomato, cabbage, holy basil, and bird pepper were germination less than 100 percentages. However, there had no significant difference in percent germination (P>0.05).

4.2 Length measurement from root to shoot

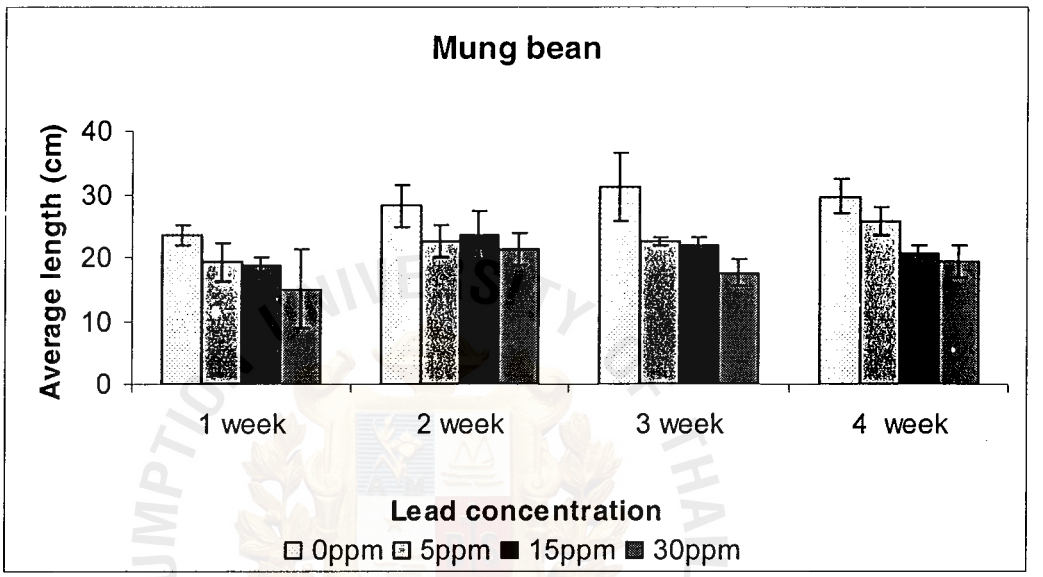
Seedlings were grown in different concentrations of lead under same conditions. Seedlings were harvested weekly. Length of seedling was measured from root to shoot (Appendix D).

Average length of mung bean (Figure 5) had significant difference ($P<0.05$) after one week exposure to lead any concentration. Differences in the average length were observed when the seedlings were exposed for a longer period. Mung bean showed high sensitivity to lead concentrations in the media. Growth retardation was observed from as early as one week after exposure to lead concentrations. Average length of tomato (figure 6) had no significant difference ($P>0.05$) after one week exposure to lead any concentration, but it showed significant difference ($P<0.05$) after two week exposure to lead. Differences in the average length were observed. Growth retardation of tomato was observed after exposure to lead of two week onward.

Average length of holy basil (Figure 7) had no significant difference ($P>0.05$) after two week exposure to lead any concentration, but it showed significant difference ($P<0.05$) after three week exposure to lead. Differences in the average length were observed. Holy basil seemed to be less sensitivity to lead concentrations than mung bean and tomato, growth retardation was observed after exposure to lead of three week onward.

Average length of bird pepper (Figure 8) had no significant difference ($P>0.05$) after three week exposure to lead any concentration. However, it showed significant difference ($P<0.05$) after four week exposure to lead. Differences in the average length were observed. Bird pepper seemed to be very less sensitivity to lead concentrations than mung bean, tomato and holy basil. Growth retardation of bird pepper was observed after exposure to lead of four week.

Figure 9, average length of morning glory, cucumber, lettuce, sweet basil, kale, and cabbage showed no significant difference ($P>0.05$) after one to four week exposure to lead any concentration. Growth retardation of six species can not be observed, all six species did not seem to be affected by lead concentrations during the four week exposure.



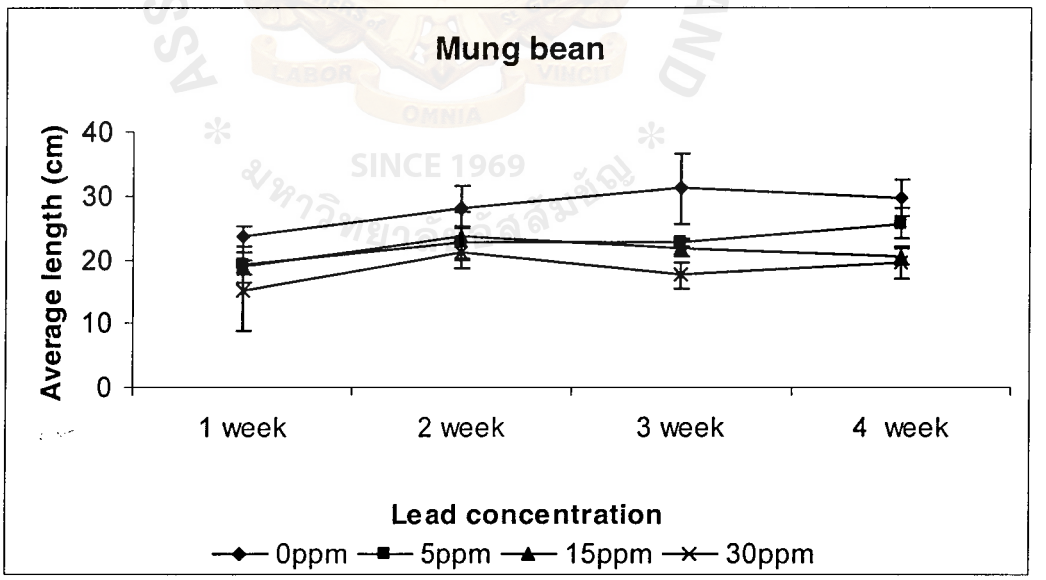
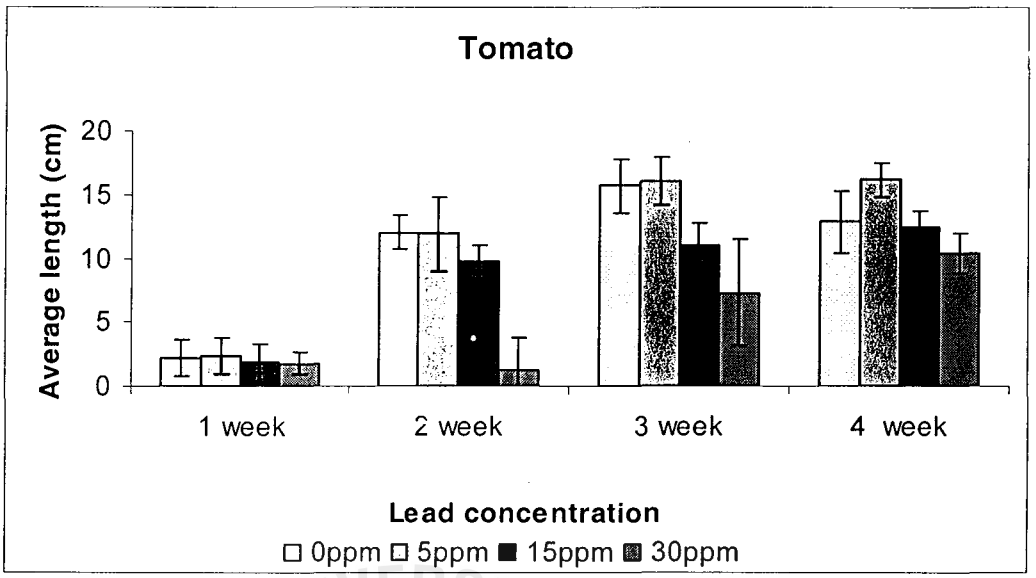


Figure 5: Column and line chart types for average length of mung bean had a significant difference ($P<0.05$) after one week exposure to lead onward. Values represent the mean ±SD of five replicate samples.



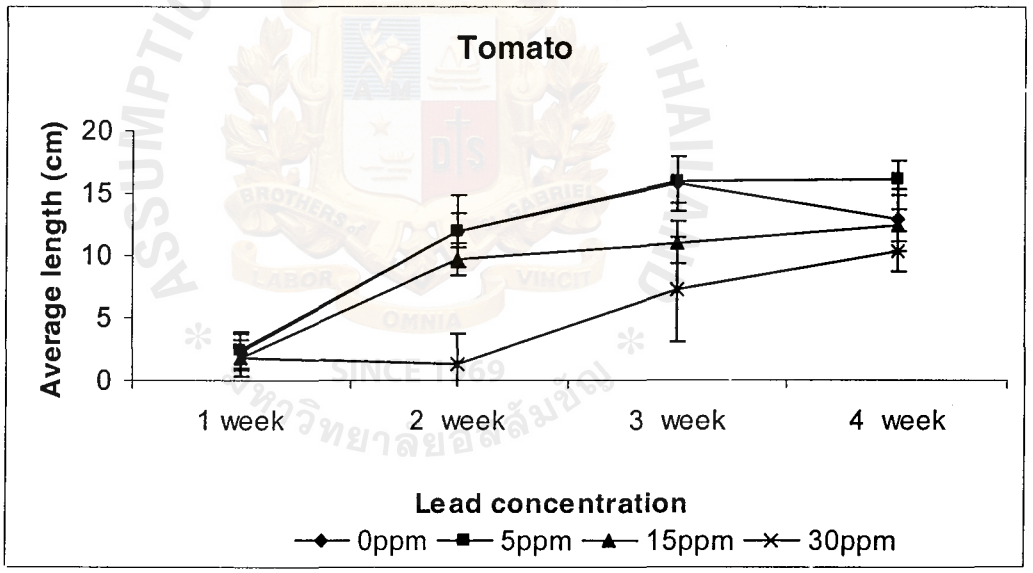
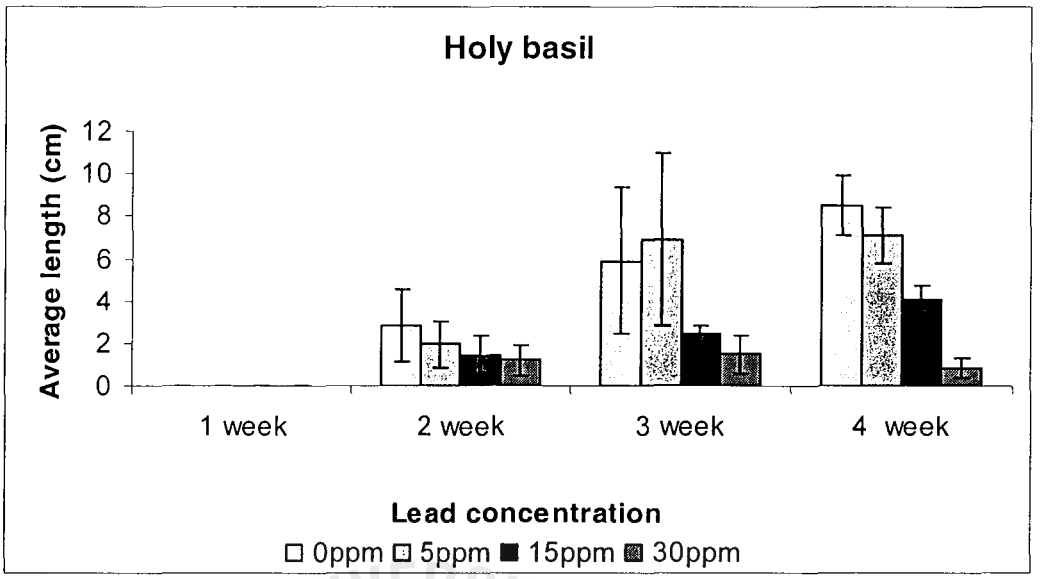


Figure 6: Column and line chart types for average length of tomato showed no significant difference ($P>0.05$) after one week exposure to lead. However, average length showed significant difference ($P<0.05$) after exposure to lead of two week onward. Values represent the mean ±SD of five replicate samples.



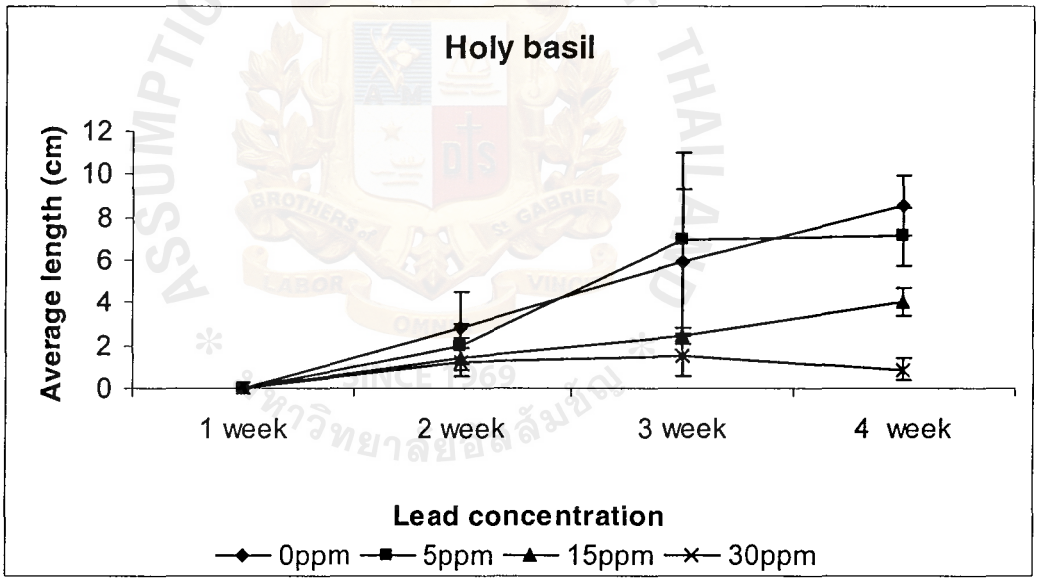
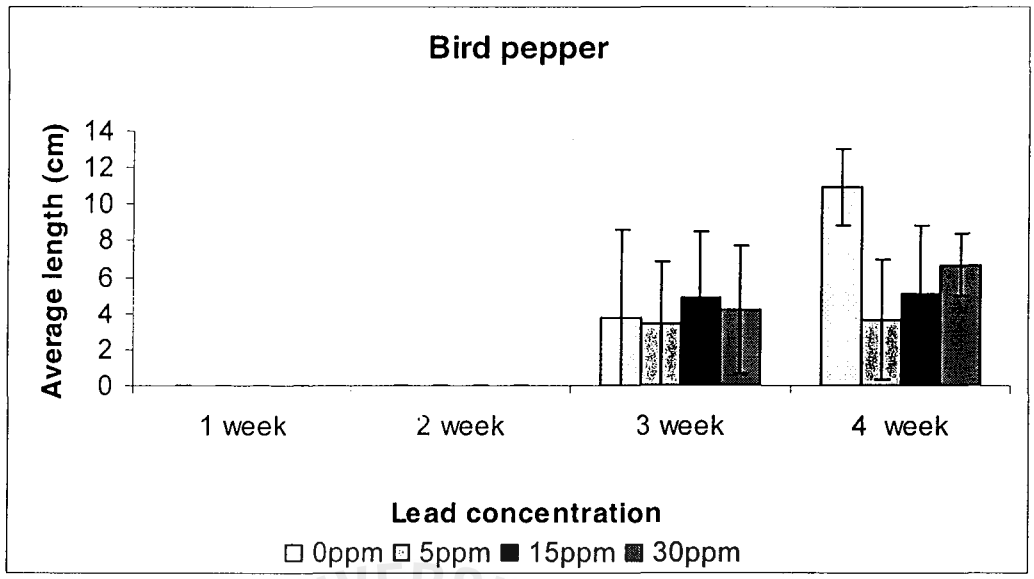


Figure 7: Column and line chart types for average length of holy basil showed no significant difference ($P>0.05$) after one week exposure to lead. However, there was a significant difference ($P<0.05$) after exposure to lead of three week onward. Values represent the mean ±SD of five replicate samples.



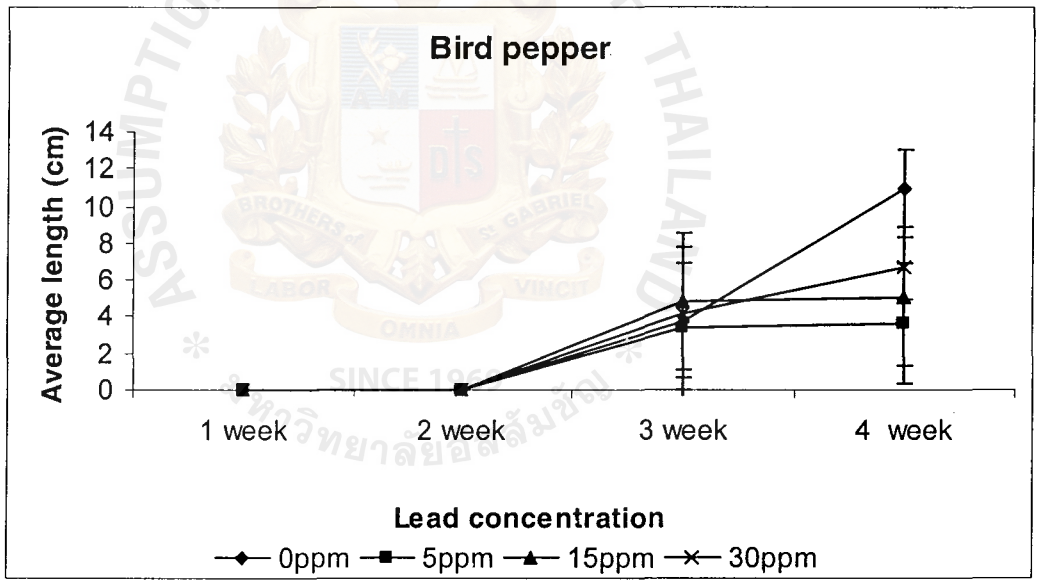
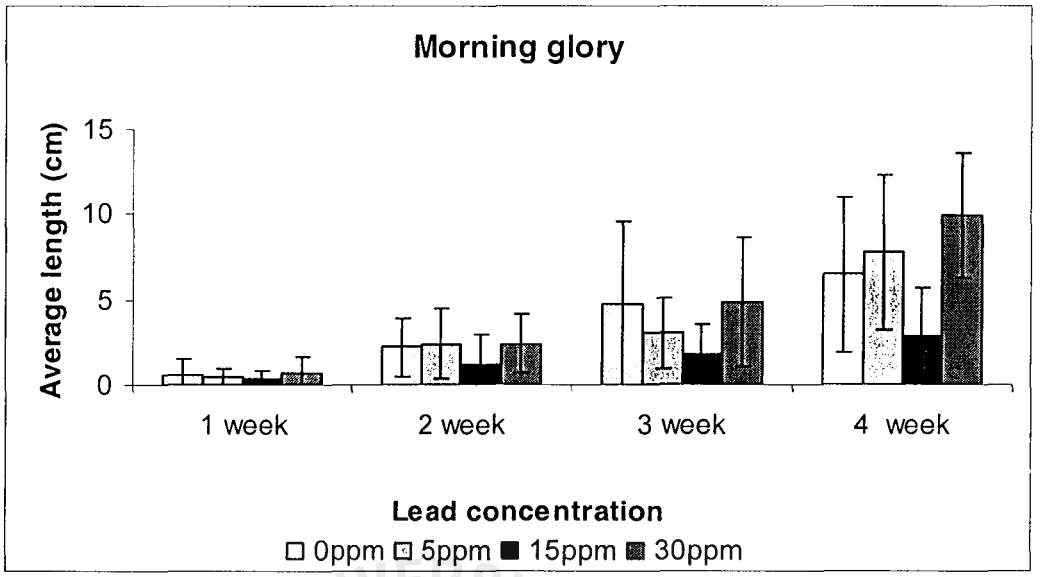


Figure 8: Column and line chart types for average length of bird pepper showed no significant difference ($P>0.05$) after three week exposure to lead. However, there was a significant difference ($P<0.05$) after four week exposure to lead. Values represent the mean ±SD of five replicate samples.



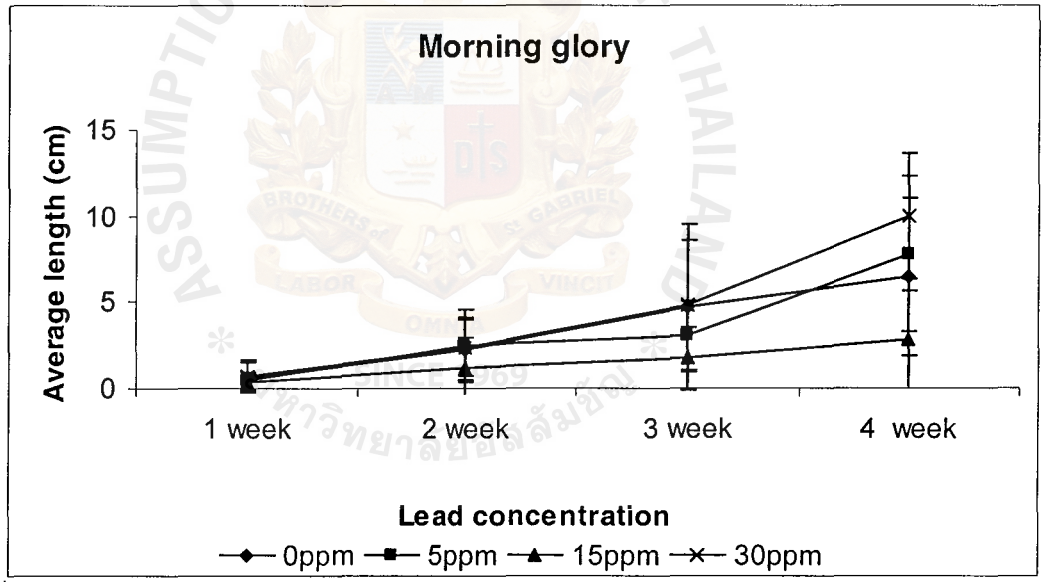
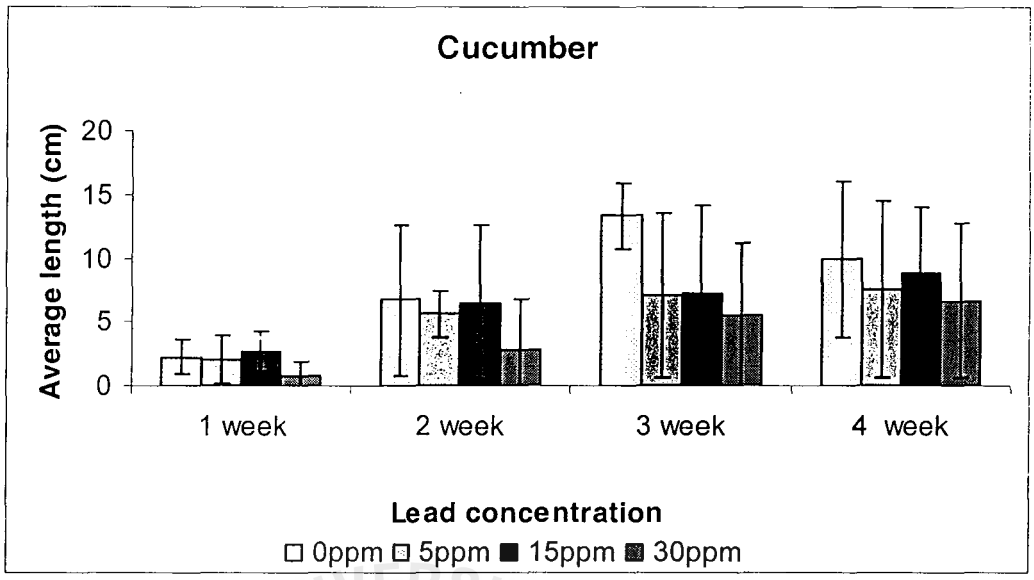


Figure 9: Column and line chart types for average length of morning glory showed no significant difference (P>0.05) after four week exposure to lead any concentration. Values represent the mean ±SD of five replicate samples.



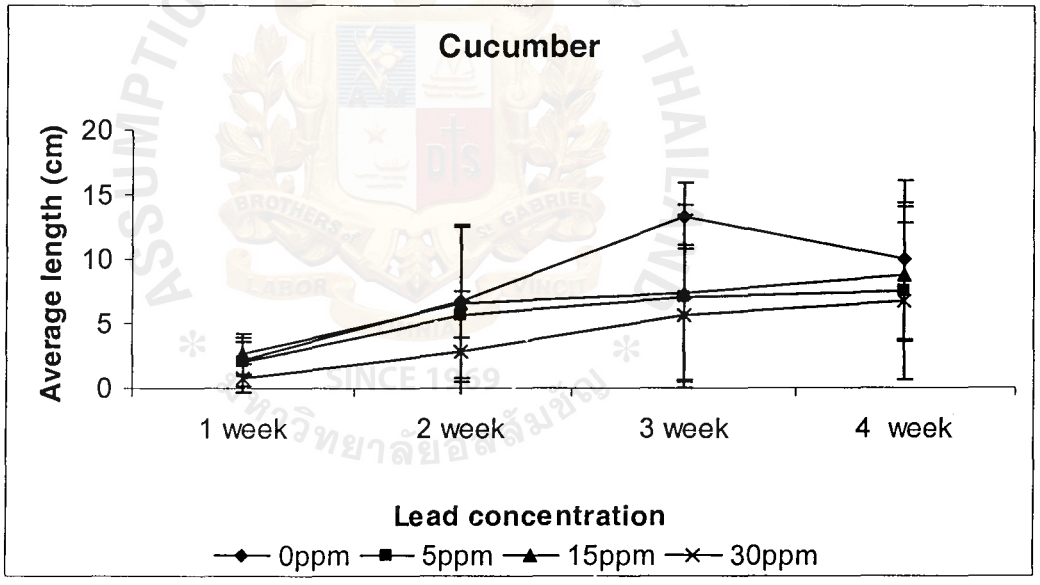
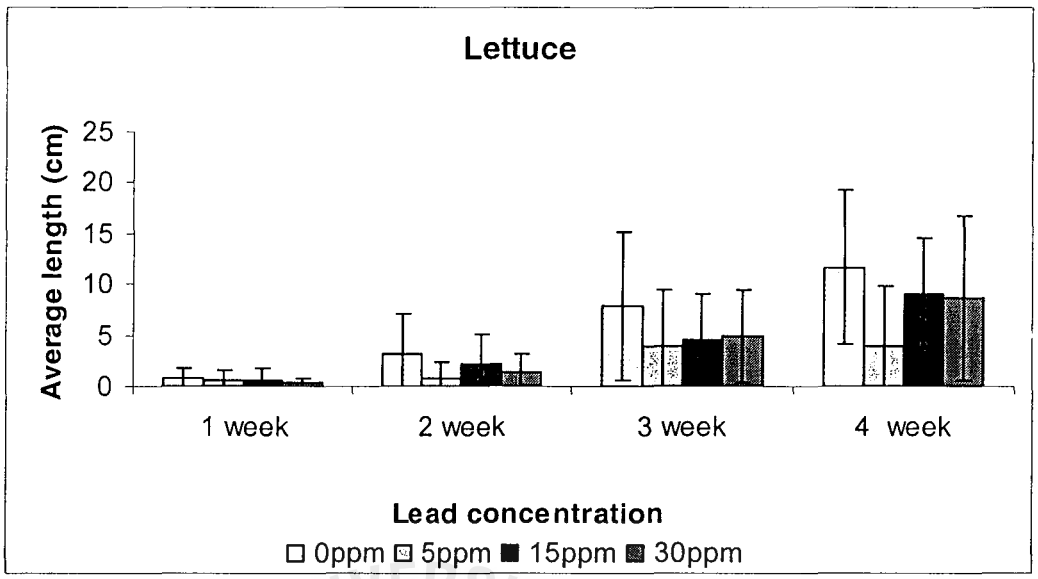


Figure 10: Column and line chart types for average length of cucumber showed no significant difference (P>0.05) after four week exposure to lead any concentration. Values represent the mean ±SD of five replicate samples.



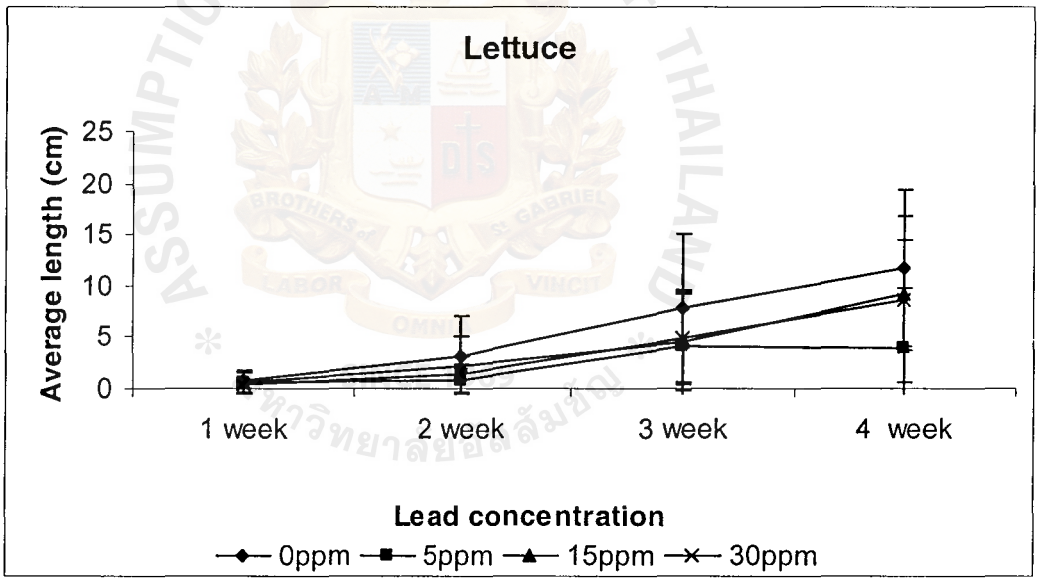
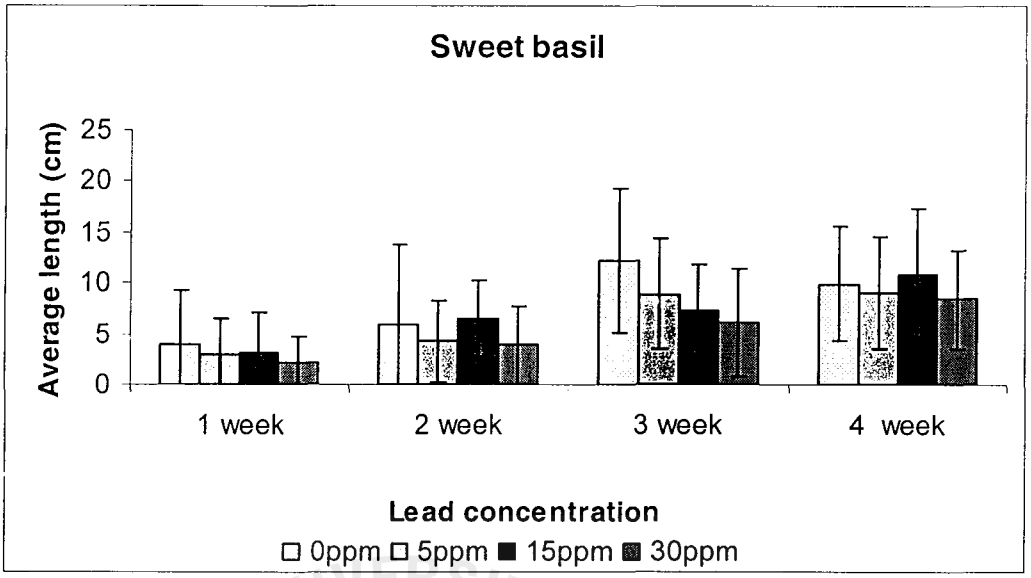


Figure 11: Column and line chart types for average length of lettuce showed no significant difference (P>0.05) after four week exposure to lead any concentration. Values represent the mean ±SD of five replicate samples.



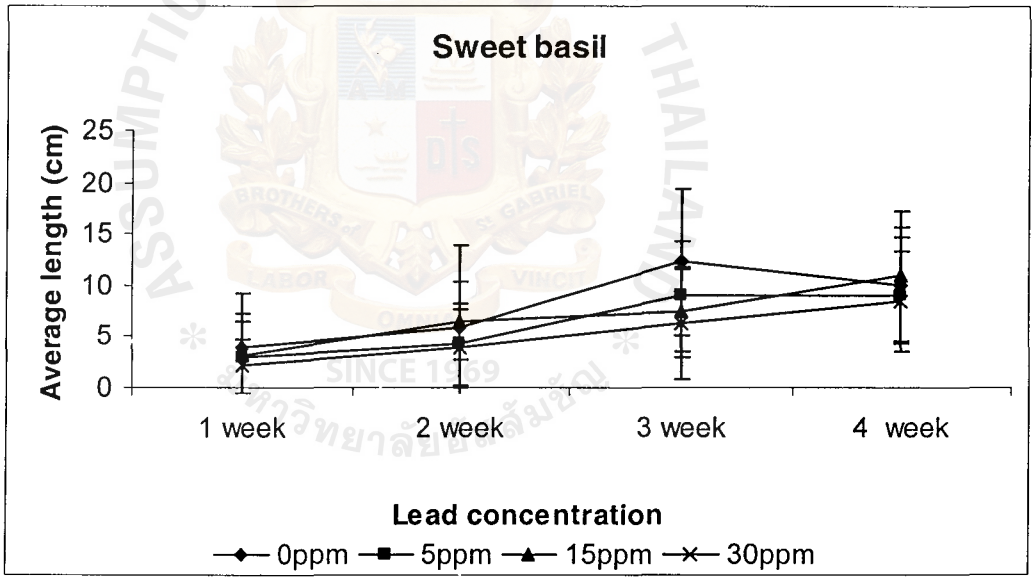
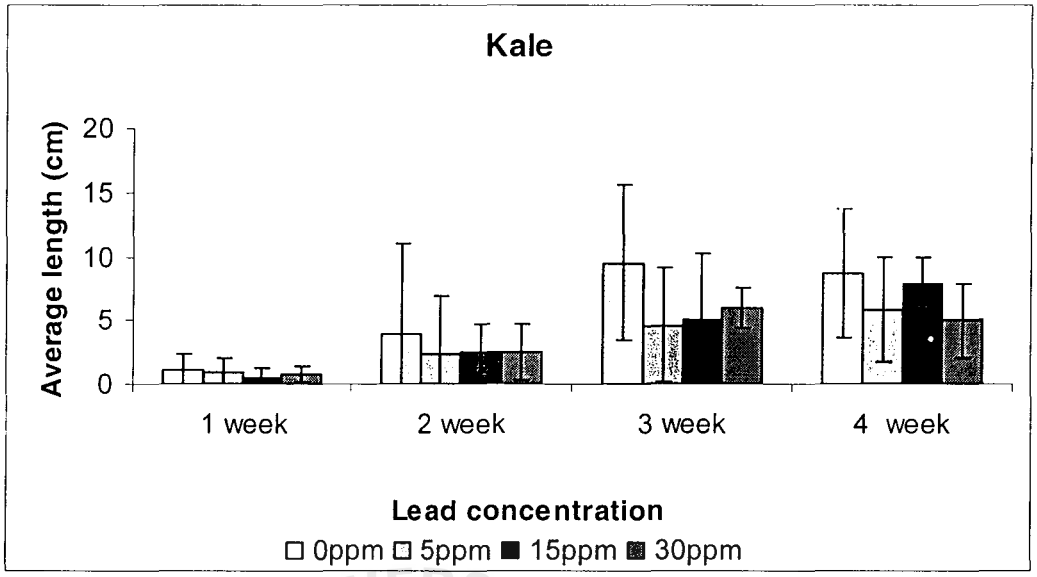


Figure 12: Column and line chart types for average length of sweet basil showed no significant difference (P>0.05) after four week exposure to lead any concentration. Values represent the mean ±SD of five replicate samples.



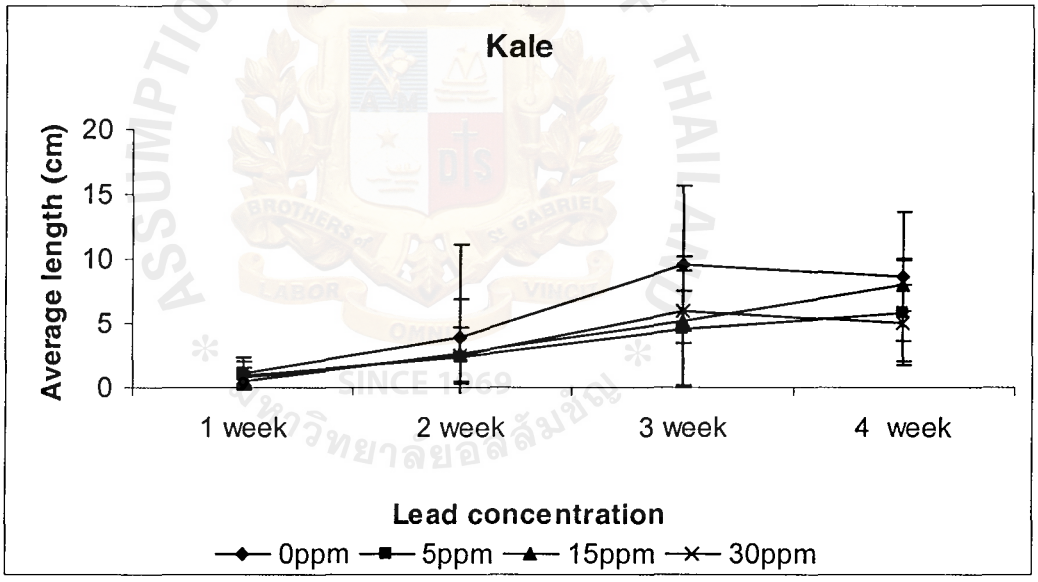
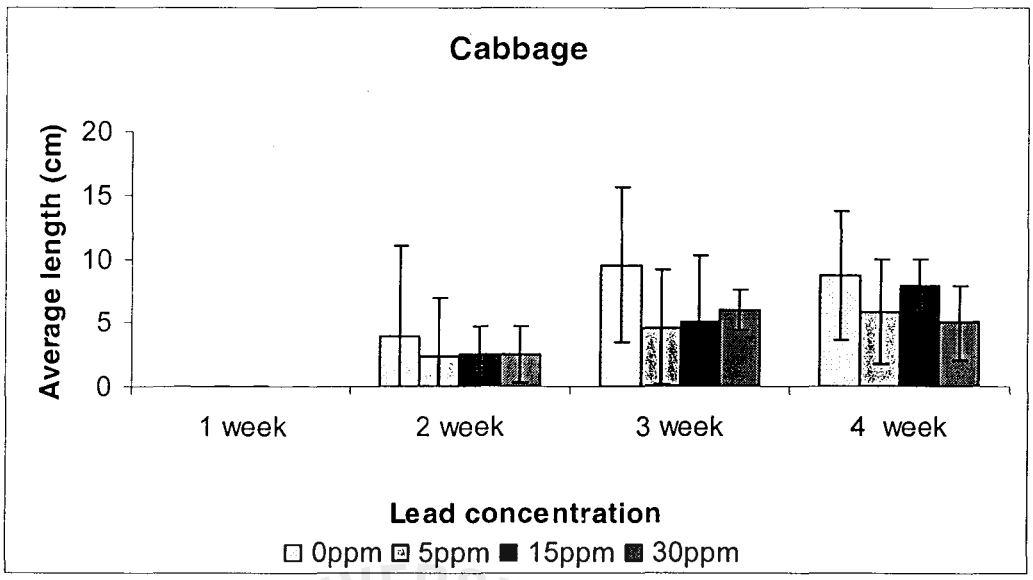


Figure 13: Column and line chart types for average length of kale showed no significant difference (P>0.05) after four week exposure to lead any concentration. Values represent the mean ±SD of five replicate samples.



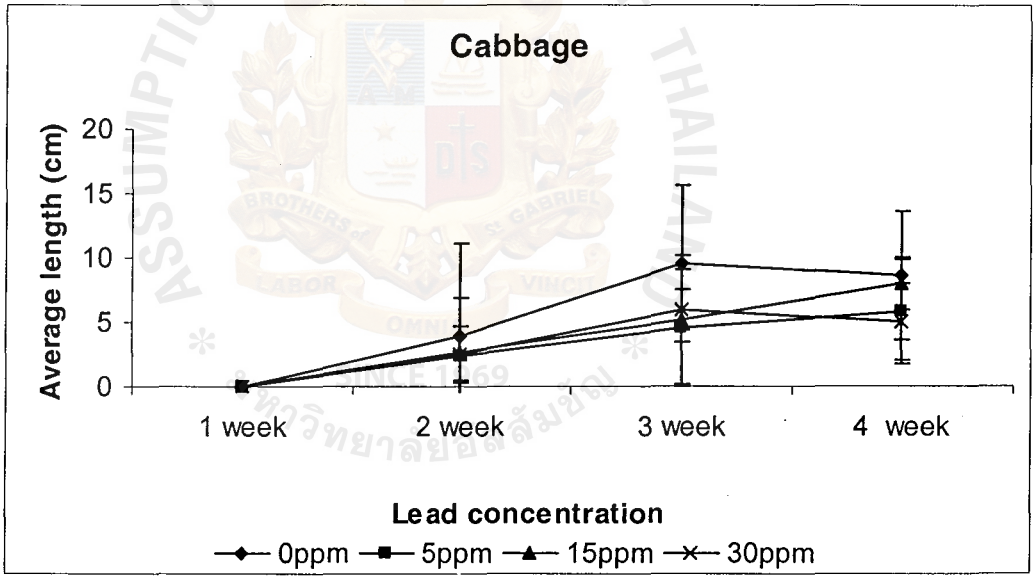


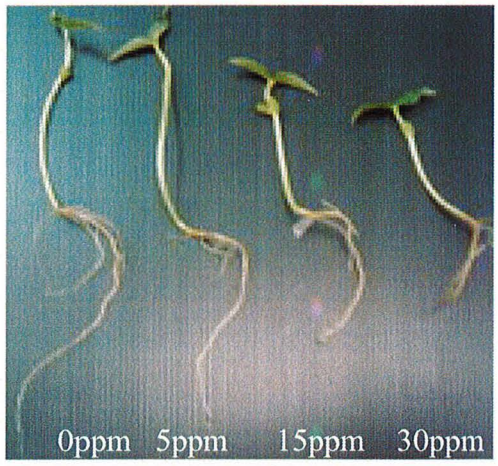
Figure 14: Column and line chart types for average length of cabbage showed no significant difference (P>0.05) after four week exposure to lead any concentration. Values represent the mean ±SD of five replicate samples.

4.3 Plant physiological changes

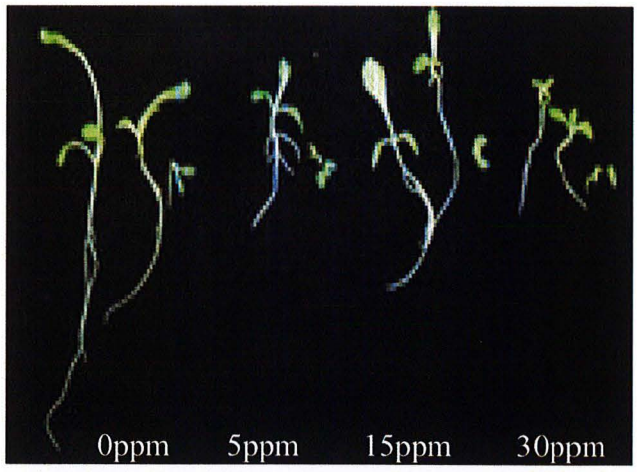
The seedling still grew in the presence of high concentrations of lead. However, the subsequent seedlings growth (after the breakage of seed coat) was severely inhibited at much lower concentrations of lead. Mung bean, cucumber, morning glory, sweet basil, lettuce, kale, tomato, cabbage, holy basil, and bird pepper are dicotyledonous plants. In many dicots the primary roots continues to elongate and forms the taproot. Many smaller branch roots may grow from the taproot (Martin and Rene, 2006). The effect of lead on root growth was observed. Figure 15 shows a decrease in the growth of vegetables during taproot elongation, with increasing lead concentration (from 5 ppm to 30 ppm). The taproot growth was decreased after exposure to lead at 5 ppm, 15 ppm and 30 ppm of lead concentrations as compared to the control.

EDTA was added to completely dissolve the lead nitrate solution. EDTA also caused easier and higher rate of translocation of lead to the shoot as compared to other parts of the plants as research done by Andrew D. Vassil and Co. in Indian mustard. EDTA destroys the physiological barrier(s) in roots by removal of stabilizing Zn^{2+} and Ca^{2+} from the plasma membrane. The primary effect of lead toxicity in plants is a rapid inhibition of root growth, probably due to the inhibition of cell division in the root tip (Lee Y, 2000). So in this study Pb and EDTA may play an importance role in decreasing a taproots elongation.

This result indicated that lead had negatively effects on root elongation of mung bean, cucumber, morning glory, sweet basil, lettuce, kale, tomato, cabbage, holy basil, and bird pepper. The vegetables were not tolerant to lead toxicity even at low (5 ppm) concentrations.

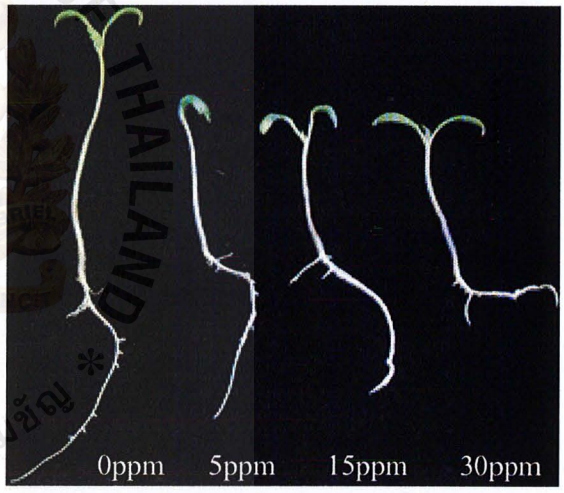


A-Mung bean (1 week)



B-Lettuce (2 week)

C-Kale (2 week)



D-Tomato (2 week)

E-Holy basil (2 week)

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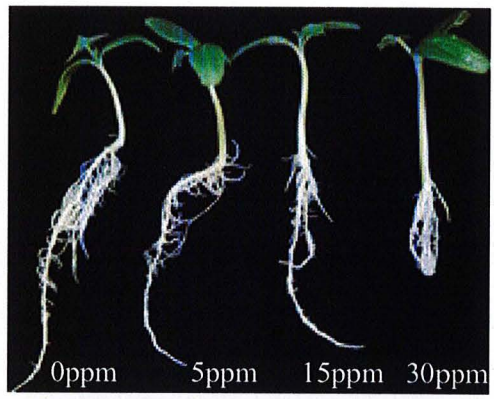
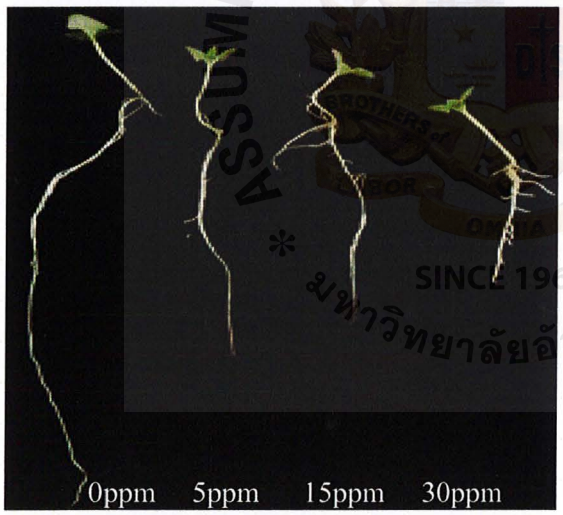
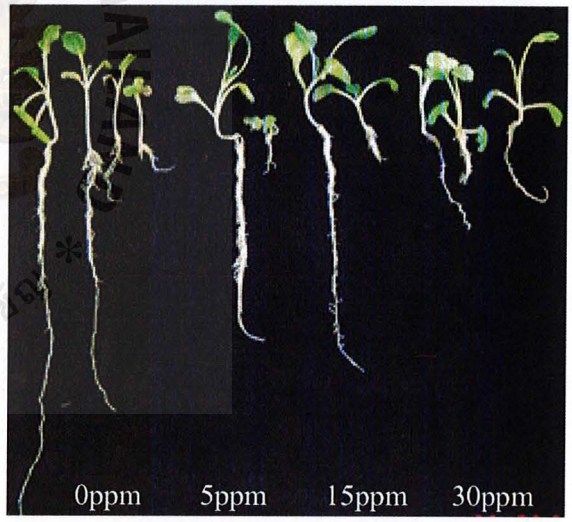
F- Morning glory (3 week)



G-Cucumber (3 week)



H- Sweet basil (3 week)



I-Cabbage (4 week)

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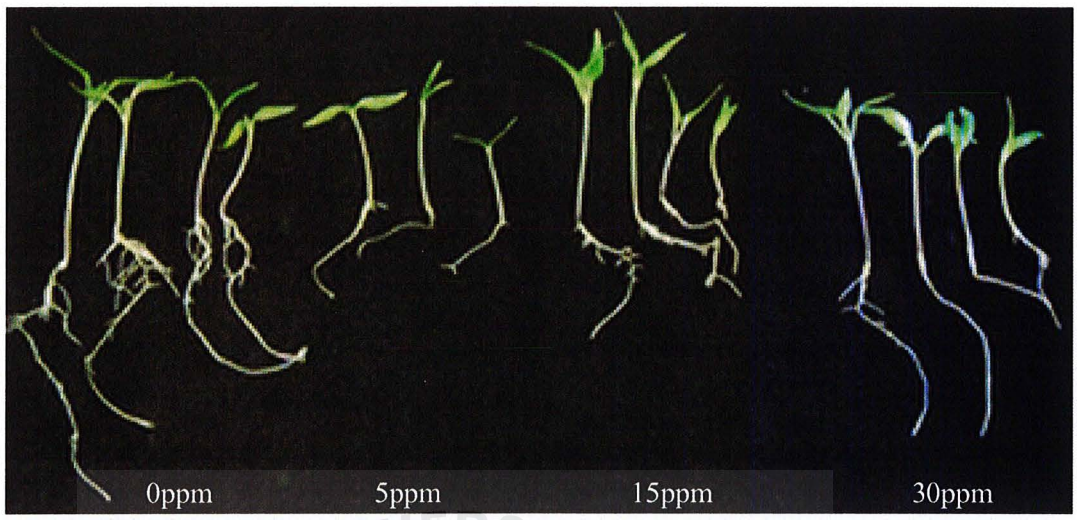

J-Bird pepper (4 week)

Figure 15: Physiological changes of the primary roots in seedlings after exposure to lead. Mung bean (A) was harvested after one week exposure to lead. Lettuce (B), kale (C), tomato (D), and holy basil (E) were harvested after two week exposure to lead. Morning glory (F), cucumber (G), and sweet basil (H) were harvested after three week exposure to lead. Cabbage (I) and bird pepper (J) were harvested after four week exposure to lead.

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Chapter 5

Conclusions and Recommendations

5.1 Conclusions

5.1.1 This study had determined the effect of lead on seed germination and seedling growth in common vegetables in Thailand. Based on the results, it can be concluded that the seed germination of the common vegetables in this experiment was not seriously affected ($P>0.05$) by concentrations of lead at 5 ppm, 15 ppm and 30 ppm.

5.1.2 Mung bean, cucumber, morning glory, sweet basil, lettuce, kale, tomato, cabbage, holy basil, and bird pepper have different response to lead concentrations.

Mung bean showed high sensitivity to lead concentrations in the media. Growth retardation was observed from as early as one week after exposure to lead. In tomato, growth retardation was observed after exposure to lead of two week onward. Holy basil seemed to be less sensitivity to lead concentration than mung bean and tomato, growth retardation was observed after exposure to lead of three week onward. Bird pepper seemed to be very less sensitivity to lead concentration than mung bean, tomato and holy basil. Growth retardation of bird pepper was observed after four week exposure to lead.

Morning glory, cucumber, lettuce, sweet basil, kale, and cabbage did not seem to be affected by lead concentrations during the four week exposure, growth retardation of six species can not be observed.

5.1.3 Development of root system seemed to be negatively affected by the presence of lead, even as low as 5 ppm, in all plant species in this study. Even though, average growth, measured by the length from shoots to root, did not show any effects, formation of lateral roots was impaired in all treatments.

5.1.4 Holy basil and sweet basil is the same genus but it cannot be generalized to have similar response to lead concentrations.

5.2 Recommendations

5.2.1 The potential for EDTA accumulation should be considered when are used to study metal uptake and nutritional requirements in plants. EDTA can be increased the mobility and uptake of metal contamination and destroys the physiological barrier(s) in roots that normally function to control uptake and translocation of solutes.

5.2.2 Level of lead accumulation should be determined to define the plant species suitable for growing in lead contaminated area.

5.2.3 In field conditions, average length should measure both the root and the shoot separately because lead might affect the shoot, the root, or both.

5.2.4 Longer exposure period maybe required to study effects of lead to shoots development.

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Appendix A

Media formulation

The compositions of White (1963) used in tissue culture medium to study effects of lead on germination and development of common vegetables.

Table A-1: Compositions of nutrient solution in the media (Modified White 1963)

Stock No.	Compounds	Amount (g/50ml)	Stock	Used (ml/l)
1	KNO_3	0.8	200x	5
	$Ca(NO_3)_2$	2		
2	$MgSO_4.7H_2O$	7.2	200x	5
3	$MnSO_4.4H_2O$	0.053	200x	5
	$ZnSO_4.7H_2O$	0.030		
	$Fe(SO_4)_3$	0.035		
	Na_2SO_4	2		
4	KCl	1.3	400x	2.5
	KI	0.015		
	H_3BO_3	0.030		
5	$NaH_2.PO_4.H_2O$	0.186	200x	5
6	Glycine	0.009	600x	1.66
	Nicotinic acid	0.015		
	Vitamin B_1	0.003		
	Vitamin B_6	0.030		

Appendix B

Percentage of seed germination

Table B-1: Percentage of seed germinations in four week cultures

Species	Lead concentration			
	0ppm	5ppm	15ppm	30ppm
Mung bean	100	100	100	100
Cucumber	85	70	75	50
Morning glory	70	80	55	80
Sweet basil	65	70	75	70
Lettuce	70	50	65	65
Kale	85	80	75	85
Tomato	95	100	100	80
Cabbage	66.67	80	73.33	66.67
Holy basil	80	80	86.67	73.33
Bird pepper	80	60	80	90

Table B-2: Statistic analysis of percent mung bean germination in four week cultures

Between-Subjects Factors

		Value Label	N
Pb Con.	1	0ppm	4
	2	5ppm	4
	3	15ppm	4
	4	30ppm	4

Tests of Between-Subjects Effects

Dependent Variable: %Germination

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.000[a]	3	.000	.	.
Intercept	400.000	1	400.000	.	.
TRT	.000	3	.000	.	.
Error	.000	12	.000		
Total	400.000	16			
Corrected Total	.000	15			

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

Post Hoc Tests

Pb Con.

Multiple Comparisons

Dependent Variable: %Germination

	(I) Pb Con.	(J) Pb Con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	.00	.00	1.000	.[a]	.
		15ppm	.00	.00	1.000	.[a]	.
		30ppm	.00	.00	1.000	.[a]	.
	5ppm	0ppm	.00	.00	1.000	.[a]	.
		15ppm	.00	.00	1.000	.[a]	.
		30ppm	.00	.00	1.000	.[a]	.
	15ppm	0ppm	.00	.00	1.000	.[a]	.
		5ppm	.00	.00	1.000	.[a]	.
		30ppm	.00	.00	1.000	.[a]	.
	30ppm	0ppm	.00	.00	1.000	.[a]	.
		5ppm	.00	.00	1.000	.[a]	.
		15ppm	.00	.00	1.000	.[a]	.

Based on observed means.

a. Range values cannot be computed.

Table B-3: Statistic analysis of percent cucumber germination in four week cultures

Between-Subjects Factors

		Value Label	N
Pb Con.	1	0ppm	4
	2	5ppm	4
	3	15ppm	4
	4	30ppm	4

Tests of Between-Subjects Effects

Dependent Variable: %Germination

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6.500[a]	3	2.167	3.467	.051
Intercept	196.000	1	196.000	313.600	.000
TRT	6.500	3	2.167	3.467	.051
Error	7.500	12	.625		
Total	210.000	16			
Corrected Total	14.000	15			

a. R Squared = .464 (Adjusted R Squared = .330)

Post Hoc Tests

Pb Con.

Multiple Comparisons

Dependent Variable: %Germination

	(I) Pb Con.	(J) Pb Con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	.75	.56	.205	-.47	1.97
		15ppm	.50	.56	.389	-.72	1.72
		30ppm	1.75*	.56	.009	.53	2.97
	5ppm	0ppm	-.75	.56	.205	-1.97	.47
		15ppm	-.25	.56	.663	-1.47	.97
		30ppm	1.00	.56	.099	-.22	2.22
	15ppm	0ppm	-.50	.56	.389	-1.72	.72
		5ppm	.25	.56	.663	-.97	1.47
		30ppm	1.25*	.56	.045	3.20E-02	2.47
	30ppm	0ppm	-1.75*	.56	.009	-2.97	-.53
		5ppm	-1.00	.56	.099	-2.22	.22
		15ppm	-1.25*	.56	.045	-2.47	-3.20E-02

Based on observed means.

*. The mean difference is significant at the .05 level.

Table B-4: Statistic analysis of percent morning glory germination in four week cultures

Between-Subjects Factors

		Value Label	N
Pb Con.	1	0ppm	4
	2	5ppm	4
	3	15ppm	4
	4	30ppm	4

Tests of Between-Subjects Effects

Dependent Variable: %Germination

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.188[a]	3	1.396	2.913	.078
Intercept	203.063	1	203.063	423.783	.000
TRT	4.188	3	1.396	2.913	.078
Error	5.750	12	.479		
Total	213.000	16			
Corrected Total	9.938	15			

a. R Squared = .421 (Adjusted R Squared = .277)

Post Hoc Tests

Pb Con.

Multiple Comparisons

Dependent Variable: %Germination

	(I) Pb Con.	(J) Pb Con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	-.50	.49	.327	-1.57	.57
		15ppm	.75	.49	.151	-.32	1.82
		30ppm	-.50	.49	.327	-1.57	.57
	5ppm	0ppm	.50	.49	.327	-.57	1.57
		15ppm	1.25*	.49	.025	.18	2.32
		30ppm	.00	.49	1.000	-1.07	1.07
	15ppm	0ppm	-.75	.49	.151	-1.82	.32
		5ppm	-1.25*	.49	.025	-2.32	-.18
		30ppm	-1.25*	.49	.025	-2.32	-.18
	30ppm	0ppm	.50	.49	.327	-.57	1.57
		5ppm	.00	.49	1.000	-1.07	1.07
		15ppm	1.25*	.49	.025	.18	2.32

Based on observed means.

*. The mean difference is significant at the .05 level.

Table B-5: Statistic analysis of percent sweet basil germination in four week cultures

Between-Subjects Factors

		Value Label	N
Pb Con.	1	0ppm	4
	2	5ppm	4
	3	15ppm	4
	4	30ppm	4

Tests of Between-Subjects Effects

Dependent Variable: %Germination

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.500[a]	3	.167	.364	.780
Intercept	196.000	1	196.000	427.636	.000
TRT	.500	3	.167	.364	.780
Error	5.500	12	.458		
Total	202.000	16			
Corrected Total	6.000	15			

a. R Squared = .083 (Adjusted R Squared = -.146)

Post Hoc Tests

Pb Con.

Multiple Comparisons

Dependent Variable: %Germination

	(I) Pb Con.	(J) Pb Con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	-.25	.48	.611	-1.29	.79
		15ppm	-.50	.48	.317	-1.54	.54
		30ppm	-.25	.48	.611	-1.29	.79
	5ppm	0ppm	.25	.48	.611	-.79	1.29
		15ppm	-.25	.48	.611	-1.29	.79
		30ppm	.00	.48	1.000	-1.04	1.04
	15ppm	0ppm	.50	.48	.317	-.54	1.54
		5ppm	.25	.48	.611	-.79	1.29
		30ppm	.25	.48	.611	-.79	1.29
	30ppm	0ppm	.25	.48	.611	-.79	1.29
		5ppm	.00	.48	1.000	-1.04	1.04
		15ppm	-.25	.48	.611	-1.29	.79

Based on observed means.

Table B-6: Statistic analysis of percent lettuce germination in four week cultures

Between-Subjects Factors

		Value Label	N
Pb Con.	1	0ppm	4
	2	5ppm	4
	3	15ppm	4
	4	30ppm	4

Tests of Between-Subjects Effects

Dependent Variable: %Germination

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.250[a]	3	.750	1.636	.233
Intercept	156.250	1	156.250	340.909	.000
TRT	2.250	3	.750	1.636	.233
Error	5.500	12	.458		
Total	164.000	16			
Corrected Total	7.750	15			

a. R Squared = .290 (Adjusted R Squared = .113)

Post Hoc Tests

Pb Con.

Multiple Comparisons

Dependent Variable: %Germination

	(I) Pb Con.	(J) Pb Con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	1.00	.48	.059	-4.30E-02	2.04
		15ppm	.25	.48	.611	-.79	1.29
		30ppm	.25	.48	.611	-.79	1.29
	5ppm	0ppm	-1.00	.48	.059	-2.04	4.30E-02
		15ppm	-.75	.48	.143	-1.79	.29
		30ppm	-.75	.48	.143	-1.79	.29
	15ppm	0ppm	-.25	.48	.611	-1.29	.79
		5ppm	.75	.48	.143	-.29	1.79
		30ppm	.00	.48	1.000	-1.04	1.04
	30ppm	0ppm	-.25	.48	.611	-1.29	.79
		5ppm	.75	.48	.143	-.29	1.79
		15ppm	.00	.48	1.000	-1.04	1.04

Based on observed means.

Table B-7: Statistic analysis of percent kale germination in four week cultures

Between-Subjects Factors

		Value Label	N
Pb Con.	1	0ppm	4
	2	5ppm	4
	3	15ppm	4
	4	30ppm	4

Tests of Between-Subjects Effects

Dependent Variable: %Germination

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.687[a]	3	.229	.440	.729
Intercept	264.063	1	264.063	507.000	.000
TRT	.688	3	.229	.440	.729
Error	6.250	12	.521		
Total	271.000	16			
Corrected Total	6.937	15			

a. R Squared = .099 (Adjusted R Squared = -.126)

Post Hoc Tests

Pb Con.

Multiple Comparisons

Dependent Variable: %Germination

	(I) Pb Con.	(J) Pb Con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	.25	.51	.633	-.86	1.36
		15ppm	.50	.51	.347	-.61	1.61
		30ppm	.00	.51	1.000	-1.11	1.11
	5ppm	0ppm	-.25	.51	.633	-1.36	.86
		15ppm	.25	.51	.633	-.86	1.36
		30ppm	-.25	.51	.633	-1.36	.86
	15ppm	0ppm	-.50	.51	.347	-1.61	.61
		5ppm	-.25	.51	.633	-1.36	.86
		30ppm	-.50	.51	.347	-1.61	.61
	30ppm	0ppm	.00	.51	1.000	-1.11	1.11
		5ppm	.25	.51	.633	-.86	1.36
		15ppm	.50	.51	.347	-.61	1.61

Based on observed means.

Table B-8: Statistic analysis of percent tomato germination in four week cultures

Between-Subjects Factors

		Value Label	N
Pb Con.	1	0ppm	4
	2	5ppm	4
	3	15ppm	4
	4	30ppm	4

Tests of Between-Subjects Effects

Dependent Variable: %Germination

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.250[a]	3	.750	1.200	.352
Intercept	342.250	1	342.250	547.600	.000
TRT	2.250	3	.750	1.200	.352
Error	7.500	12	.625		
Total	352.000	16			
Corrected Total	9.750	15			

a. R Squared = .231 (Adjusted R Squared = .038)

Post Hoc Tests

Pb Con.

Multiple Comparisons

Dependent Variable: %Germination

	(I) Pb Con.	(J) Pb Con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	-.25	.56	.663	-1.47	.97
		15ppm	.00	.56	1.000	-1.22	1.22
		30ppm	.75	.56	.205	-.47	1.97
	5ppm	0ppm	.25	.56	.663	-.97	1.47
		15ppm	.25	.56	.663	-.97	1.47
		30ppm	1.00	.56	.099	-.22	2.22
	15ppm	0ppm	.00	.56	1.000	-1.22	1.22
		5ppm	-.25	.56	.663	-1.47	.97
		30ppm	.75	.56	.205	-.47	1.97
	30ppm	0ppm	-.75	.56	.205	-1.97	.47
		5ppm	-1.00	.56	.099	-2.22	.22
		15ppm	-.75	.56	.205	-1.97	.47

Based on observed means.

Table B-9: Statistic analysis of percent cabbage germination in four week cultures

Between-Subjects Factors

		Value Label	N
Pb Con.	1	0ppm	3
	2	5ppm	3
	3	15ppm	3
	4	30ppm	3

Tests of Between-Subjects Effects

Dependent Variable: %Germination

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.917[a]	3	.306	.244	.863
Intercept	154.083	1	154.083	123.267	.000
TRT	.917	3	.306	.244	.863
Error	10.000	8	1.250		
Total	165.000	12			
Corrected Total	10.917	11			

a. R Squared = .084 (Adjusted R Squared = -.260)

Post Hoc Tests

Pb Con.

Multiple Comparisons

Dependent Variable: %Germination

	(I) Pb Con.	(J) Pb Con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	-.67	.91	.486	-2.77	1.44
		15ppm	-.33	.91	.724	-2.44	1.77
		30ppm	.00	.91	1.000	-2.11	2.11
	5ppm	0ppm	.67	.91	.486	-1.44	2.77
		15ppm	.33	.91	.724	-1.77	2.44
		30ppm	.67	.91	.486	-1.44	2.77
	15ppm	0ppm	.33	.91	.724	-1.77	2.44
		5ppm	-.33	.91	.724	-2.44	1.77
		30ppm	.33	.91	.724	-1.77	2.44
	30ppm	0ppm	.00	.91	1.000	-2.11	2.11
		5ppm	-.67	.91	.486	-2.77	1.44
		15ppm	-.33	.91	.724	-2.44	1.77

Based on observed means.

Table B-10: Statistic analysis of percent holy basil germination in four week cultures

Between-Subjects Factors

		Value Label	N
Pb Con.	1	0ppm	3
	2	5ppm	3
	3	15ppm	3
	4	30ppm	3

Tests of Between-Subjects Effects

Dependent Variable: %Germination

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.667[a]	3	.222	.242	.864
Intercept	192.000	1	192.000	209.455	.000
TRT	.667	3	.222	.242	.864
Error	7.333	8	.917		
Total	200.000	12			
Corrected Total	8.000	11			

a. R Squared = .083 (Adjusted R Squared = -.260)

Post Hoc Tests

Pb Con.

Multiple Comparisons

Dependent Variable: %Germination

	(I) Pb Con.	(J) Pb Con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	.00	.78	1.000	-1.80	1.80
		15ppm	-.33	.78	.681	-2.14	1.47
		30ppm	.33	.78	.681	-1.47	2.14
	5ppm	0ppm	.00	.78	1.000	-1.80	1.80
		15ppm	-.33	.78	.681	-2.14	1.47
		30ppm	.33	.78	.681	-1.47	2.14
	15ppm	0ppm	.33	.78	.681	-1.47	2.14
		5ppm	.33	.78	.681	-1.47	2.14
		30ppm	.67	.78	.419	-1.14	2.47
	30ppm	0ppm	-.33	.78	.681	-2.14	1.47
		5ppm	-.33	.78	.681	-2.14	1.47
		15ppm	-.67	.78	.419	-2.47	1.14

Based on observed means.

Table B-11: Statistic analysis of percent bird pepper germination in four week cultures

Between-Subjects Factors

		Value Label	N
Pb Con.	1	0ppm	2
	2	5ppm	2
	3	15ppm	2
	4	30ppm	2

Tests of Between-Subjects Effects

Dependent Variable: %Germination

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.375[a]	3	.792	1.267	.398
Intercept	120.125	1	120.125	192.200	.000
TRT	2.375	3	.792	1.267	.398
Error	2.500	4	.625		
Total	125.000	8			
Corrected Total	4.875	7			

a. R Squared = .487 (Adjusted R Squared = .103)

Post Hoc Tests

Pb Con.

Multiple Comparisons

Dependent Variable: %Germination

	(I) Pb Con.	(J) Pb Con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	1.00	.79	.275	-1.19	3.19
		15ppm	.00	.79	1.000	-2.19	2.19
		30ppm	-.50	.79	.561	-2.69	1.69
	5ppm	0ppm	-1.00	.79	.275	-3.19	1.19
		15ppm	-1.00	.79	.275	-3.19	1.19
		30ppm	-1.50	.79	.131	-3.69	.69
	15ppm	0ppm	.00	.79	1.000	-2.19	2.19
		5ppm	1.00	.79	.275	-1.19	3.19
		30ppm	-.50	.79	.561	-2.69	1.69
	30ppm	0ppm	.50	.79	.561	-1.69	2.69
		5ppm	1.50	.79	.131	-.69	3.69
		15ppm	.50	.79	.561	-1.69	2.69

Based on observed means.

Appendix C

Data of dry weight

Table C-1: Dry weight (mg) of mung bean from 1 to 4 week cultures

Week	Lead concentration (N)*			
	0ppm	5ppm	15ppm	30ppm
1	55.08 (5)	49.72 (5)	49.60 (5)	51.00 (5)
2	60.56 (5)	39.70 (5)	46.94 (5)	50.40 (5)
3	57.98 (5)	65.38 (5)	62.46 (5)	34.78 (5)
4	54.40 (5)	58.70 (5)	57.90 (5)	61.40 (5)

* The number of samples per collection.

Table C-2: Dry weight (mg) of cucumber from 1 to 4 week cultures

Week	Lead concentration (N)*			
	0ppm	5ppm	15ppm	30ppm
1	28.93(4)	29.80 (3)	27.38 (5)	21.00 (2)
2	27.53 (4)	28.42 (5)	23.40 (3)	21.10 (2)
3	34.78 (5)	29.33 (3)	32.03 (3)	34.10 (3)
4	38.93 (4)	33.10 (4)	34.83 (4)	37.40 (3)

* The number of samples per collection.

Table C-3: Dry weight (mg) of morning glory from 1 to 4 week cultures

Week	Lead concentration (N)*			
	0ppm	5ppm	15ppm	30ppm
1	38.40 (3)	47.23 (3)	46.50 (2)	40.87 (3)
2	17.68 (4)	17.58 (4)	35.53 (3)	27.43 (4)
3	30.30 (3)	27.20 (4)	20.70 (3)	23.95 (4)
4	28.00 (4)	25.00 (5)	22.43 (3)	32.36 (5)

* The number of samples per collection.

Table C-4: Dry weight (mg) of sweet basil from 1 to 4 week cultures

Week	Lead concentration (N)*			
	0ppm	5ppm	15ppm	30ppm
1	1.45 (2)	0.73 (3)	0.97 (3)	0.63 (3)
2	1.60 (3)	1.67 (3)	1.50 (4)	1.80 (3)
3	2.88 (4)	3.50 (4)	3.33 (4)	2.53 (4)
4	4.13 (4)	3.63 (4)	5.55 (4)	3.50 (4)

* The number of samples per collection.

Table C-5: Dry weight (mg) of lettuce from 1 to 4 week cultures

Week	Lead concentration (N)*			
	0ppm	5ppm	15ppm	30ppm
1	0.75 (4)	0.83 (3)	1.10 (2)	1.37 (3)
2	1.53 (3)	1.47 (3)	1.38 (4)	1.15 (4)
3	5.27 (3)	4.15 (2)	4.70 (3)	4.17 (3)
4	6.63 (4)	4.25 (2)	4.33 (4)0	4.50 (3)

* The number of samples per collection.

Table C-6: Dry weight (mg) of kale from 1 to 4 week cultures

Week	Lead concentration (N)*			
	0ppm	5ppm	15ppm	30ppm
1	5.23 (4)	5.98 (4)	4.47 (3)	5.60 (4)
2	8.08 (5)	5.64 (5)	8.58 (4)	7.83 (4)
3	14.40 (4)	15.03 (3)	16.57 (3)	12.46 (5)
4	14.05 (4)	15.03 (4)	12.24 (5)	12.93 (4)

* The number of samples per collection.

Table C-7: Dry weight (mg) of tomato from 1 to 4 week cultures

Week	Lead concentration (N)*			
	0ppm	5ppm	15ppm	30ppm
1	5.23 (4)	5.98 (4)	4.47 (3)	5.60 (4)
2	8.08 (5)	5.64 (5)	8.58 (4)	7.83 (4)
3	14.40 (4)	15.03 (3)	16.57 (3)	12.46 (5)
4	14.05 (4)	15.03 (4)	12.24 (5)	12.93 (4)

* The number of samples per collection.

Table C-8: Dry weight (mg) of cabbage from 2 to 4 week cultures

Week	Lead concentration (N)*			
	0ppm	5ppm	15ppm	30ppm
2	8.37 (3)	6.63 (4)	7.70 (5)	6.90 (2)
3	11.47 (3)	10.00 (3)	13.70 (2)	13.50 (4)
4	14.35 (4)	10.16 (5)	9.30 (4)	15.48 (4)

* The number of samples per collection.

Table C-9: Dry weight (mg) of holy basil from 2 to 4 week cultures

Week	Lead concentration (N)*			
	0ppm	5ppm	15ppm	30ppm
2	0.43 (4)	0.40 (4)	0.27 (4)	0.30 (4)
3	0.63 (4)	0.43 (4)	0.22 (5)	0.38 (4)
4	0.76 (5)	0.38 (5)	0.46 (5)	0.13 (4)

* The number of samples per collection.

TableC-10: Dry weight (mg) of bird pepper from 3 to 4 week cultures

Week	Lead concentration (N)*			
	0ppm	5ppm	15ppm	30ppm
3	2.93 (3)	2.90 (3)	3.65 (4)	3.68 (4)
4	6.25 (5)	3.53 (3)	5.83 (4)	5.28 (5)

* The number of samples per collection.

Appendix D

Length measurement and analysis

Table D-1: Length of mung bean, measuring from root to shoot

week	1 week				2 week				3 week				4 week			
Rep.	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm
1	25.00	22.50	19.50	18.80	25.40	24.50	24.50	25.20	33.20	22.00	23.00	18.90	28.00	25.10	20.80	21.20
2	25.00	20.10	19.30	17.10	26.50	22.80	19.20	21.00	30.30	22.50	19.50	18.20	31.00	26.00	22.10	21.20
3	21.70	15.10	19.80	15.00	29.10	25.60	28.60	18.20	22.80	22.80	22.70	14.40	32.80	28.50	20.10	18.80
4	24.00	20.70	17.30	19.60	26.30	20.10	20.40	21.20	37.80	23.40	22.50	16.70	30.50	26.30	21.00	20.60
5	22.10	17.70	18.00	4.50	33.40	20.20	25.00	20.10	31.20	22.20	21.50	19.50	25.70	22.30	18.50	15.30
Average	23.56	19.22	18.78	15.00	28.14	22.64	23.54	21.14	31.06	22.58	21.84	17.54	29.60	25.64	20.50	19.42
SD	1.58	2.87	1.08	6.13	3.25	2.48	3.79	2.56	5.45	0.55	1.42	2.04	2.77	2.25	1.33	2.50

Table D-2: Length of cucumber, measuring from root to shoot

week	1 week				2 week				3 week				4 week			
Rep.	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm
1.00	2.50	4.20	2.10	2.00	6.10	8.40	9.40	6.30	14.40	10.90	13.20	8.90	9.80	13.70	13.90	10.90
2.00	2.10	2.60	2.80	2.10	2.50	6.50	12.00	7.80	10.00	12.40	13.70	12.50	13.10	11.50	10.40	11.50
3.00	3.00	3.10	1.50	0.00	15.00	4.70	11.20	0.00	16.90	11.90	9.60	6.50	16.30	12.40	10.50	11.00
4.00	3.60	0.00	5.40	0.00	9.90	4.00	0.00	0.00	12.20	0.00	0.00	0.00	10.50	0.00	9.30	0.00
5.00	0.00	0.00	1.50	0.00	0.00	4.60	0.00	0.00	13.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	2.24	1.98	2.66	0.82	6.70	5.64	6.52	2.82	13.32	7.04	7.30	5.58	9.94	7.52	8.82	6.68
SD	1.37	1.90	1.62	1.12	5.96	1.80	6.03	3.90	2.56	6.45	6.85	5.52	6.11	6.91	5.22	6.10

Table D-3: Length of morning glory, measuring from root to shoot

week	1 week				2 week				3 week				4 week			
Rep.	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm
1	2.20	1.20	1.10	0.50	2.50	3.80	1.10	4.10	4.70	5.80	4.20	4.60	7.00	14.30	3.20	11.10
2	0.70	0.30	0.50	1.20	4.50	5.30	0.80	3.60	8.50	3.40	1.50	4.20	11.70	9.60	5.30	6.20
3	0.30	0.60	0.00	2.10	2.90	1.50	4.20	3.00	10.50	3.20	2.90	10.50	9.30	4.50	5.80	14.20
4	0.00	0.00	0.00	0.00	1.20	1.50	0.00	1.20	0.00	2.70	0.00	4.90	4.20	7.50	0.00	6.10
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.80	0.00	12.00
Average	0.64	0.42	0.32	0.76	2.22	2.42	1.22	2.38	4.74	3.02	1.72	4.84	6.44	7.74	2.86	9.92
SD	0.92	0.50	0.49	0.90	1.71	2.11	1.74	1.72	4.80	2.07	1.84	3.74	4.55	4.51	2.79	3.62

Table D-4: Length of sweet basil, measuring from root to shoot

week	1 week				2 week				3 week				4 week			
Rep.	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm
1	10.30	7.20	8.50	5.00	0.50	6.40	6.70	7.50	18.30	10.90	11.20	0.70	13.50	10.20	13.20	8.80
2	9.20	6.50	6.50	5.00	12.10	8.80	9.50	7.50	13.30	10.20	8.70	10.20	11.10	8.60	16.60	10.60
3	0.00	0.60	0.50	0.50	16.60	6.00	8.30	4.20	14.40	14.50	7.00	10.50	12.90	14.50	12.50	10.70
4	0.00	0.00	0.00	0.00	0.00	0.00	8.00	0.00	15.20	9.00	9.80	9.40	12.10	12.00	12.20	12.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	3.90	2.86	3.10	2.10	5.84	4.24	6.50	3.84	12.24	8.92	7.34	6.16	9.92	9.06	10.90	8.42
SD	5.35	3.66	4.08	2.66	7.93	4.02	3.77	3.76	7.09	5.39	4.38	5.32	5.62	5.52	6.34	4.84

Table D-5: Length of lettuce, measuring from root to shoot

week	1 week				2 week				3 week				4 week			
Rep.	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm
1	2.30	0.30	2.60	1.00	8.50	3.60	5.00	3.00	12.60	10.00	9.50	7.00	11.70	12.80	11.60	17.20
2	0.50	0.30	0.30	0.50	6.10	0.20	0.30	3.70	12.50	10.10	3.80	9.00	11.10	7.10	14.10	12.90
3	0.70	2.20	0.00	0.50	1.40	0.10	0.20	0.30	14.30	0.00	9.10	8.50	20.90	0.00	10.20	13.30
4	0.50	0.00	0.00	0.00	0.00	0.00	5.70	0.20	0.00	0.00	0.00	0.00	14.60	0.00	9.60	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	0.80	0.56	0.58	0.40	3.20	0.78	2.24	1.44	7.88	4.02	4.48	4.90	11.66	3.98	9.10	8.68
SD	0.88	0.93	1.14	0.42	3.88	1.58	2.85	1.76	7.23	5.50	4.67	4.53	7.59	5.81	5.37	8.10

Table D-6: Length of kale, measuring from root to shoot

week	1 week				2 week				3 week				4 week			
Rep.	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm
1	3.10	2.50	1.80	1.60	2.00	10.40	4.10	5.40	15.00	8.80	12.00	4.50	11.60	9.00	11.50	6.80
2	1.60	1.50	0.50	1.30	16.70	1.10	5.40	2.10	13.00	9.20	6.50	4.50	8.50	10.00	6.90	7.20
3	0.40	0.30	0.30	0.90	0.20	0.20	1.40	0.90	12.40	5.00	7.00	7.70	12.10	6.50	7.20	6.00
4	0.30	0.50	0.00	0.30	0.30	0.10	2.00	3.90	7.20	0.00	0.00	5.50	11.00	3.50	7.70	5.10
5	0.00	0.00	0.00	0.00	0.30	0.10	0.00	0.00	0.00	0.00	0.00	7.50	0.00	0.00	6.40	0.00
Average	1.08	0.96	0.52	0.82	3.90	2.38	2.58	2.46	9.52	4.60	5.10	5.94	8.64	5.80	7.94	5.02
SD	1.28	1.03	0.75	0.67	7.19	4.50	2.16	2.20	6.05	4.51	5.13	1.57	5.02	4.10	2.05	2.92

Table D-7: Length of tomato, measuring from root to shoot

week	1 week				2 week				3 week				4 week			
Rep.	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm
1	2.00	3.80	3.00	1.50	11.50	10.20	9.80	5.60	16.80	18.50	11.20	7.90	9.90	14.00	13.20	12.20
2	4.00	0.80	3.50	1.44	13.80	11.90	11.40	0.80	17.70	17.60	11.50	10.10	16.00	16.30	11.60	9.50
3	2.10	1.00	1.60	0.60	12.50	17.00	7.70	0.00	16.40	14.60	8.80	8.90	10.80	17.50	14.10	9.00
4	3.00	3.20	1.00	2.70	12.10	10.30	10.00	0.00	15.60	14.90	13.50	9.60	13.60	17.00	10.90	12.00
5	0.00	3.30	0.00	2.50	10.10	10.20	9.60	0.00	12.20	14.50	10.20	0.00	13.90	16.00	12.30	9.10
Average	2.22	2.42	1.82	1.75	12.00	11.92	9.70	1.28	15.74	16.02	11.04	7.30	12.84	16.16	12.42	10.36
SD	1.48	1.41	1.44	0.86	1.36	2.93	1.32	2.44	2.12	1.89	1.73	4.16	2.47	1.34	1.27	1.60

Table D-8: Length of cabbage, measuring from root to shoot

week	1 week*				2 week				3 week				4 week			
Rep.	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm
1	-	-	-	-	15.00	3.10	6.50	5.60	9.90	1.00	9.90	6.40	24.00	12.40	3.40	6.40
2	-	-	-	-	1.00	0.50	1.00	0.80	13.50	6.60	3.40	6.00	16.00	3.50	2.00	6.90
3	-	-	-	-	0.90	0.10	0.10	0.00	2.00	10.50	0.00	6.10	6.20	2.50	0.80	6.80
4	-	-	-	-	0.00	0.10	0.70	0.00	0.00	0.00	0.00	4.20	4.40	1.00	14.00	0.70
5	-	-	-	-	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00
Average	-	-	-	-	3.38	0.76	1.90	1.28	5.08	3.62	2.66	4.54	10.12	4.04	4.04	4.16
SD	-	-	-	-	6.51	1.32	2.60	2.44	6.23	4.72	4.31	2.68	9.72	4.80	5.71	3.49

* Length on the first week was not measured since the specimen still too young to be measured.

Table D-9: Length of holy basil, measuring from root to shoot

week	1 week*				2 week				3 week				4 week			
Rep.	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm
1	-	-	-	-	2.70	2.40	1.30	1.70	8.50	9.50	2.10	2.40	8.60	6.20	4.30	1.00
2	-	-	-	-	4.00	2.70	2.30	1.40	7.70	10.30	2.90	1.50	9.30	9.00	4.40	1.10
3	-	-	-	-	3.40	2.30	2.10	1.50	6.10	6.80	2.80	1.70	10.30	5.70	3.70	0.90
4	-	-	-	-	4.10	2.30	1.50	1.40	7.20	7.90	2.20	1.90	8.00	7.80	4.70	1.30
5	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	2.30	0.00	6.50	6.70	3.10	0.00
Average	-	-	-	-	2.84	1.94	1.44	1.20	5.90	6.90	2.46	1.50	8.54	7.08	4.04	0.86
SD	-	-	-	-	1.68	1.10	0.90	0.68	3.41	4.09	0.36	0.90	1.43	1.33	0.64	0.50

* Length on the first week was not measured since the specimen still too young to be measured.

Table D-10: Length of bird pepper, measuring from root to shoot

week	1 week*				2 week				3 week				4 week			
Rep.	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm	0ppm	5ppm	15ppm	30ppm
1	-	-	-	-	-	-	-	-	6.00	3.50	9.90	5.30	11.70	6.10	5.10	5.70
2	-	-	-	-	-	-	-	-	11.20	6.90	6.60	5.80	11.70	5.70	8.30	5.70
3	-	-	-	-	-	-	-	-	1.50	6.80	3.00	8.70	8.00	6.30	3.00	8.70
4	-	-	-	-	-	-	-	-	0.00	0.00	4.50	1.20	9.90	0.00	9.00	8.20
5	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	13.50	0.00	0.00	4.90
Average	-	-	-	-	-	-	-	-	3.74	3.44	4.80	4.20	10.96	3.62	5.08	6.64
SD	-	-	-	-	-	-	-	-	4.84	3.43	3.73	3.56	2.09	3.31	3.74	1.69

* Length on the first week was not measured since germination did not occur.
On the second week, the specimen was still too young to be measured.

Table D-11: Statistic analysis of length for mung bean (1 week)

Between-Subjects Factors

		Value Label	N
Pb con.	1	0ppm	5
	2	5ppm	5
	3	15ppm	5
	4	30ppm	5

Tests of Between-Subjects Effects

Dependent Variable: Length (cm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	184.060[a]	3	61.353	4.962	.013
Intercept	7326.792	1	7326.792	592.579	.000
TRT	184.060	3	61.353	4.962	.013
Error	197.828	16	12.364		
Total	7708.680	20			
Corrected Total	381.888	19			

a. R Squared = .482 (Adjusted R Squared = .385)

Post Hoc Tests

Pb con.

Multiple Comparisons

Dependent Variable: Length (cm)

	(I) Pb con.	(J) Pb con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	4.3400	2.2239	.069	-.3744	9.0544
		15ppm	4.7800*	2.2239	.047	6.556E-02	9.4944
		30ppm	8.5600*	2.2239	.001	3.8456	13.2744
	5ppm	0ppm	-4.3400	2.2239	.069	-9.0544	.3744
		15ppm	.4400	2.2239	.846	-4.2744	5.1544
		30ppm	4.2200	2.2239	.076	-.4944	8.9344
	15ppm	0ppm	-4.7800*	2.2239	.047	-9.4944	-6.5557E-02
		5ppm	-.4400	2.2239	.846	-5.1544	4.2744
		30ppm	3.7800	2.2239	.109	-.9344	8.4944
	30ppm	0ppm	-8.5600*	2.2239	.001	-13.2744	-3.8456
		5ppm	-4.2200	2.2239	.076	-8.9344	.4944
		15ppm	-3.7800	2.2239	.109	-8.4944	.9344

Based on observed means.

*. The mean difference is significant at the .05 level.

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Table D-12: Statistic analysis of length for mung bean (2 week)

Between-Subjects Factors

		Value Label	N
Pb con.	1	0ppm	5
	2	5ppm	5
	3	15ppm	5
	4	30ppm	5

Tests of Between-Subjects Effects

Dependent Variable: Length (cm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	136.537[a]	3	45.512	4.841	.014
Intercept	11390.764	1	11390.764	1211.719	.000
TRT	136.538	3	45.513	4.841	.014
Error	150.408	16	9.401		
Total	11677.710	20			
Corrected Total	286.945	19			

a. R Squared = .476 (Adjusted R Squared = .378)

Post Hoc Tests

Pb con.

Multiple Comparisons

Dependent Variable: Length (cm)

	(I) Pb con.	(J) Pb con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	5.5000*	1.9391	.012	1.3892	9.6108
		15ppm	4.6000*	1.9391	.031	.4892	8.7108
		30ppm	7.0000*	1.9391	.002	2.8892	11.1108
	5ppm	0ppm	-5.5000*	1.9391	.012	-9.6108	-1.3892
		15ppm	-.9000	1.9391	.649	-5.0108	3.2108
		30ppm	1.5000	1.9391	.450	-2.6108	5.6108
	15ppm	0ppm	-4.6000*	1.9391	.031	-8.7108	-.4892
		5ppm	.9000	1.9391	.649	-3.2108	5.0108
		30ppm	2.4000	1.9391	.234	-1.7108	6.5108
	30ppm	0ppm	-7.0000*	1.9391	.002	-11.1108	-2.8892
		5ppm	-1.5000	1.9391	.450	-5.6108	2.6108
		15ppm	-2.4000	1.9391	.234	-6.5108	1.7108

Based on observed means.

*. The mean difference is significant at the .05 level.

Table D-13: Statistic analysis of length for mung bean (3 week)

Between-Subjects Factors

		Value Label	N
Pb con.	1	0ppm	5
	2	5ppm	5
	3	15ppm	5
	4	30ppm	5

Tests of Between-Subjects Effects

Dependent Variable: Length (cm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	480.186[a]	3	160.062	17.681	.000
Intercept	10815.900	1	10815.900	1194.764	.000
TRT	480.186	3	160.062	17.681	.000
Error	144.844	16	9.053		
Total	11440.930	20			
Corrected Total	625.030	19			

a. R Squared = .768 (Adjusted R Squared = .725)

Post Hoc Tests

Pb con.

Multiple Comparisons

Dependent Variable: Length (cm)

	(I) Pb con.	(J) Pb con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	8.4800*	1.9029	.000	4.4460	12.5140
		15ppm	9.2200*	1.9029	.000	5.1860	13.2540
		30ppm	13.5200*	1.9029	.000	9.4860	17.5540
	5ppm	0ppm	-8.4800*	1.9029	.000	-12.5140	-4.4460
		15ppm	.7400	1.9029	.702	-3.2940	4.7740
		30ppm	5.0400*	1.9029	.018	1.0060	9.0740
	15ppm	0ppm	-9.2200*	1.9029	.000	-13.2540	-5.1860
		5ppm	-.7400	1.9029	.702	-4.7740	3.2940
		30ppm	4.3000*	1.9029	.038	.2660	8.3340
	30ppm	0ppm	-13.5200*	1.9029	.000	-17.5540	-9.4860
		5ppm	-5.0400*	1.9029	.018	-9.0740	-1.0060
		15ppm	-4.3000*	1.9029	.038	-8.3340	-.2660

Based on observed means.

*. The mean difference is significant at the .05 level.

Table D-14: Statistic analysis of length for mung bean (4 week)

Between-Subjects Factors

		Value Label	N
Pb con.	1	0ppm	5
	2	5ppm	5
	3	15ppm	5
	4	30ppm	5

Tests of Between-Subjects Effects

Dependent Variable: Length (cm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	335.498[a]	3	111.833	21.527	.000
Intercept	11319.282	1	11319.282	2178.880	.000
TRT	335.498	3	111.833	21.527	.000
Error	83.120	16	5.195		
Total	11737.900	20			
Corrected Total	418.618	19			

a. R Squared = .801 (Adjusted R Squared = .764)

Post Hoc Tests

Pb con.

Multiple Comparisons

Dependent Variable: Length (cm)

	(I) Pb con.	(J) Pb con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	3.9600*	1.4415	.014	.9041	7.0159
		15ppm	9.1000*	1.4415	.000	6.0441	12.1559
		30ppm	10.1800*	1.4415	.000	7.1241	13.2359
	5ppm	0ppm	-3.9600*	1.4415	.014	-7.0159	-.9041
		15ppm	5.1400*	1.4415	.003	2.0841	8.1959
		30ppm	6.2200*	1.4415	.001	3.1641	9.2759
	15ppm	0ppm	-9.1000*	1.4415	.000	-12.1559	-6.0441
		5ppm	-5.1400*	1.4415	.003	-8.1959	-2.0841
		30ppm	1.0800	1.4415	.465	-1.9759	4.1359
	30ppm	0ppm	-10.1800*	1.4415	.000	-13.2359	-7.1241
		5ppm	-6.2200*	1.4415	.001	-9.2759	-3.1641
		15ppm	-1.0800	1.4415	.465	-4.1359	1.9759

Based on observed means.

*. The mean difference is significant at the .05 level.

Table D-15: Statistic analysis of length for tomato (1 week)

Between-Subjects Factors

		Value Label	N
Pb con.	1	0ppm	5
	2	5ppm	5
	3	15ppm	5
	4	30ppm	5

Tests of Between-Subjects Effects

Dependent Variable: Length (cm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.549[a]	3	.516	.296	.828
Intercept	84.214	1	84.214	48.312	.000
TRT	1.549	3	.516	.296	.828
Error	27.890	16	1.743		
Total	113.654	20			
Corrected Total	29.440	19			

a. R Squared = .053 (Adjusted R Squared = -.125)

Post Hoc Tests

Pb con.

Multiple Comparisons

Dependent Variable: Length (cm)

	(I) Pb con.	(J) Pb con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	-.2000	.8350	.814	-1.9702	1.5702
		15ppm	.4000	.8350	.638	-1.3702	2.1702
		30ppm	.4720	.8350	.580	-1.2982	2.2422
	5ppm	0ppm	.2000	.8350	.814	-1.5702	1.9702
		15ppm	.6000	.8350	.483	-1.1702	2.3702
		30ppm	.6720	.8350	.433	-1.0982	2.4422
	15ppm	0ppm	-.4000	.8350	.638	-2.1702	1.3702
		5ppm	-.6000	.8350	.483	-2.3702	1.1702
		30ppm	7.200E-02	.8350	.932	-1.6982	1.8422
	30ppm	0ppm	-.4720	.8350	.580	-2.2422	1.2982
		5ppm	-.6720	.8350	.433	-2.4422	1.0982
		15ppm	-7.2000E-02	.8350	.932	-1.8422	1.6982

Based on observed means.

Table D-16: Statistic analysis of length for tomato (2 week)

Between-Subjects Factors

		Value Label	N
Pb con.	1	0ppm	5
	2	5ppm	5
	3	15ppm	5
	4	30ppm	5

Tests of Between-Subjects Effects

Dependent Variable: Length (cm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	386.562[a]	3	128.854	28.430	.000
Intercept	1522.512	1	1522.512	335.929	.000
TRT	386.562	3	128.854	28.430	.000
Error	72.516	16	4.532		
Total	1981.590	20			
Corrected Total	459.078	19			

a. R Squared = .842 (Adjusted R Squared = .812)

Post Hoc Tests

Pb con.

Multiple Comparisons

Dependent Variable: Length (cm)

	(I) Pb con.	(J) Pb con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	8.000E-02	1.3464	.953	-2.7743	2.9343
		15ppm	2.3000	1.3464	.107	-.5543	5.1543
		30ppm	10.7200*	1.3464	.000	7.8657	13.5743
	5ppm	0ppm	-8.0000E-02	1.3464	.953	-2.9343	2.7743
		15ppm	2.2200	1.3464	.119	-.6343	5.0743
		30ppm	10.6400*	1.3464	.000	7.7857	13.4943
	15ppm	0ppm	-2.3000	1.3464	.107	-5.1543	.5543
		5ppm	-2.2200	1.3464	.119	-5.0743	.6343
		30ppm	8.4200*	1.3464	.000	5.5657	11.2743
	30ppm	0ppm	-10.7200*	1.3464	.000	-13.5743	-7.8657
		5ppm	-10.6400*	1.3464	.000	-13.4943	-7.7857
		15ppm	-8.4200*	1.3464	.000	-11.2743	-5.5657

Based on observed means.

*. The mean difference is significant at the .05 level.

Table D-17: Statistic analysis of length for tomato (3 week)

Between-Subjects Factors

		Value Label	N
Pb con.	1	0ppm	5
	2	5ppm	5
	3	15ppm	5
	4	30ppm	5

Tests of Between-Subjects Effects

Dependent Variable: Length (cm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	260.285[a]	3	86.762	12.227	.000
Intercept	3137.512	1	3137.512	442.168	.000
TRT	260.286	3	86.762	12.227	.000
Error	113.532	16	7.096		
Total	3511.330	20			
Corrected Total	373.817	19			

a. R Squared = .696 (Adjusted R Squared = .639)

Post Hoc Tests

Pb con.

Multiple Comparisons

Dependent Variable: Length (cm)

	(I) Pb con.	(J) Pb con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	-.2800	1.6847	.870	-3.8515	3.2915
		15ppm	4.7000*	1.6847	.013	1.1285	8.2715
		30ppm	8.4400*	1.6847	.000	4.8685	12.0115
	5ppm	0ppm	.2800	1.6847	.870	-3.2915	3.8515
		15ppm	4.9800*	1.6847	.009	1.4085	8.5515
		30ppm	8.7200*	1.6847	.000	5.1485	12.2915
	15ppm	0ppm	-4.7000*	1.6847	.013	-8.2715	-1.1285
		5ppm	-4.9800*	1.6847	.009	-8.5515	-1.4085
		30ppm	3.7400*	1.6847	.041	.1685	7.3115
	30ppm	0ppm	-8.4400*	1.6847	.000	-12.0115	-4.8685
		5ppm	-8.7200*	1.6847	.000	-12.2915	-5.1485
		15ppm	-3.7400*	1.6847	.041	-7.3115	-.1685

Based on observed means.

*. The mean difference is significant at the .05 level.

Table D-18: Statistic analysis of length for tomato (4 week)

Between-Subjects Factors

		Value Label	N
Pb con.	1	0ppm	5
	2	5ppm	5
	3	15ppm	5
	4	30ppm	5

Tests of Between-Subjects Effects

Dependent Variable: Length (cm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	86.526[a]	3	28.842	9.538	.001
Intercept	3351.460	1	3351.460	1108.287	.000
TRT	86.526	3	28.842	9.538	.001
Error	48.384	16	3.024		
Total	3486.370	20			
Corrected Total	134.910	19			

a. R Squared = .641 (Adjusted R Squared = .574)

Post Hoc Tests

Pb con.

Multiple Comparisons

Dependent Variable: Length (cm)

	(I) Pb con.	(J) Pb con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	-3.3200*	1.0998	.008	-5.6515	-.9885
		15ppm	.4200	1.0998	.708	-1.9115	2.7515
		30ppm	2.4800*	1.0998	.039	.1485	4.8115
	5ppm	0ppm	3.3200*	1.0998	.008	.9885	5.6515
		15ppm	3.7400*	1.0998	.004	1.4085	6.0715
		30ppm	5.8000*	1.0998	.000	3.4685	8.1315
	15ppm	0ppm	-.4200	1.0998	.708	-2.7515	1.9115
		5ppm	-3.7400*	1.0998	.004	-6.0715	-1.4085
		30ppm	2.0600	1.0998	.079	-.2715	4.3915
	30ppm	0ppm	-2.4800*	1.0998	.039	-4.8115	-.1485
		5ppm	-5.8000*	1.0998	.000	-8.1315	-3.4685
		15ppm	-2.0600	1.0998	.079	-4.3915	.2715

Based on observed means.

*. The mean difference is significant at the .05 level.

Table D-19: Statistic analysis of length for holy basil (2 week)

Between-Subjects Factors

		Value Label	N
Pb con.	1	0ppm	5
	2	5ppm	5
	3	15ppm	5
	4	30ppm	5

Tests of Between-Subjects Effects

Dependent Variable: Length (cm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7.894[a]	3	2.631	1.979	.158
Intercept	68.820	1	68.820	51.754	.000
TRT	7.893	3	2.631	1.979	.158
Error	21.276	16	1.330		
Total	97.990	20			
Corrected Total	29.170	19			

a. R Squared = .271 (Adjusted R Squared = .134)

Post Hoc Tests

Pb con.

Multiple Comparisons

Dependent Variable: Length (cm)

	(I) Pb con.	(J) Pb con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	.9000	.7293	.235	-.6461	2.4461
		15ppm	1.4000	.7293	.073	-.1461	2.9461
		30ppm	1.6400*	.7293	.039	9.392E-02	3.1861
	5ppm	0ppm	-.9000	.7293	.235	-2.4461	.6461
		15ppm	.5000	.7293	.503	-1.0461	2.0461
		30ppm	.7400	.7293	.325	-.8061	2.2861
	15ppm	0ppm	-1.4000	.7293	.073	-2.9461	.1461
		5ppm	-.5000	.7293	.503	-2.0461	1.0461
		30ppm	.2400	.7293	.746	-1.3061	1.7861
	30ppm	0ppm	-1.6400*	.7293	.039	-3.1861	-9.3922E-02
		5ppm	-.7400	.7293	.325	-2.2861	.8061
		15ppm	-.2400	.7293	.746	-1.7861	1.3061

Based on observed means.

*. The mean difference is significant at the .05 level.

Table D-20: Statistic analysis of length for holy basil (3 week)

Between-Subjects Factors

		Value Label	N
Pb con.	1	0ppm	5
	2	5ppm	5
	3	15ppm	5
	4	30ppm	5

Tests of Between-Subjects Effects

Dependent Variable: Length (cm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	102.486[a]	3	34.162	4.661	.016
Intercept	351.122	1	351.122	47.905	.000
TRT	102.486	3	34.162	4.661	.016
Error	117.272	16	7.330		
Total	570.880	20			
Corrected Total	219.758	19			

a. R Squared = .466 (Adjusted R Squared = .366)

Post Hoc Tests

Pb con.

Multiple Comparisons

Dependent Variable: Length (cm)

	(I) Pb con.	(J) Pb con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	-1.0000	1.7122	.567	-4.6298	2.6298
		15ppm	3.4400	1.7122	.062	-.1898	7.0698
		30ppm	4.4000*	1.7122	.021	.7702	8.0298
	5ppm	0ppm	1.0000	1.7122	.567	-2.6298	4.6298
		15ppm	4.4400*	1.7122	.020	.8102	8.0698
		30ppm	5.4000*	1.7122	.006	1.7702	9.0298
	15ppm	0ppm	-3.4400	1.7122	.062	-7.0698	.1898
		5ppm	-4.4400*	1.7122	.020	-8.0698	-.8102
		30ppm	.9600	1.7122	.583	-2.6698	4.5898
	30ppm	0ppm	-4.4000*	1.7122	.021	-8.0298	-.7702
		5ppm	-5.4000*	1.7122	.006	-9.0298	-1.7702
		15ppm	-.9600	1.7122	.583	-4.5898	2.6698

Based on observed means.

*. The mean difference is significant at the .05 level.

Table D-21: Statistic analysis of length for holy basil (4 week)

Between-Subjects Factors

		Value Label	N
Pb con.	1	0ppm	5
	2	5ppm	5
	3	15ppm	5
	4	30ppm	5

Tests of Between-Subjects Effects

Dependent Variable: Length (cm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	174.258[a]	3	58.086	52.200	.000
Intercept	526.338	1	526.338	473.007	.000
TRT	174.258	3	58.086	52.200	.000
Error	17.804	16	1.113		
Total	718.400	20			
Corrected Total	192.062	19			

a. R Squared = .907 (Adjusted R Squared = .890)

Post Hoc Tests

Pb con.

Multiple Comparisons

Dependent Variable: Length (cm)

	(I) Pb con.	(J) Pb con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	1.4600*	.6672	.044	4.569E-02	2.8743
		15ppm	4.5000*	.6672	.000	3.0857	5.9143
		30ppm	7.6800*	.6672	.000	6.2657	9.0943
	5ppm	0ppm	-1.4600*	.6672	.044	-2.8743	-4.5688E-02
		15ppm	3.0400*	.6672	.000	1.6257	4.4543
		30ppm	6.2200*	.6672	.000	4.8057	7.6343
	15ppm	0ppm	-4.5000*	.6672	.000	-5.9143	-3.0857
		5ppm	-3.0400*	.6672	.000	-4.4543	-1.6257
		30ppm	3.1800*	.6672	.000	1.7657	4.5943
	30ppm	0ppm	-7.6800*	.6672	.000	-9.0943	-6.2657
		5ppm	-6.2200*	.6672	.000	-7.6343	-4.8057
		15ppm	-3.1800*	.6672	.000	-4.5943	-1.7657

Based on observed means.

*. The mean difference is significant at the .05 level.

Table D-22: Statistic analysis of length for bird pepper (3 week)

Between-Subjects Factors

		Value Label	N
Pb con.	1	0ppm	5
	2	5ppm	5
	3	15ppm	5
	4	30ppm	5

Tests of Between-Subjects Effects

Dependent Variable: Length (cm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5.265[a]	3	1.755	.114	.951
Intercept	327.241	1	327.241	21.201	.000
TRT	5.266	3	1.755	.114	.951
Error	246.964	16	15.435		
Total	579.470	20			
Corrected Total	252.229	19			

a. R Squared = .021 (Adjusted R Squared = -.163)

Post Hoc Tests

Pb con.

Multiple Comparisons

Dependent Variable: Length (cm)

	(I) Pb con.	(J) Pb con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	.3000	2.4848	.905	-4.9675	5.5675
		15ppm	-1.0600	2.4848	.675	-6.3275	4.2075
		30ppm	-.4600	2.4848	.855	-5.7275	4.8075
	5ppm	0ppm	-.3000	2.4848	.905	-5.5675	4.9675
		15ppm	-1.3600	2.4848	.592	-6.6275	3.9075
		30ppm	-.7600	2.4848	.764	-6.0275	4.5075
	15ppm	0ppm	1.0600	2.4848	.675	-4.2075	6.3275
		5ppm	1.3600	2.4848	.592	-3.9075	6.6275
		30ppm	.6000	2.4848	.812	-4.6675	5.8675
	30ppm	0ppm	.4600	2.4848	.855	-4.8075	5.7275
		5ppm	.7600	2.4848	.764	-4.5075	6.0275
		15ppm	-.6000	2.4848	.812	-5.8675	4.6675

Based on observed means.

Table D-23: Statistic analysis of length for bird pepper (4 week)

Between-Subjects Factors

		Value Label	N
Pb con.	1	0ppm	5
	2	5ppm	5
	3	15ppm	5
	4	30ppm	5

Tests of Between-Subjects Effects

Dependent Variable: Length (cm)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	150.997[a]	3	50.332	6.260	.005
Intercept	864.612	1	864.612	107.539	.000
TRT	150.997	3	50.332	6.260	.005
Error	128.640	16	8.040		
Total	1144.250	20			
Corrected Total	279.637	19			

a. R Squared = .540 (Adjusted R Squared = .454)

Post Hoc Tests

Pb con.

Multiple Comparisons

Dependent Variable: Length (cm)

	(I) Pb con.	(J) Pb con.	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
LSD	0ppm	5ppm	7.3400*	1.7933	.001	3.5383	11.1417
		15ppm	5.8800*	1.7933	.005	2.0783	9.6817
		30ppm	4.3200*	1.7933	.028	.5183	8.1217
	5ppm	0ppm	-7.3400*	1.7933	.001	-11.1417	-3.5383
		15ppm	-1.4600	1.7933	.428	-5.2617	2.3417
		30ppm	-3.0200	1.7933	.112	-6.8217	.7817
	15ppm	0ppm	-5.8800*	1.7933	.005	-9.6817	-2.0783
		5ppm	1.4600	1.7933	.428	-2.3417	5.2617
		30ppm	-1.5600	1.7933	.397	-5.3617	2.2417
	30ppm	0ppm	-4.3200*	1.7933	.028	-8.1217	-.5183
		5ppm	3.0200	1.7933	.112	-.7817	6.8217
		15ppm	1.5600	1.7933	.397	-2.2417	5.3617

Based on observed means.

*. The mean difference is significant at the .05 level.

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