การกระจายตัวของแคดเมียมในแปลงทดลองปลูกผักคะน้า ระดับห้องปฏิบัติการเมื่อรดโดยน้ำปนเปื้อนแคดเมียม

นางสาวจุฑามาศ ทรัพย์ประดิษฐ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต

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DISTRIBUTION OF CADMIUM IN LABORATORY-SCALE KALE CULTIVATION IRRIGATED WITH CADMIUM CONTAMINATED WATER

Miss Jutamas Suppradid

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for the Degree of Master of Science Program in Environmental Management
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By	Miss Jutamas Suppradid
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Thesis Co- Advisor	-

Accepted by the Graduate School, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

....Dean of the Graduate School
(Assistant Professor M.R. Kalaya Tingsabadh, Ph.D.)

THESIS COMMITTEE

....Chairman
(Manaskorn Rachakornkij, Ph.D.)

....Thesis Advisor
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....Member
(Associate Professor Alissara Reungsang, Ph.D.)

....Member
(Assistant Professor Suraphong Wattanachira, D.Eng.)

....Member
(Ekawan Luepromchai, Ph.D.)

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การศึกษานี้มีวัตถุประสงค์เพื่อหาการกระจายตัวและการสะสมของแคดเมียมในดิน ผักคะน้า และน้ำซึม เมื่อใช้น้ำที่มีการปนเปื้อนแคดเมียมที่ความเข้มข้นต่างๆมาใช้ในการเพาะปลูก รวมทั้ง เพื่อศึกษาความปลอดภัยของพืช ในการเพาะปลูกระยะยาว น้ำรดที่ใช้ในการศึกษามีความเข้มข้นของแคดเมียม เท่ากับ 0.010, 0.014, 0.023, 0.771, 1.291, 2.361, 5.531 และ 7.982 มิลลิกรัมต่อลิตร ตามลำดับ พืชที่นำมาศึกษาคือ ผักคะน้า และมีการปลูกทั้งหมด 4 ครั้งต่อเนื่องในดินเดียวกัน ในแปลงทดลองเส้นผ่านศูนย์กลาง 1.0 เมตร สูง 0.4 เมตร จากผลการศึกษาพบว่า แคดเมียมมีการกระจายตัวและสะสมส่วนใหญ่ในดิน และในสัดส่วนเล็กน้อยในผักคะน้า และน้ำซึม ความเข้มข้นของแคดเมียมในน้ำซึมเฉลี่ย มีค่าน้อย (0.002 ถึง 0.044 มิลลิกรัม ต่อลิตร) เมื่อเปรียบเทียบกับความเข้มข้นของแคดเมียมในน้ำรด แคดเมียมในน้ำรดไม่ควรเกิน 0.023 มิลลิกรัม ต่อลิตร ถ้าต้องการน้ำซึมมีค่าอยู่ใน มาตรฐานน้ำดื่ม ของประเทศไทย การสะสมของแคดเมียมในผักคะน้าพบมากที่สุด ในราก ใบ และลำต้น ตามลำดับ ผลการศึกษาพบว่า น้ำรดที่มีการปนเปื้อนของแคดเมียมไม่เกิน 0.023 มิลลิกรัม ต่อลิตร สามารถนำมาใช้ปลูกผักคะน้าที่มีการปนเปื้อนในพืช (ใบและลำต้น) ไม่เกินมาตรฐานบริโภคของ European Commission (EU)

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The main objective of this study was to assess the cadmium distribution in soil, kale, and infiltrated water when irrigated with cadmium contaminated water at different concentrations. The sub objective was to assess crop safety under long term cultivation of kale. The irrigated water with eight cadmium concentrations: 0.010, 0.014, 0.023, 0.771, 1.291, 2.361, 5.531, and 7.982 mg/L were synthesized. Four rotations of kale (*Brassica oleracea var. alboglaba*) were consecutively grown in the same soil in eight laboratory-scale plot, diameter 1.0 m and height 0.4 m. It was found that cadmium added was mainly adsorbed in soil while a small proportion absorbed in kale and infiltrated water. The infiltrated water had relatively low average cadmium concentrations 0.002 – 0.044 mg/L as compared with irrigated water. Based on Thailand drinking water standard, cadmium in irrigated water should not exceed 0.023 mg/L. The cadmium accumulation in kale was highest in root, stem, and leaf, respectively. The irrigated water with cadmium not exceeding of 0.023 mg/L is suggested based on crop safety (leaf and stem) of European Commission (EU) standard.

Field of study Environmental Management (Inter-Department) Student's signature Jutamas Suppradid
Advisor's signature Seni Karnchanawong
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LIST OF ABBREVIATIONS

ATSDR	Agency for Toxic Substances and Disease Registry
ANZFA	Australia New Zealand Food Authority
˚ C	Degree Celsius
Cd	Cadmium
$CdCl_2.2.5H_2O$	Cadmium Chloride
d	Day
EPA	Environmental Protection Agency
EU	European Commission
mg /kg	Milligram per kilogram
CEC	Cation Exchange Capacity
N	Nitrogen
P	Phosphorus
K	Potassium
m	Meter
cm	Centimeter
kg/rai	Kilogram per rai
MCL	Maximum contaminant level
MCLG	Maximum contaminant level goal
mg/L	Milligram per liter
WHO	World Health Organization
RfD	Reference Dose
RfC	Reference Concentration

CHAPTER I

INTRODUCTION

1.1 Motivations

Thailand is a fertile agricultural country which broadly includes crop cultivation, forestry, livestock breeding, and fisheries. Nowadays, the existing agricultural land has been partly shifted to non-farm use in response to urbanization and expanding industrial zones. The expansion of industries which are not sufficiently managed commits aggression to agricultural areas. Moreover, some industries still illegally discard wastewater to surface water which is a main water resource in Thailand for the utility of agricultural activities; as a result, the water is contaminated.

From the environmental standpoint, metals may be categorized into two groups. The first group is essential metals, which are required in trace element for microorganisms as nutrients, but are poisonous in a greater quantity. This group consists of As, Cr, Co, Cu, Ni, Se, Va, Zn, and etc. Another group is potentially toxic trace element and is not known to have any nutritional value. These groups comprise of Pb, Hg, Be, Ur, Ag, Cd, and etc (Kojima and Lee, 2001). Particularly, small amounts of cadmium taken in over many years may cause kidney damage and fragile bones. In addition, short-term health effects include a flu-like illness with chills, headache, aching and/or fever. High exposure to cadmium may cause nausea, salivation, vomiting, cramps, and diarrhea. Moreover, long-term exposure can cause anemia, loss of sense of smell, and fatigue. A syndrome called Itai-Itai described in

Japan, has been associated with chronic ingestion of cadmium. In 2004, Thailand has a large problem about the contamination of cadmium from mining into the environment in Padang, Tak province. A large amount of cadmium contaminated water was used for cultivation, which resulted in cadmium contaminated agricultural produce.

Kale (*Brassica oleracea var. alboglaba*) is vegetable commonly consumed in Asia such as China, Hong Kong, Taiwan, Malaysia, and Thailand. Due to the short life cycle of kale and tolerant on high temperature, kale is favorably cultivated in Thailand.

1.2 Objectives

1.2.1 To assess the cadmium distribution in soil, kale, and infiltrated water when irrigated with cadmium contaminated water at different concentrations.

1.2.2 To assess the safety of crop grown by contaminated water.

1.2.3 To study the long term effects of using cadmium contaminated water for cultivation of kale.

1.3 Hypothesis

1.3.1 Kale is a vegetable commonly consumed in Thailand. If the irrigation water is contaminated by cadmium, the heavy metal may transport to soil, plant, and irrigated water. This phenomenon is unpredictable due to complexity in plant-soil matrix. The relationship between cadmium concentration and its distribution may be non-linear.

1.3.2 Long term application of cadmium contaminated water will cause cadmium accumulation in both soil and kale.

1.4 Scope of this Study

1.4.1 The experiment was conducted in eight laboratory-scale plots, made from pre-cast concrete ring (diameter 1.0 m x height 0.4 m) and filled with 0.1 m -height gravel and 0.25 m -height top soil. Geotextile is placed in between gravel and soil layer. Transparent plastic sheet is used as a cover to prevent rain water from entering the plots.

1.4.2 The irrigated waters were synthesized from tap water and cadmium chloride, resulting in cadmium concentrations of 0.005, 0.01, 0.03, 0.5, 1.0, 2.0, 5.0, and 7.0 mg/L respectively. The cadmium concentrations of 0.005, 0.01, and 0.03 mg/L represented Class-3 water quality standard, drinking water standard, and industrial effluent standard, respectively. The cadmium concentrations of 0.5, 1.0, and 2.0 mg/L represented industrial effluent standards which do not comply with the standards while cadmium concentrations of 5.0 and 7.0 mg/L represented untreated wastewater.

1.4.3 The plant grown was kale (*Brassica oleracea var. alboglaba*), which is favorable vegetable commonly cultivated in Thailand.

1.4.4 The laboratory-scale cultivation was referred to the typical agricultural practices, i.e. applications of fertilizer, pesticide, water, etc., in the nearby area.

1.4.5 The kale cultivation was done consecutively for 4 crops during August 2004 – February 2005, representing long term study.

1.5 Benefits of this Study

1.5.1 To obtain the amount of cadmium concentrations in soil, kale, and infiltrated water and plant safety.

1.5.2 To obtain the fate and transport of cadmium in kale cultivation.

1.5.3 To assess whether present water standards on cadmium are suitable for cultivation.

CHAPTER II

BACKGROUND AND LITERATURE REVIEWS

2.1 Cadmium

2.1.1 Properties

Cadmium is an element that occurs naturally in the earth's crust. Cadmium is not usually present in the environment as a pure metal, but as a mineral combined with other elements such as oxygen (cadmium oxide), chlorine (cadmium chloride), or sulfur (cadmium sulfate, cadmium sulfide) (ATSDR, 1999). The summary of its relevant physico-chemical properties is presented in Table 2.1.

Table 2.1: Physical and chemical properties of Cadmium and Cadmium chloride (Adapted from http://www.atsdr.cdc.gov/toxprofiles/tp5-c3.pdf)

Properties	**Characteristics**	
	Cadmium	**Cadmium chloride**
Molecular weight	112.41	183.32
Physical state	Lustrous solid	Rhombohedral crystal
Melting point	321°C	568°C
Boiling point	765°C	960°C
Density	8.65g/cm^{3}at 25°C	3.33g/cm^{3}at 20°C
Color	Silver-white	Colorless
Odor	Odorless	Odorless
Solubility: **Water** **Organic solvent**	 Insoluble Acid, NH_4NO_3, hot H_2SO_4	 Soluble Acetone, slightly soluble in methanol and ethanol
Vapor pressure	1 mmHg at 394°C	10 mmHg at 656°C; 40mmHg at 736°C; 760mmHg at 967°C

2.1.2 Use of Cadmium

Cadmium is a by-product of the primary non ferrous metal industry. Rather than disposing of it as a waste, engineers have been able to utilize its unique properties for many important industrial applications (http://www.cadmium.org/introduction.html). The use of cadmium compounds falls into five categories: active electrode materials in nickel-cadmium batteries (70% of total cadmium use); pigments used mainly in plastics, ceramics, and glasses (12%); stabilizers for polyvinyl chloride (PVC) against heat and light (17%); engineering coatings on steel and some nonferrous metals (8%); and components of various specialized alloys (2%) (ATSDR, 1999).

The United Nation Economic and Social Commission for Asia and the Pacific (UNESCAP) reported that the rapid industrialization of much of South-East Asia has led to the potential for heavy metal contamination of soil in a variety of ways and on a variety of scales. The principal ways can be classified into four ways: mining activity, industrial activity, wastewater reuse, and fertilizers.

In Thailand, mining activity spread mine spoil and tailings by the use of heavy metals in ore processing. Much mining activity is unregulated resulting in pollution over quite a large area (http://www.unescap.org/esd/water/publications/CD/escap-iwmi/keynote.pdf).

2.1.3 Source and Environmental Fate

Cadmium distributions arise from two major source categories: natural source and anthropogenic source.

2.1.3.1 Natural Source

Even though the average cadmium concentration in the earth's crust is generally placed between 0.1 and 0.5 mg/kg, much higher levels may accumulate in sedimentary rocks, and marine phosphates. In addition, weathering and erosion of parent rocks result in the transport by rivers of large quantities of cadmium to the world's oceans. Moreover, volcanic activity is also a major natural source of cadmium release to the atmosphere. Furthermore, forest fires have also been reported as a natural source of cadmium air emissions.

2.1.3.2 Anthropogenic Source

Anthropogenic activities are associated with industrialization and agricultural activities such as atmospheric deposition, waste disposal, waste incineration, urban effluent, vehicle exhausts, fertilizer application and long-term application of sewage sludge in agricultural land (Vig et al., 2003).

a) Mining activity

Wu (2001) reported that Thailand’s mineral industry consisted of a small mining and mineral processing sector of ferrous and nonferrous metals and a large mining and mineral processing sector of industrial minerals. Mining activity spread of mine spoil and tailings and, in some cases, by the use of heavy metals in ore processing.

Saksirin (1995) studied the heavy metal contamination from zinc refinery in Ping River (Figure 2.1), which receives heavy metal, especially cadmium and zincs from both direct and indirect ways, i.e. community and industry situated in Ping Basin. Some heavy metal disperses through river, precipitate and accumulates in sediment, and enters the food web system. The last consumer who receives high concentration heavy metal is human.

Prayut (1999) studied the distribution of cadmium and zinc in soil from zinc mining activity. The analysis of soil contamination with cadmium and zinc was done in 3 areas: the upstream and downstream areas, located in the same watershed as the zinc mine, and the adjacent area outside the watershed boundary. The results showed that the total cadmium and zinc contamination in the downstream area was higher than that in the upstream area and in the adjacent area.

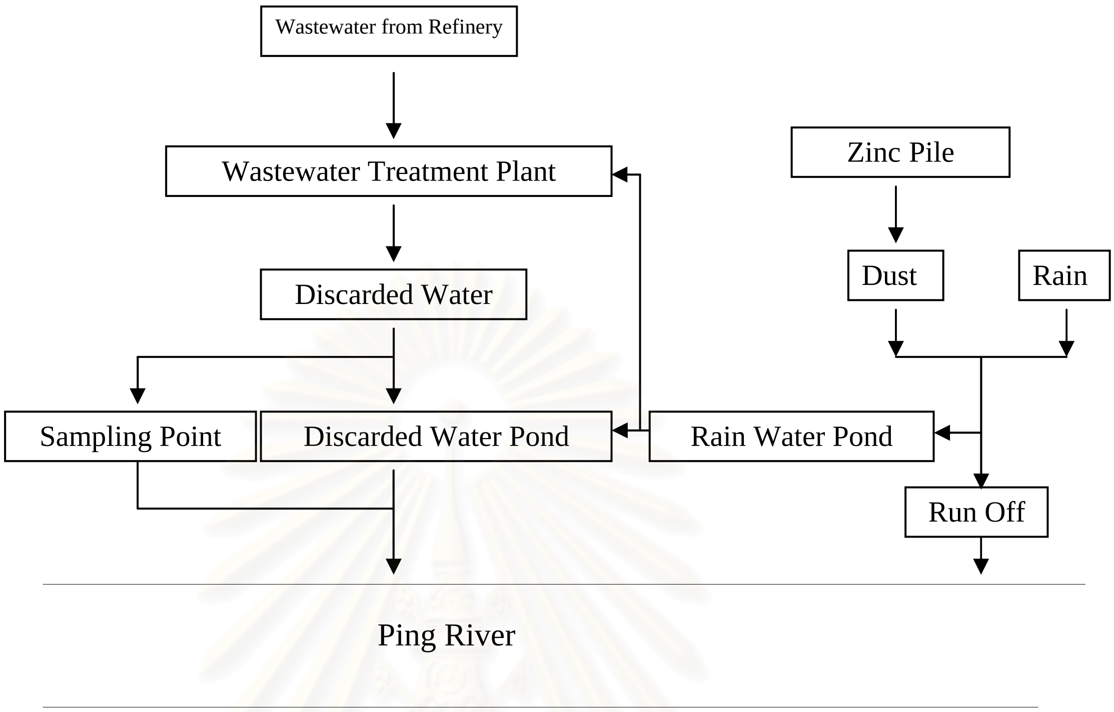


Figure 2.1: Distribution of Heavy Metal from Zinc Refinery (Adapt from Saksirin, 1995).

b) Industrial Activity

The processing and reclamation of metals by industry has led to the widespread contamination of soils in urban and peri-urban areas. It can even happen in more rural areas where cottage industries are processing metals.

c) Wastewater Reuse

Wastewater is potentially a valuable source of both water and nutrients and there is a long history of the use of untreated wastewater for irrigation. Some of the remaining wastewater is inadvertently used because it is mixed with surface water in canals carrying irrigation water. The wastewater can result in contamination traveling large distances largely through the transport of contaminated sediments. While the use of treated wastewater would be much better both for human health and for the environment, this seems unlikely to be adopted on a large scale in the near future.

Land application of raw domestic and industrial wastewater in combination with fertilizers is being used extensively to grow vegetable around sewer disposal sites in India. The amounts of cadmium present in the industrial wastewater were higher than the maximum permissible limit of cadmium prescribed by FAO. The amounts of cadmium presented in soil irrigated with raw domestic and industrial wastewater were higher as compared to the maximum per permissible limit established by EU for toxic metals (Antil et al., 2001).

d) Fertilizers

Aside from the indirect effect of nitrogen fertilizers on soil acidification, phosphate fertilizers can increase the soil loads of various trace metals, most notably cadmium and uranium. The extent of trace metals contamination depends on the geological source of the phosphate rocks used in making the fertilizers. In New Zealand, cadmium levels had increased in the topsoil of New Zealand soil and cadmium levels increase is associated with the application of phosphate fertilizer. Over 80% of the cadmium added in phosphate fertilizer had remained in the topsoil (Taylor, 1997). Fertilizers commonly used in Argentina were analyzed to determine concentrations of chromium, cadmium, copper, zinc, nickel and lead. Rock phosphate contained the highest levels of cadmium and zinc. The levels of cadmium and lead were significantly relative to those naturally present in soils. Continuous fertilization of soils could increase the heavy metal contents exceeding natural abundances in soils, and transfer of these metals to the human food chain must not be overlooked (Carmelo, 1997).

2.1.4 Health Effect

Cadmium is a widespread heavy metal in the environment and in our bodies. Cadmium is very poisonous and only excreted in very small amounts. Cadmium can cause damage to all types of body cells. By damaging the cell membrane, cadmium increases the permeability of the cells, one of the consequences being that the transfer of other heavy metals into the cells is facilitated. In the acute stage, cadmium intoxication causes enteritis. A slow accumulation of cadmium takes place, mainly in the kidneys; the liver and bones are other important sites for cadmium storage. Extremes cases of chronic cadmium toxicity lead to osteomalacia and bone fractures, as in the polluted areas in Japan (McLaughlin et al., 1999).

2.1.5 Regulations

The U.S. Environmental Protection Agency (EPA) classifies cadmium as a probable human carcinogen (Group B1) and has established a reference dose (RfD) of 0.0005 mg/kg body weight/day in water and 0.001 mg/kg body weight/day in food. The reference concentration (RfC) is undergoing review by an EPA Workgroup. Cadmium is generally subject to specific regulatory limits. The EPA has set the maximum contaminant level goal (MCLG) for cadmium in drinking water is

0.005 mg/L and the maximum contaminant level (MCL) is 0.005 mg/L (ATSDR, 1999).

In Thailand, according to the Enhancement and Conservation of National Environment Quality Act B.E. 2535 (1992), Cadmium level in surface water Class-3 water quality standard should not exceed 0.005 mg/L. The drinking water and industrial effluent standards are 0.01 and 0.03 mg/L, respectively.

The Australia New Zealand Food Authority (ANZFA) and European Commission have set the cadmium level in vegetable is 0.1 mg Cd/ kg (wet weight).

The European Commission has set the maximum permissible limit in soil is 3.0 mg Cd /kg (dry weight) (Antil et al., 2001).

2.2 Fate of Cadmium in Soil

Cadmium is relatively mobile in soils and groundwater compared to other metals such as lead and copper. During weathering cadmium goes readily into solution, it may also form several complex ions ($CdCl^+$, $CdOH^+$, $CdHCO_3^+$, $CdCl_3^-$, $CdCl_4^{2-}$, $Cd(OH)_3^-$, and $Cd(OH)_4^{2-}$) and organic chelates. Sorption, rather than precipitation, often controls the distribution of cadmium in soils. As with all metal species in soils, complex formation complicates its partitioning phenomena. The most important valence state of cadmium in the natural environment is +2 and the most important factors which control the Cd ion mobility are pH and oxidation potential. Cadmium is the most mobile in acidic soil within the range of pH 4.5 to 5.5, while in alkaline soil Cd is rather immobile. Alloway (1990) reported that Cd^{+2} predominated in soils, with concentrations of the neutral species $CdSO_4$ and $CdCl_2$ increasing as a function of pH. The key factors that control the sorption of cadmium include pH, organic matter, and hydrous oxide content.

2.3 Kale Cultivation

Kale is in Brassicaceae family and its scientific name is *Brassica oleracea* var. *alboglaba*. Kale is vegetable commonly cultivated and consumed in Asia such as China, Hong Kong, Taiwan, Malaysia, and Thailand. Kale is grown for consuming on leaf and stem. Kale is a leafy vegetable that can grow in a sunny location, moderately moist, and rich soil. Kale can fully grown at the average temperature of 20°C, however Kale can tolerate on high temperature. Most cultivars grown in Thailand are open-pollinated types. Kale has a very short growing season.
(http://www.doae.go.th/library/html/detail.kana/index.html)

2.3.1 Type of Kale

In general, the cultivars classified into three types that cultivated in Thailand; broad leaf, pointed leaf, and long petiole.
(http://www.fao.org/DOCREP/004/AC145E/AC145E09.htm)

Broad Leaf: It is the old type of Kale. They are widely adapted cultivars that can be grown under a wide range of conditions. The plant has a large stem and short internodes. The leaves are broad, round thick and crispy making it popular among consumers. This type includes Fang No.1 (DOA) and Large leaf (Chia Tai) cultivars.

Pointed Leaf: The plant has a large stem, long internodes and smooth pointed leaves. It is heat and disease tolerant and is widely grown at present. Other well-known cultivars are Long Stalk (Chia tai) and Red Arrow (Eastwest). The crop takes 30–55 days from seeding to harvest. This type is represented by the cultivar P.L.20 (DOA).

Long Petiole: This type is grown for its stem and petiole. The cultivars include Maejo No.1 (DOA) and Super 094 (Chia Tai F1). The plant has a large stem and long internodes. The leaves are narrow, pointed, with a thick-long petiole. It is well suited for inter-regional transport and distribution as it has better keeping quality.

2.3.2 Soil Preparation

Soil should be worked to a depth of at least 15-20 centimeters and smoothed before planting.

2.3.3 Cultivation

As with other cool-season brassicas, kale should be planted in mid-August. It would take about 14 days to germinate. Thin seedlings are to stand 6 inches apart when they are 3 to 4 inches tall. Kale is not a heavy feeder and easy cultivated.

2.3.3.1 Watering

Kale grows best with uniform soil moisture. Watering sufficiently is to moisten the soil to a depth of at least 6 inches. Avoid light sprinklings, which encourage shallow rooting. The critical periods for moisture are stand establishment and crop maturation. Mulching can help conserve water and reduce weeds. Use very shallow cultivation to help keep crops free of weeds.

2.3.3.2 Fertilizing

The chemical fertilizer (N: P: K=15:15:15) should be applied after transplanting at the rate of 50 kg/rai. Because of kale is a leaf and stem vegetable, high nitrogen fertilizer should be utilized. After 7 and 14 day, the chemical fertilizer (N: P: K= 46:0:0) is applied at the rate of 25 kg/rai.

2.3.4 Harvesting

Kale flavor is best just before the flowers open. The central heads will never approach the size of commercial kale; however, harvest the secondary shots for an extended harvest.

2.3.5 Insects Control

Control flea beetles on the young seedlings with floating row covers and/or applications of “Rotenone ™”. After transplanting, application of carbonyl was used to control worms.

2.4 Literature Review

2.4.1 Accumulation of Heavy Metals in Plants

Kijjanapanich and Karnchanawong (2004) studied water quality of infiltrate from laboratory-scale plots, which were irrigated by different types of effluent from domestic wastewater treatment plants. Raw domestic wastewater (RW), primary treatment effluent (PE), activated sludge treatment effluent (AS), aerated lagoon effluent (AL) and irrigation canal water were comparatively employed to irrigate rice, aster, kale and cabbage. The water qualities of infiltrates were not significantly different among these irrigated waters, except for microbiological property.

Karnchanawong et al. (2002) studied heavy metal contamination in edible crops, irrigated by effluent from domestic wastewater treatment plant. Zinc and copper were measured in higher level than cadmium and lead in all crops, whereas rice adsorbed highest amount of heavy metal. The heavy metal contamination is much lower than maximum permissible level and safe for consumption.

Jiang et al. (2001) investigated the effect of Cd^{+2} concentrations on the root, bulk and shoot growth of garlic and accumulation of Cd^{+2} in those parts. The range of cadmium chloride concentration was 10^{-6}-10^{-2} M. The authors reported that cadmium stimulated root length at lower concentrations (10^{-6}-10^{-5} M) significantly ($P< 0.005$) during the entire treatment period. The cadmium content in roots of garlic increased with increasing solution concentrations of Cd^{+2}.

Alloway et al. (1990) studied the accumulation of cadmium in vegetables grown on soils contaminated from a variety of source. The experiment was investigated in greenhouse pots. The result showed that eight soils of total sources were significantly related to cadmium accumulation in the edible plant tissues. In addition, the concentration of cadmium in the soil increased, while the proportion available to the plant decreased.

Dudka et al. (1996) studied the effect of highly elevated levels of Cd, Pb, and Zn in soil contaminated by smelter flue-dust in different crop plants. A 4-year field experiment was conducted to study the transfer of Cd, Pb, and Zn from soil contaminated by smelter flue-dust to crop plants grown in a rotation. The soil was amended with Pb-Zn smelter flue-dust to simulate the long-term effect that the smelting of non-ferrous metal ore has on arable soils. Concentration of Cd, Pb, and Zn in barley grain, barley straw, meadow bluegrass, red clover, and potatoes were generally low. The highest metal concentrations were found in potato tuber, meadow bluegrass, and barley straw.

2.4.2 Toxicity of Cadmium

Yilmaz et al. (2004) investigated the toxic effects of cadmium chloride in the guppy (*Poecillia reiculata*) by determination of 96-h LC_{50} values and evaluated behavioral disorders of the guppy exposure to different concentration of cadmium chloride. The result showed that the behavioral changes observed in fish were swimming in imbalance manner, capsizing, attaching to the surface, difficulty in breathing and gathering around the ventilation fitter.

Youn-Joo An (2004) investigated the differential toxicity and bioavailability of Cd to sweet corn, wheat, cucumber, and sorghum in laboratory soil microcosms by recommendation some sensitive plant species to assess an ecotoxicity in cadmium- amended soil. The endpoints of measurement were seed germination and seedling growth (shoot and root). The result illustrated that the presence of cadmium decreased the seedling growth. EC_{50} values for shoot or root growth were calculated by Trimmed Spearman-Karber method. Root growth was more sensitive endpoint than shoot growth because of the greater accumulation of Cd to the root. Moreover, bioavailability and transport of Cd within plant were related to concentration and species.

2.4.3 Method

Tűzen (2003) determined the concentrations of heavy metals in the soil, mushroom and plant samples by flame and graphite furnace atomic absorption spectrophotometer after dry ashing, wet ashing and microwave digestion. The study of sample preparation procedures showed that microwave digestion method was the best. Good accuracy was assured by the analysis of standard reference materials. The relative standard deviations for all measured metal concentration were lower than 10%.

2.4.4 Transport of Heavy Metal

Xue et al (2003) compared the migration of Cu and Zn from two soil type to the River Kleine Aa and evaluated the transport of Cu and Zn in the catchments via artificial drainage-aided soil leaching. Long-term manure-borne copper and zinc input to grassland soils resulted in their catchments in water concentrations that often exceeded the surface water quality criteria. Elevated metal concentrations in the soil solution do not necessarily cause greater loss to water because of the greater water retention capacity of the organic matter. Therefore, artificially drained organic matter can contribute significantly to the observed elevated Cu and Zn concentration of the river.

CHAPTER III

METHODOLOGY

3.1 Laboratory-Scale Plot

Eight laboratory-scale plots were made from pre-cast concrete ring (diameter 1.0 m x height 0.4 m) and covered with transparent plastic sheet to prevent rainwater as shown in the Figure 3.1. Two additional plots (number 9, 10) were used for seedling preparation. The plots were filled with 0.1 m -height gravel and 0.25 m -height top soil. Geotextile was used to separate between gravel and soil layer. A PVC pipe with diameter of 1 inch was installed at the bottom of concrete ring to drain the infiltrated water. The 6 mm holes were drilled at every 0.025 m along the pipe. Details of plots, constructed on the roof at Department of Environmental Engineering, Chiang Mai University, are shown in Figure 3.2 and 3.3.

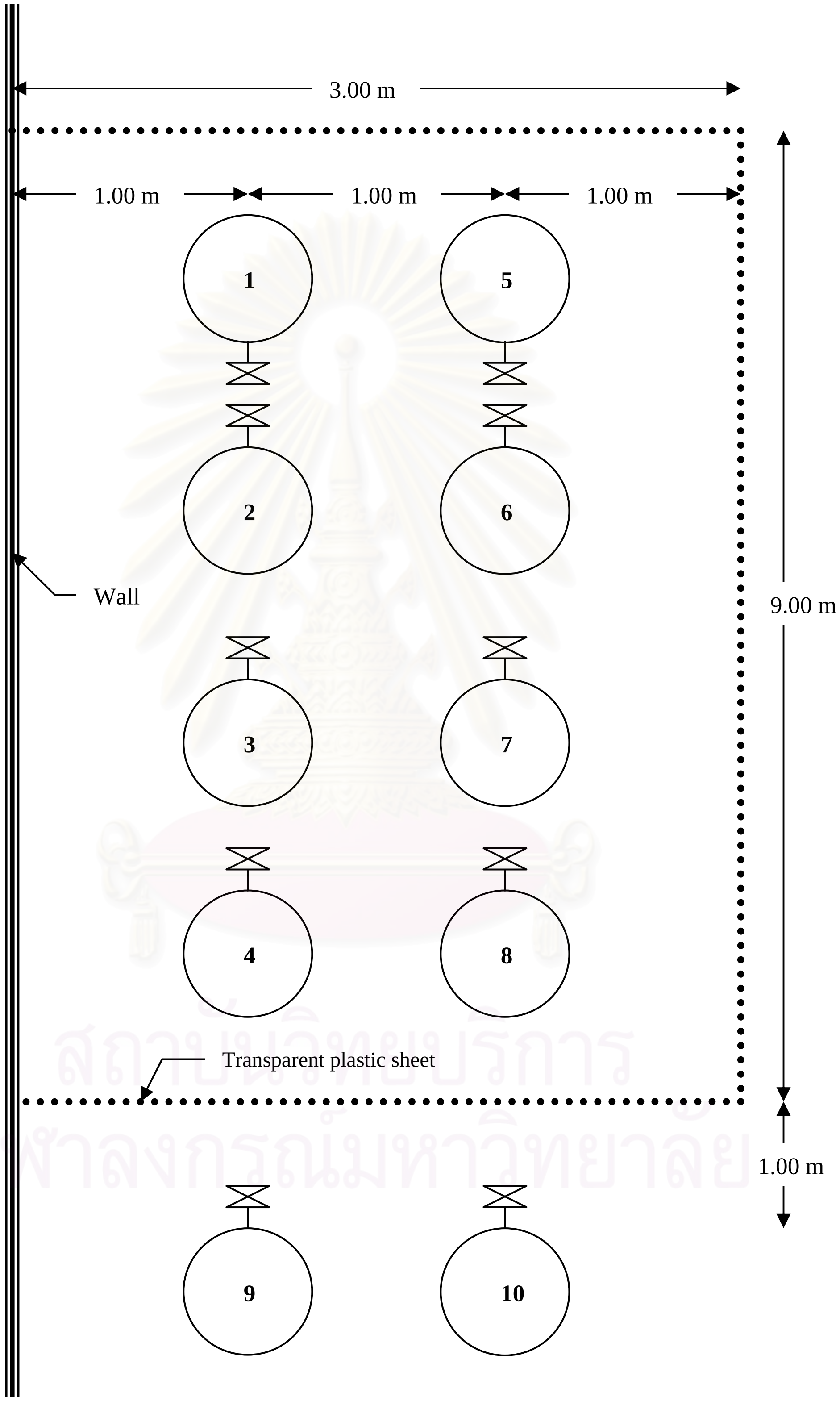
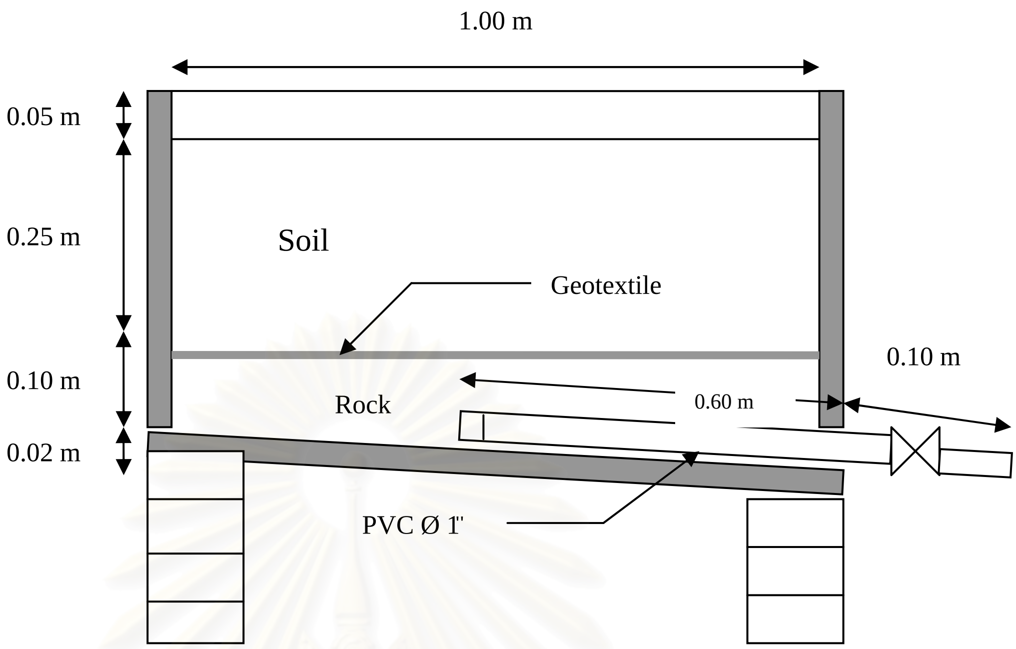
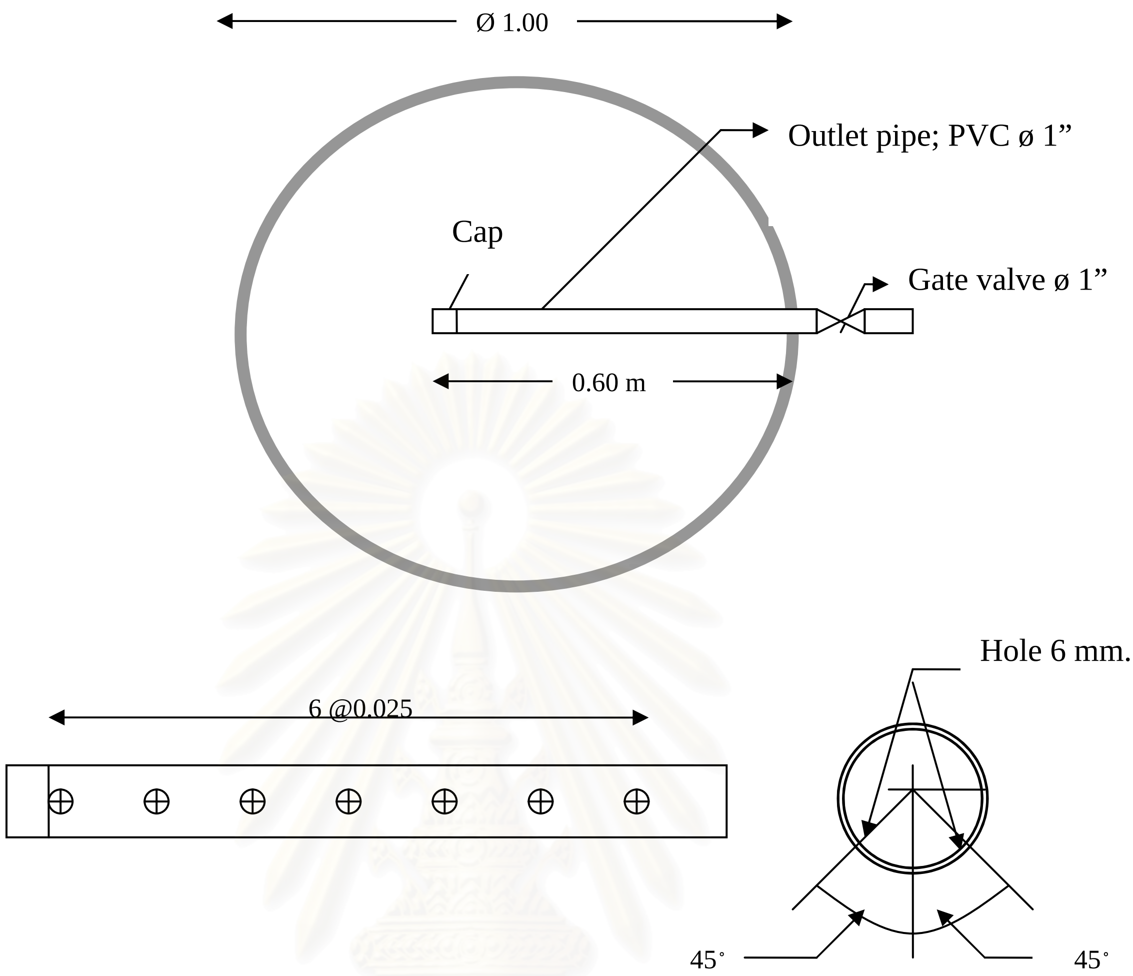


Figure3.1: Plan of laboratory-scale plots.



a) Side view

Figure 3.2: Details of laboratory-scale plots.



b) Top view of pre-cast concrete ring and outlet pipe

Figure 3.2: Details of laboratory-scale plots (Continue).

Figure 3.3: Photographs of laboratory-scales plot.

3.2 Kale Cultivation

Seeds were sowed in plot number 9 and 10 as shown in Figure 3.4. The seedlings were transplanted when they were 9-10 cm in height or about 25-30 days after sowing. Totally 18 seedlings were transplanted per plot at the spacing of 20 x 20 cm (Karnchanawong et al., 2003). Chemical fertilizers were used according to agricultural practiced in the area. The first compound fertilizer (N: P: K=15:15:15) were applied after transplanting at the rate of 50 kg/rai (312.5 kg/ha). Seven days later, the urea fertilizer (N: P: K= 46:0:0) was applied at the rate of 25 kg/rai (156.2 kg/ha). Fourteen days after transplanting, the urea fertilizer was used again at the same rate.

The pesticide, carbaryl, was mixed at 2-3 g/L of water and sprayed every 2 weeks after transplanting. Kale was harvested when they grown about 30-40 days after transplanting. Four consecutive cultivations are presented in Table 3.1.

Figure 3.4: The seedling preparation.

Table 3.1: Kale cultivation period

Crop Number	Seedling Preparation	Transplanted	Harvested	Growing Period on plot, day
1	5 Jul. 04	3 Aug. 04	7 Sep. 04	35
2	22 Aug. 04	25 Sep. 04	25 Oct. 04	27
3	16 Nov. 04	7 Dec. 04	30 Dec. 04	22
4	24 Dec. 04	15 Jan. 04	15 Feb. 04	28

3.3 Irrigated Water Preparation

Cadmium chloride ($CdCl_2.2.5H_2O$, Univar, reagent grade, 99.0%) was used without further purification. The 1,000 mg Cd/L stock solution was prepared. The irrigated water was daily prepared with tap water and stock solution to the required concentration of cadmium, 0.005, 0.01, 0.03, 0.5, 1.0, 2.0, 5.0, and 7.0 mg/L. The irrigation rate was at $13m^3$/ (rai.day) or 81.2 m^3/ (ha.day) which was equivalent to 6 L/ (plot.day). The irrigated water was poured once in the morning. Grab samples of irrigated water were collected every 3 days.

3.4 Infiltrated Water Collection

Composite sample accumulated during 3 day period were collected from infiltrated water tank, 10 L, in each plot. Total infiltrated volume was recorded. The samples were filtered through 0.45-µm membrane filter, acidified with nitric acid to a pH 2 and stored in a refrigerator at approximately 4˚C prior to analysis (APHA, 1998).

3.5 Soil

Soil samples were collected by core sampler, Figure 3.5, at 15-20 cm depth from the soil surface. This level represents root zone of kale.

Figure 3.5: Core sampler.

3.5.1 Before Cultivation

3.5.1.1 The test soil was collected from agricultural area in Chiang Mai province before cultivation, representing no exogenous input of cadmium.

3.5.1.2 Soil sample was sieved to remove gravel and debris and was dried for 24 hr at 105˚C.

3.5.1.3 The soil sample was sent to the Department of Civil Engineering and Faculty of Agriculture, Chiang Mai University for analysis. The parameters included specific gravity (Specific Gravity Test; AASHTO T100-70), grain size distribution (Hydrometer Analysis; AASHTO T87-70), organic matter, total nitrogen, phosphorus, potassium, and cation exchange capacity.

3.5.2 After Harvesting

3.5.2.1 Four soil samples from laboratory-scale kale cultivation were collected. The four sampling points as shown in Figure 3.6 were mixed into one sample.

3.5.2.2 Soil samples were dried for 24 hr at 105˚C, ground and sieved to remove gravel, kept in the desiccator prior to digest with microwave digestion (Appendix A) and analysis by atomic absorption spectrophotometer (Appendix B).

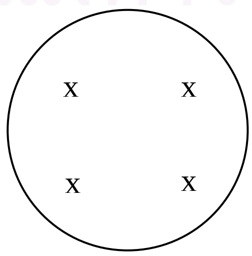


Figure 3.6: Soil sampling points in each plot.

3.6 Plant Sample Collection

3.6.1 During harvesting, stems, at 1.0 cm above soil surface, were cut prior to weighting. Roots were removed from soil, washed and dried in open air for 1 hour before weighting.

3.6.2 Five matured plants, out of eighteen in each plot, were taken, as in Figure 3.7, for further analysis.

3.6.3 Kale samples were cleaned with tap water repeatedly and finally with de-ionized water. They were mixed according to root, stem, and leaves, resulting in three samples in each plot.

3.6.4 Samples were dried in an oven at 75˚C for about 72 hours and grinded by grinding mill. All kale samples were kept in the desiccator prior to digestion and analysis.

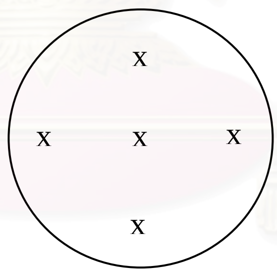


Figure 3.7: Plant sampling points.

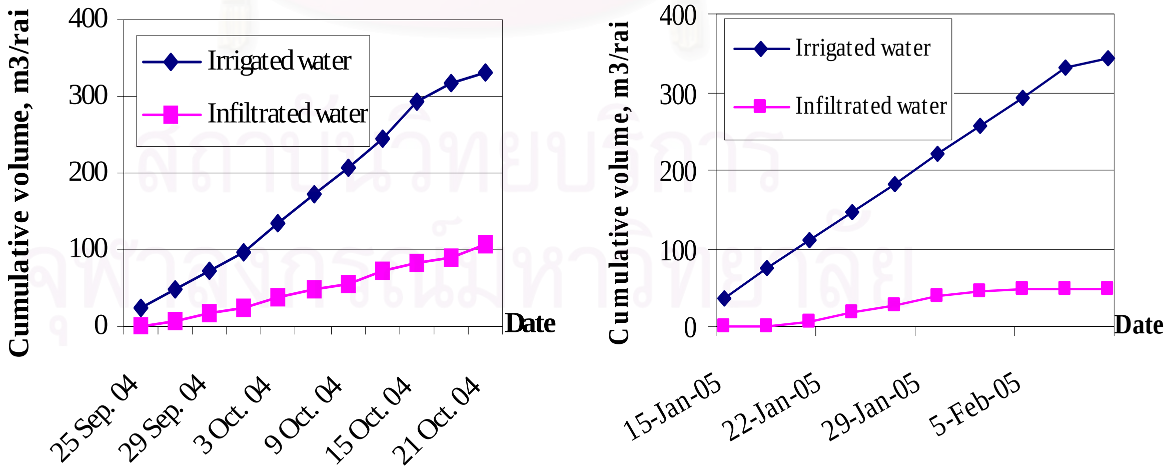
CHAPTER IV

RESULTS AND DISCUSSION

4.1 Water Usage and Quality

4.1.1 Amount of Irrigated and Infiltrated Water

Kale cultivation periods for crop 1, 2, 3, and 4 were in August – September 2004, September – October 2004, December 2004, and January – February 2005, respectively. Four crops of kale cultivation can be classified into two seasons; rainy season (crop 1 and 2) and dry season (crop 3 and 4). The cumulative volume of irrigated and infiltrated water throughout the study is summarized in Table 4.1 while the typical patterns are shown in Figure 4.1.



a) Plot 3 (0.03 mg Cd/L), crop 2 representing rainy period

b) Plot 8 (7.0 mg Cd/L), crop 4 representing dry period

Figure 4.1: Typical cumulative volume of irrigated and infiltrated water.

Table 4.1: Cumulative volume of irrigated and infiltrated water in kale cultivation.

Crop	Growing period	Plot number	Target cadmium concentration, mg/L	Cumulative volume, m^3/rai		
				Irrigated water	Infiltrated water	Infiltrated, % of total water input
1	August to September 2004	1	0.005	427	154.6	36.2
		2	0.01	427	167.7	39.3
		3	0.03	427	160.1	37.5
		4	0.5	427	178.2	41.7
		5	1.0	427	178.1	41.7
		6	2.0	427	171.4	40.1
		7	5.0	427	157.5	36.9
		8	7.0	427	169.1	39.6
	Average					39.1
2	September to October 2004	1	0.005	330	86.4	26.2
		2	0.01	330	117.4	35.6
		3	0.03	330	105.3	31.9
		4	0.5	330	99.7	30.2
		5	1.0	330	85.5	25.9
		6	2.0	330	99.4	30.1
		7	5.0	330	111.3	33.7
		8	7.0	330	103.9	31.5
	Average					30.6
3	December 2004	1	0.005	269	69.5	25.8
		2	0.01	269	85.2	31.7
		3	0.03	269	71.1	26.4
		4	0.5	269	86.4	32.1
		5	1.0	269	43.0	16.0
		6	2.0	269	53.4	19.8
		7	5.0	269	49.9	18.5
		8	7.0	269	63.6	23.6
	Average					24.2
4	January to February 2005	1	0.005	342	58.7	17.2
		2	0.01	342	71.1	20.8
		3	0.03	342	70.1	20.5
		4	0.5	342	61.7	18.0
		5	1.0	342	24.9	7.3
		6	2.0	342	49.5	14.5
		7	5.0	342	48.3	14.1
		8	7.0	342	48.7	14.2
	Average					15.8

The rate of irrigated water in each crop of kale cultivation was fixed while the total irrigated volume per crop was different depending on cultivation period, as shown in Table 3.1. The average percentage of infiltrated water on total water input gradually decreased from 39.1 % to 15.8 %. It is clearly shown that infiltrated volume depends on season. For example, rainy season cultivation (i.e. high temperature, high humidity, and short sunlight) had very high amount of infiltrated water in the first cultivation as shown in Table C.8. The data on temperature, humidity, and sunlight are presented in Appendix C.

4.1.2 Cadmium Concentration in Irrigated Water

During Crop 1 study, it was found that analytical results were exceptionally high, possibly due to insufficient experiences of researchers. All cadmium data in crop 1 were therefore excluded from this study.

The cadmium concentrations in irrigated water were expected at the concentration of 0.005, 0.01, 0.03, 0.5, 1.0, 2.0, 5.0, and 7.0 mg Cd/L, respectively. However**,** the discrepancy in preparation of the cadmium concentration resulted in some variations and the actual concentrations were different from the targeted concentrations as presented in Table 4.2. Figure 4.2 shows the relationship between cadmium in target concentrations and actual concentrations of irrigated water which is still acceptable (R^2 = 0.988). It was found that concentration variations were very high in plot 1 where a target value was the lowest. In low cadmium concentration of irrigated water, the preparation of irrigated water to met target concentration was difficult due to personal accuracy.

The pH of irrigated water was in neutral range with pH values ranging from 7.1 to 8.0, as shown in Table C.5 – C.8. The tolerance limit of pH for irrigation ranged from 6.0 to 9.0 (Rattan et al., 2005 and Patel et al., 2004) and the irrigated water had pH within the permissible limit.

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dddjsld

Table 4.2: Target and actual concentration of cadmium in irrigated water.

Plot Number	Target concentration in irrigated water , mg/L	Actual concentration, mg/L						
		Crop 2		Crop 3		Crop 4		Average
		Range	Mean	Range	Mean	Range	Mean	
1	0.005	0.002-0.017	0.008	0.001-0.011	0.005	0.002-0.045	0.018	0.010
2	0.01	0.003-0.025	0.010	0.003-0.021	0.009	0.004-0.047	0.025	0.014
3	0.03	0.002-0.040	0.018	0.004-0.017	0.012	0.006-0.084	0.040	0.023
4	0.5	0.064-1.060	0.804	0.820-1.046	0.910	0.260-1.083	0.600	0.771
5	1.0	1.270-1.710	1.424	1.260-1.780	1.479	0.550-1.400	0.971	1.291
6	2.0	2.290-2.840	2.557	2.360-2.630	2.524	1.160-2.550	2.003	2.361
7	5.0	5.340-6.390	5.830	5.540-6.310	5.926	2.470-5.750	4.837	5.531
8	7.0	7.510-9.060	8.269	6.400-9.880	8.538	3.480-8.640	7.139	7.982

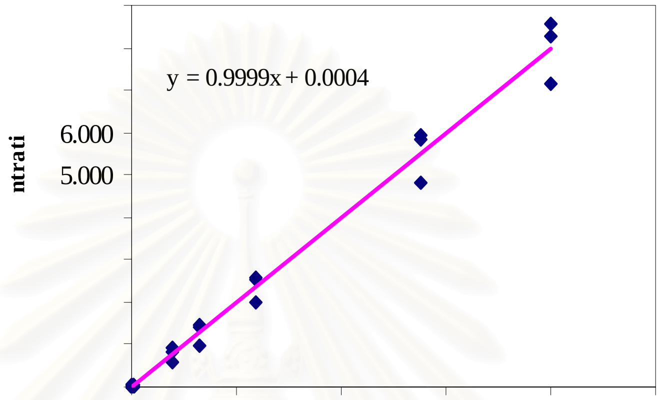


Figure 4.2: Relationship between cadmium in target and actual concentration of irrigated water.

4.1.3 Cadmium Concentration in Infiltrated Water

Figure 4.3 presents the cadmium contents in infiltrated water for the whole cultivation in each plot. The results obtained shows that cadmium in infiltrated water of any plot varied without distinct pattern under long term cultivation. In plots irrigated with low cadmium concentration, i.e. plot 1, 2, 3, cadmium in infiltrated water of the first cultivation was very high, and the concentration decreased rapidly on the consecutive cultivation. It is expected that low precision of cadmium analysis at low concentration as well as cadmium leaching during the first cultivation may be the reason. In plots with higher cadmium concentration (plot 6, 7, 8), there are no distinct pattern of cadmium concentration in infiltrated water under long term cultivation.

Cadmium concentrations in infiltrated water are summarized in Table 4.3. In this study, the third cultivation of plot 8 (7.982 mg Cd/L in irrigated water)

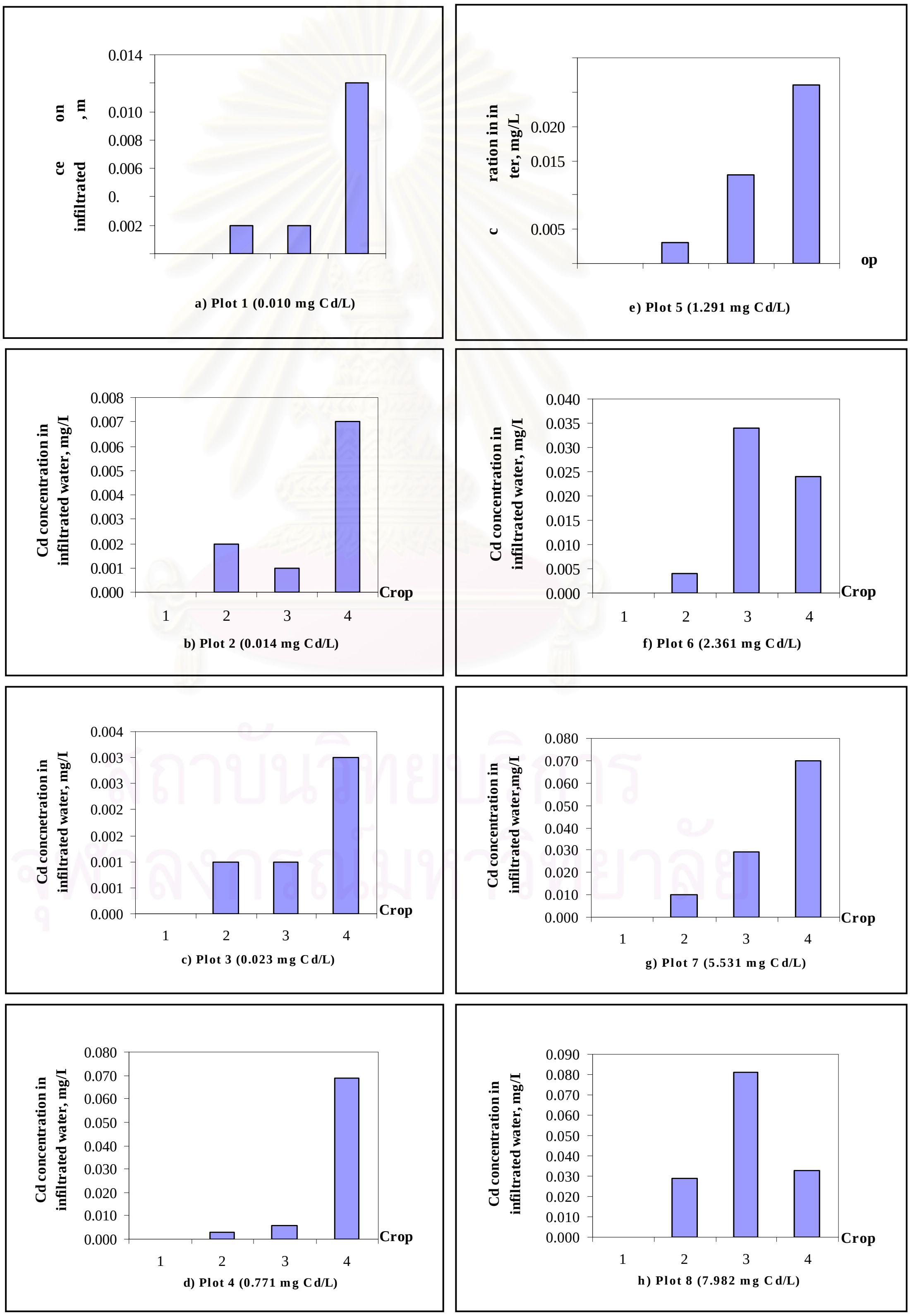


Figure 4.3: Variation of average cadmium concentration in infiltrated water.

Table 4.3: Average cadmium concentrations of infiltrated water.

Plot number	**Actual concentration in irrigated water, mg/L**	**Cadmium concentration in infiltrated water, mg/L**							**Drinking water standard, mg/L**
		Crop 2		**Crop 3**		**Crop 4**		**Average**	
		Range	**Mean**	**Range**	**Mean**	**Range**	**Mean**		
1	0.010	0.000-0.006	0.002	0.001-0.003	0.002	0.001-0.058	0.012	0.005	- EPA
2	0.014	0.000-0.007	0.002	0.000-0.003	0.001	0.001-0.043	0.007	0.003	0.005
3	0.023	0.000-0.002	0.001	0.000-0.001	0.001	0.001-0.005	0.003	0.002	- WHO
4	0.771	0.001-0.006	0.003	0.002-0.014	0.006	0.004-0.428	0.069	0.026	0.003
5	1.291	0.000-0.006	0.003	0.001-0.032	0.013	0.008-0.073	0.026	0.014	- Thailand
6	2.361	0.002-0.009	0.004	0.005-0.086	0.034	0.006-0.084	0.024	0.021	0.01
7	5.531	0.002-0.022	0.010	0.011-0.058	0.029	0.014-0.179	0.070	0.036	
8	7.982	0.004-0.073	0.020	0.028-0.164	0.081	0.024-0.052	0.033	0.044	

Remark ***** Drinking water standard.

gave the highest cadmium concentration in infiltrated water. The second and third cultivation of plot 3 (0.023 mg Cd/L in irrigated water) and plot 2 (0.014 mg Cd/L in irrigated) gave the lowest cadmium concentration in infiltrated water. Although the concentrations of heavy metals in the infiltrated water were generally low, there is a potential to leach into deeper soil and groundwater (Sukreeyapongse et al., 2002). For low concentration in irrigated water, i.e. plot 1, cadmium was not much adsorbed in soil or absorbed in kale so that cadmium in infiltrated water was rather high as compared to irrigated water. For high concentration in irrigated water, cadmium was greatly adsorbed so that very low concentrations appeared in infiltrated water. The adsorption in soil reduced cadmium to a certain low level. For high concentration in irrigated water, the infiltrated water had relatively very low cadmium concentration as compared to irrigated water. This behavior did not occur in case of low concentration in irrigated water because the sorption limitation i.e., soil adsorption and plant absorption where cadmium could not be much reduced. The percentage of cadmium difference i.e., concentrations in infiltrated water/ irrigated water, as clearly presented in Table 4.3 showed the sorption limitation. It is expected that irrigation method by pouring 6 liters of water per plot once a day created high space velocity, i.e., volume of flow/ volume of soil, thus limiting the adsorption in soil. The soil generally adsorbs cadmium to a certain concentration and the irrigated water concentrations in plot 1 and 2 were closed to that limit. Therefore, no further reduction in cadmium was found in plot 1 and 2. According to Table 4.4, this table presented mass cadmium of irrigated and infiltrated water. In this study, irrigated volume was fixed at 6 liters/ plot/day that applied from the rate of pouring of agricultural practices while infiltrated water varied according to season. Mass of cadmium in high concentration irrigated water was generally higher than in low concentration. Mass of cadmium in infiltrated water had lower values than those in irrigated water. Furthermore, mass of cadmium in infiltrated water had no variation in all cultivation.

The pH of infiltrated water was in neutral range with pH values ranging from 7.0 to 8.9, as shown in Table C.5 – C.8. For cultivation, the pH of infiltrated water did not affect on the growth of agricultural product. Moreover, kale had high tolerance limit on pH in basic range.

Table 4.4: Mass of cadmium in infiltrated water.

Plot number	Actual concentration in irrigated water, mg/L	Crop	Mass of Cd in irrigated water, mg	Mass of Cd in infiltrated water, mg	% Remaining from input
1	**0.010**	**2**	1.296	0.085	6.55
		3	0.660	0.068	10.30
		4	3.024	0.346	11.44
2	**0.014**	**2**	1.620	0.576	35.55
		3	1.188	0.042	3.54
		4	4.200	0.244	5.81
3	**0.023**	**2**	2.916	0.052	1.78
		3	1.584	0.035	2.21
		4	6.720	0.103	1.53
4	**0.771**	**2**	130.248	0.147	0.11
		3	120.120	0.254	0.21
		4	100.800	2.091	2.07
5	**1.291**	**2**	230.688	0.126	0.05
		3	195.228	0.274	0.14
		4	163.128	0.317	0.19
6	**2.361**	**2**	414.234	0.195	0.05
		3	333.168	0.891	0.27
		4	336.504	0.583	0.17
7	**5.531**	**2**	944.460	0.546	0.06
		3	782.232	0.711	0.09
		4	812.504	1.659	0.20
8	**7.982**	**2**	1339.578	1.479	0.11
		3	1127.016	2.527	0.22
		4	1199.352	0.789	0.06

United State Environmental Protection Agency (US.EPA) and World Health Organization (WHO) set maximum permissible level of cadmium content in drinking water at 0.005 and 0.003 mg/L, respectively. Thailand drinking water standard is set at 0.01 mg/L. The average data of infiltrated water in our cultivation are compared with standards as shown in Figure 4.4. In second cultivation, the cadmium contents in infiltrated water from plots having 0.010 mg Cd/L to 2.361 mg Cd/L in irrigated were lower than EPA standard. In third cultivation, only plots 1, 2, 3 with, 0.010 to 0.023 mg/L in water input had infiltrated water meeting EPA standard. In fourth cultivation, the cadmium concentrations of infiltrated water were mostly higher than EPA, WHO, and Thailand standard except plot 3 (i.e. having 0.023 mg Cd/L in irrigated water). Based on infiltrated water quality, cadmium contaminated water with concentration higher than 0.023 mg/L is not suitable since the infiltrated water can not meet Thailand drinking water standard. If the high infiltrated water reach shallow well, i.e. 2 – 3 m. below soil surface, the risk of cadmium contamination is possible when people used cadmium contaminated water for drinking. The distinct relationship between cadmium concentrations in irrigated and infiltrated water of all cultivation was not found.

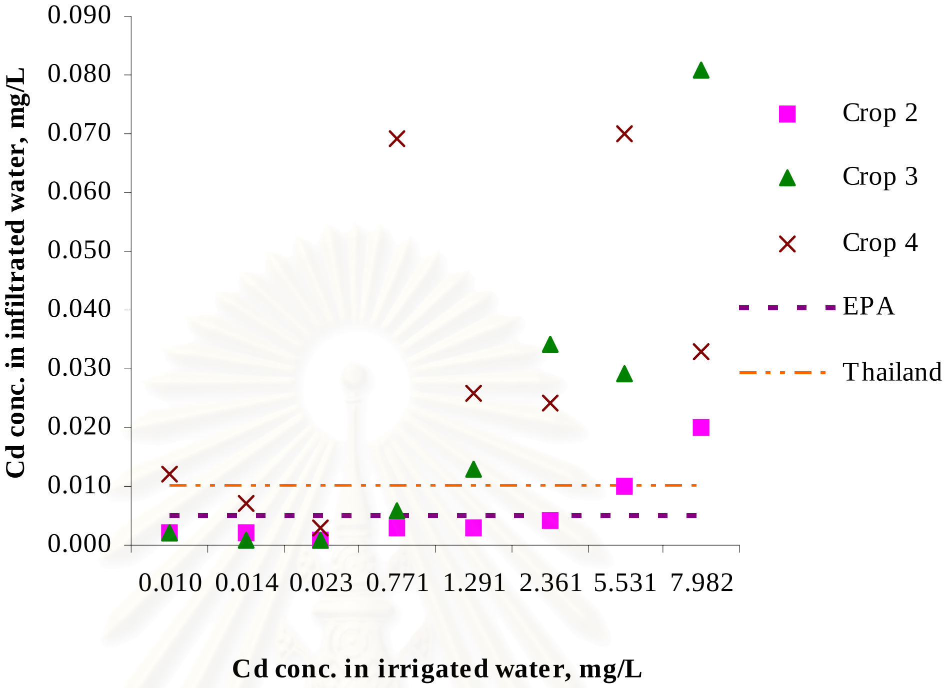


Figure 4.4: Cadmium in infiltrated water.

4.2 Soil

4.2.1 Soil Characteristics

Soil properties used in this study are presented in Table 4.5.

Table 4.5: Physiochemical properties of soil used in this study.

Parameters	Values
pH (H_2O)	6.08
Specific gravity (g/cm^3)	2.589
Organic matter (%)	2.67
Cation Exchange Capacity (cmol(+)/kg)	12.73
Nitrogen (g/kg)	1.2
Phosphorus (mg /kg)	3.24
Potassium (mg /kg)	111.8
Total cadmium (mg /kg)	0.12
Sand (%)	16.5
Silt (%)	57
Clay (%)	26.5

The pH in the cultivated soil studied was neutral. Christensen (1984) reported that soil pH is the most critical factor governing the distribution of cadmium between soil and solution. Soil pH influences plant growth directly, via the effect of the hydrogen ions, and indirectly, via effects on nutrient availability (Bewket and Stroesnjder, 2003). The specific gravity value was 2.589 g/cm^3. Value of 12.73 cmol (+)/kg was obtained for the cation exchange capacity (CEC). It had rather high CEC which was comparable in ENG-5 soil in England (21.9 cmol/kg) (Hooda and

Alloway, 1998). The CEC of soils is determined by their soil organic matter (SOM) content and the amount and type of clay minerals present. CEC is important in soil fertility for two reasons: (i) the total quantity of nutrient available to plant as exchangeable cations depends on it, and (ii) it influences the degree to which hydrogen and aluminum ions occupy the exchange complex, and thus affects the soils (Olaitan et al., 1986). The percentage of organic matter was 2.67. It was high percent of organic matter which compared with IND-5 soil in India (0.17 %) (Hooda and Alloway, 1998). Organic matter and clay content of soil can also significantly influence the concentration of soil solution Cd (Vig et al., 2003). The nutrient element (N: P: K) of cultivated soil before cultivation was 1.2 g/kg, 3.24 mg/kg, and 111.8 mg/kg, respectively. The nutrient element was added during cultivation. Indeed, the nutrient element in this studied was enough for cultivation. According to American Association of State Highway and Transportation Officials (AASHTO), particle size distribution of cultivated soil studied could be classified as sand (16.5 %), silt (57.0 %), and clay (26.5 %). Soil texture was classified as silt loam. Generally, Cadmium presents more toxicity in sandy soils than in clay soils (Vig et al., 2003). Total cadmium before kale cultivation was 0.12 mg/kg which is within EU standard (3.0 mg/kg)

4.2.2 Cadmium Contamination in Surface Soil

Generally, there are two major pathways for human exposure to soil contamination: soil-plant-human (food chain pathway) and soil-human (incidental soil digestion) (Yu-Jing et al., 2004). In this study, food chain pathway was considered. According to Figure 4.5 and Table 4.6, it was found that, in low cadmium concentration irrigated water, cadmium contamination of the whole cultivation in soil varied without distinct pattern. In high cadmium concentration irrigated water; i.e. plot 4 -8, cadmium contamination in soil showed the increasing trend under long-term cultivation. Concentration of cadmium in the soil with the addition of the highest cadmium concentration of irrigated water reached the levels observed in extremely contaminated soils in the smelting area. For example, the fourth cultivation in plot 8 (7.982 mg Cd/L of irrigated water) had highest cadmium concentration (17.4 mg/kg) which was comparable to cadmium contaminated area near a smelter in china (22.06 mg/kg) (Yu-Jing et al., 2004).

Table 4.6: Average cadmium contamination in soil.

Plot number	**Actual concentration in irrigated water, mg/L**	**Cadmium concentration in soil, mg/kg**			**EU standard*, mg/kg**
		Crop 2	**Crop 3**	**Crop 4**	
1	0.010	0.3	0.1	0.1	3.0
2	0.014	0.1	0.1	0.3	
3	0.023	0.1	0.1	0.2	
4	0.771	0.7	0.9	0.4	
5	1.291	1.4	1.0	2.8	
6	2.361	1.3	0.6	5.3	
7	5.531	1.1	2.7	6.8	
8	7.982	2.2	2.8	17.4	

Remark *****Based on dry weight soil.

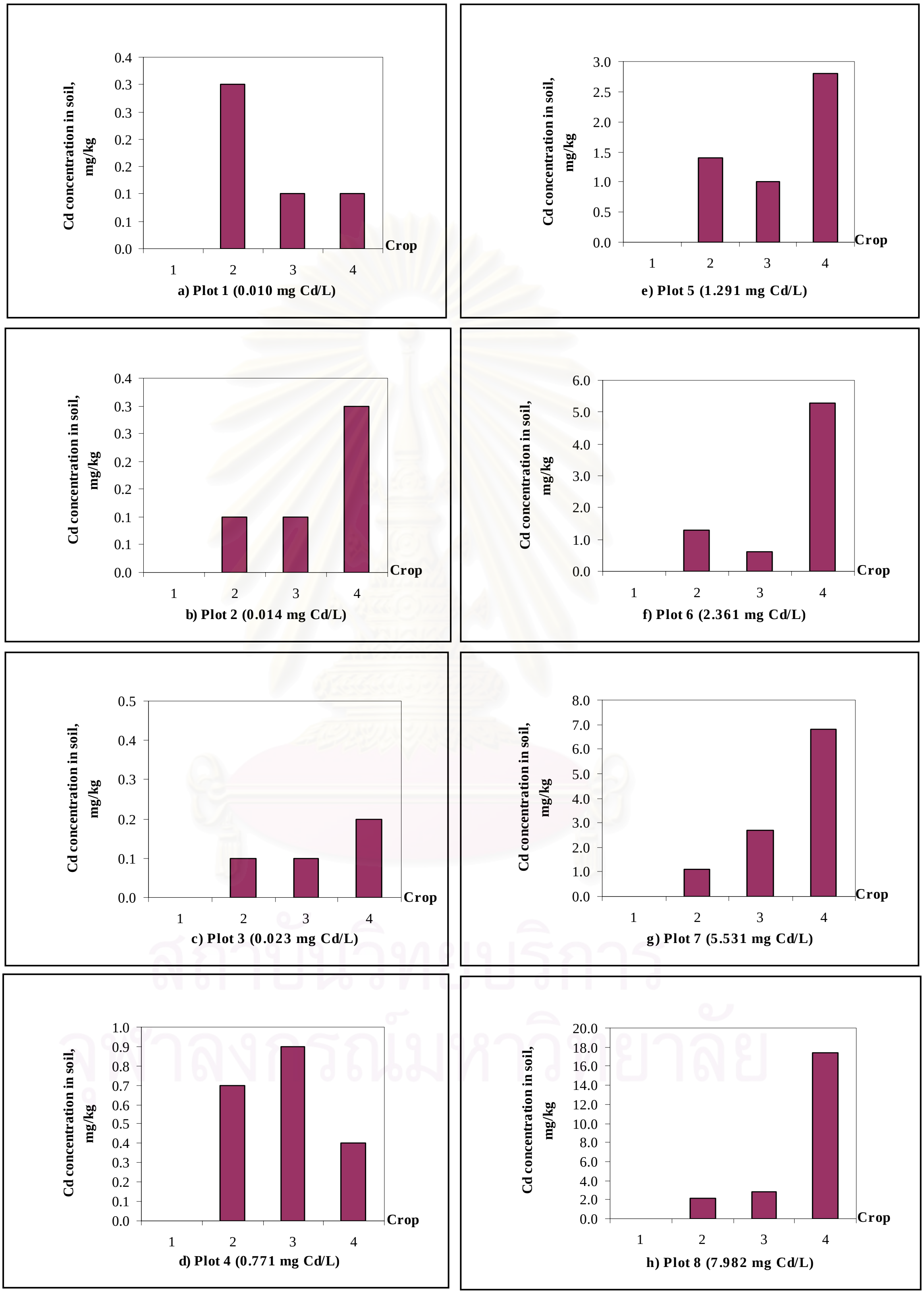


Figure 4.5: Variations of cadmium contamination in soil.

Figure 4.6 presents the cadmium concentrations in the soil comparable to EU standard. The fourth cultivation in plot 6, 7, and 8 had cadmium contents in soil exceeding EU standard while plot 5 may exceed standard under longer cultivation period. Therefore, cadmium concentration of 2.361 mg/L in irrigated water can contaminate the soil and its accumulation can exceed EU standard. According to Thai Soil Quality Standard issue 25 (National Environmental Committee Announcement, 2004), cadmium in soil for residence and agriculture must not exceed 37 mg/kg and besides of these uses must not be over than 810 mg/kg. The soil contamination from this study is still within the limit. However, based on EU standard, soil in plot 6 – 8 exceeded this standard due. Indeed, the continuous supply of cadmium contaminated water had gradually increased cadmium accumulation in soil and may lead to an increase in cadmium concentration in vegetables. The distinct relationship between cadmium concentrations in irrigated water and soil of total cultivation was not found.

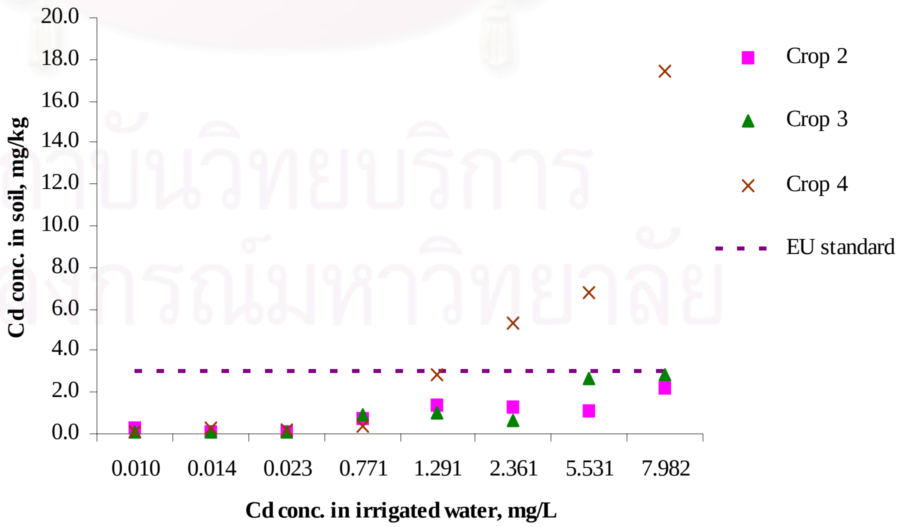


Figure 4.6: Cadmium concentration in soil.

4.3 Kale

4.3.1 Yield of Kale

The yields in all 4 cultivation are presented in Table 4.7 and Figure 4.7. It was found that there was no statistically different (P> 0.05) in yield among plots irrigated with different concentration of cadmium. During the first cultivation, the yields were very low. It is expected that the rainy season and adjustment of plant on new soil may result in low kale growth and yield. The yields during the fourth cultivation were very high. It is expected that the winter season may affect on high kale growth and yield. Cadmium in irrigated water up to 7.982 mg/L had no adverse effect on kale growth and yield. Toxicity was not found during cultivation. Velitchka et al. (1997) also reported that pepper fruits accumulated much cadmium (14.4 mg/kg dry weight) but they tolerated high concentration of cadmium in the soil (5.0 mg/kg soil) and the plant tissues without a corresponding reduction of yield.

Table 4.7: Yield of kale grown in cadmium contaminated soil.

Plot number	Actual concentration in irrigated water, mg/L	Wet weight, kg/rai			
		Crop 1	Crop 2	Crop 3	Crop 4
1	0.010	767	5032	2960	5890
2	0.014	668	3454	2007	6185
3	0.023	856	3090	1558	6898
4	0.771	633	4391	1475	6706
5	1.291	1195	4027	4431	6061
6	2.361	882	4378	2989	7185
7	5.531	872	4182	2579	5582
8	7.982	993	4129	3286	5808

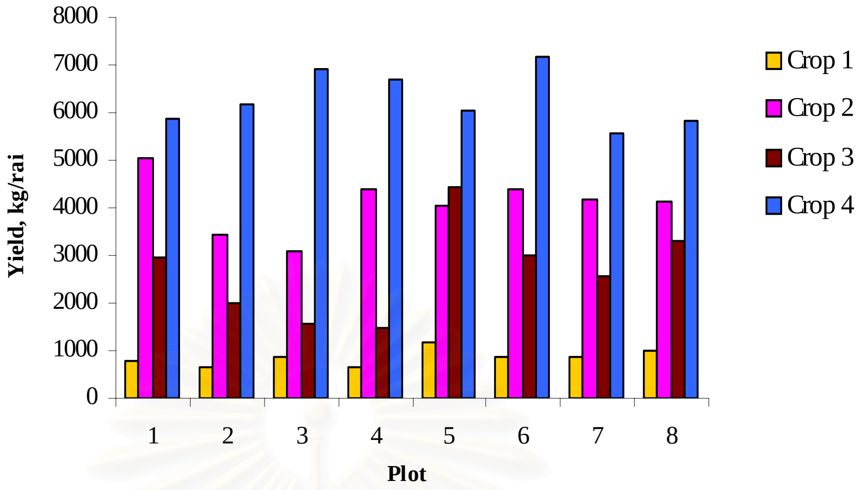


Figure 4.7: Yield of kale.

4.3.2 Cadmium Contamination in Kale

The cadmium distribution in parts of kale can be separated into three parts: root, stem, and leaf. The variations of cadmium contamination in each crop are shown in Figure 4.8 and Table 4.8. Concentrations of cadmium accumulation by root stem and leaf increased with the increasing cadmium concentration of irrigated water. The cadmium concentrations in kale ranged from 0.0 to 9.9 mg/kg wet weight for root, 0.0 to 3.0 mg/kg wet weight for stem, and 0.0 to 6.6 mg/kg wet weight for leaf in the whole cultivation. The cadmium concentrations were accumulated mainly in the roots, and only small amounts of cadmium were translocated to the leaves and the stems. The highest cadmium concentrations were observed in kale's root may be the result of contamination of the root surface with soil particles. Apparently, fine soil particles enriched in cadmium strongly adhered to root surface. In this study, soil texture was silt loam which was rather fine particle. Jiang et al. (2001), studying with garlic, found that roots accumulated cadmium more than shoots and explained by the fact that one of the normal functions of roots is to selectively acquire ions from the soil solution.

For low cadmium concentration in irrigated water, i.e. plot 1 – 3, parts of kale were within EU standard except root in plot 3. For high cadmium concentration in irrigated water, i.e. plot 4 – 8, part of kale exceeded EU standard. Plot 3 to 7 had cadmium contamination in root over EU standard, while plot 6 to 8 had cadmium contamination in stem exceeding the limit. Plot 4 to 8 had cadmium concentration in leaf exceeding EU standard. Cadmium concentration in irrigated water which produces kale (leaf and stem) for safe consumption is 0.023 mg/L where cadmium concentrations in leaf and stem were low. The relationship between cadmium concentrations in irrigated and various parts of kale of whole cultivation was not found.

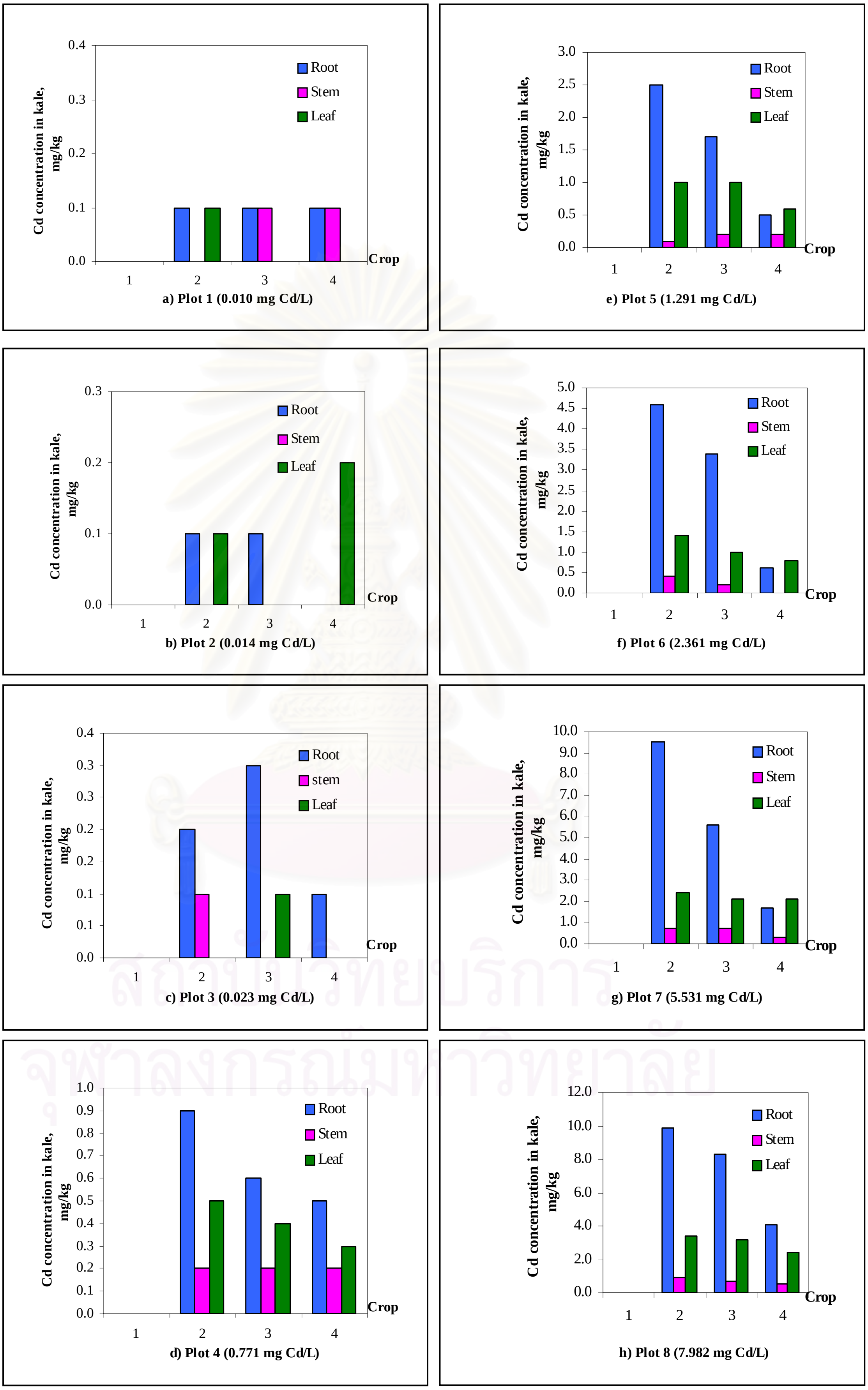
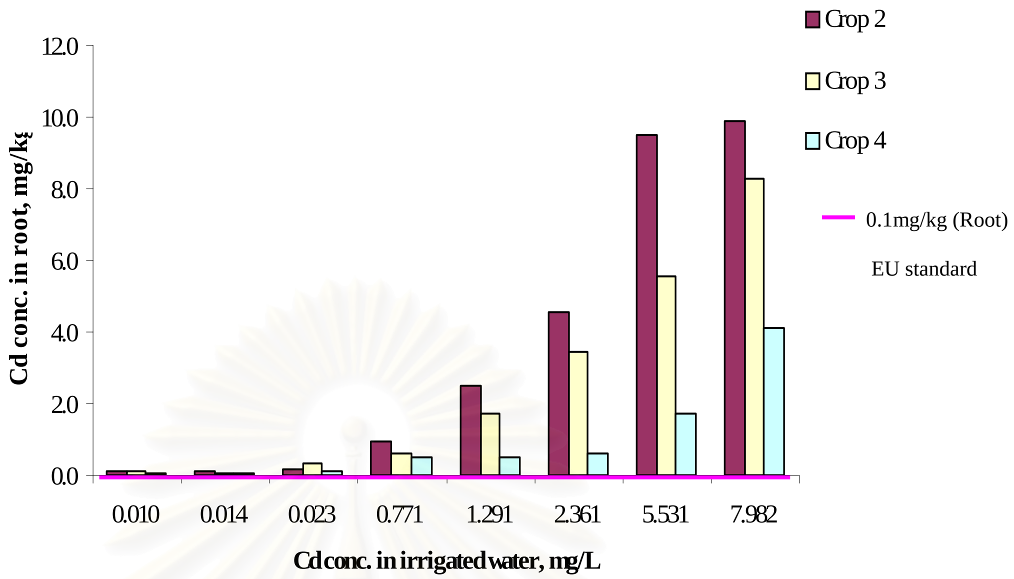


Figure 4.8: Accumulation of cadmium in parts of kale.

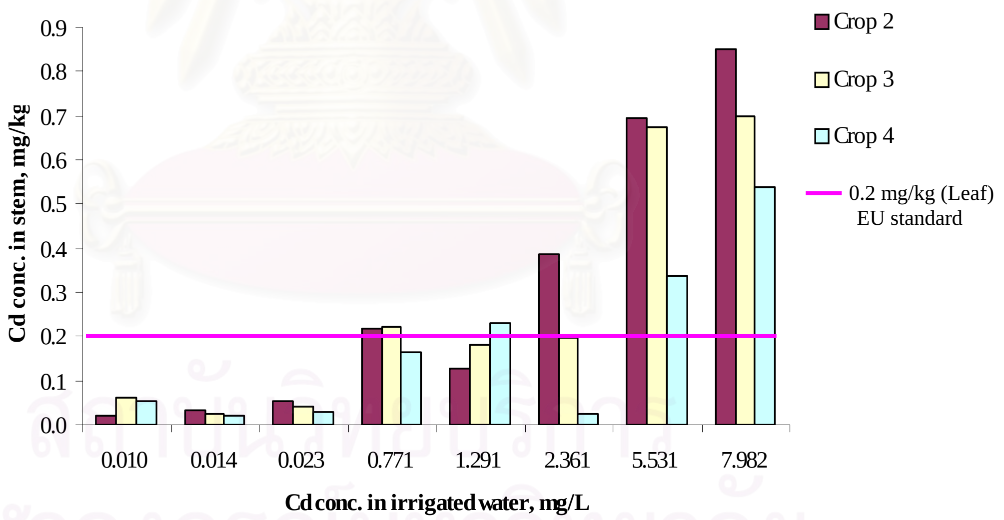
Table 4.8: Cadmium accumulation in parts of kale.

Plot number	Actual concentration in irrigated water, mg/L	Cadmium concentration in root , mg/kg				Cadmium concentration in stem , mg/kg				Cadmium concentration in leaf , mg/kg				EU*, mg/kg
		Crop 2	**Crop 3**	**Crop 4**	**Mean**	**Crop 2**	**Crop 3**	**Crop 4**	**Mean**	**Crop 2**	**Crop 3**	**Crop 4**	**Mean**	
1	**0.010**	0.10	0.12	0.07	0.10	0.02	0.06	0.05	0.04	0.07	0.04	0.00	0.04	0.10(root)
2	**0.014**	0.09	0.06	0.03	0.06	0.03	0.02	0.02	0.02	0.07	0.04	0.17	0.09	0.20(leafy)
3	**0.023**	0.19	0.32	0.10	0.20	0.06	0.04	0.03	0.04	0.03	0.09	0.01	0.04	
4	**0.771**	0.93	0.61	0.52	0.69	0.22	0.22	0.16	0.20	0.48	0.42	0.31	0.40	
5	**1.291**	2.50	1.70	0.52	1.57	0.13	0.18	0.23	0.18	0.96	0.98	0.56	0.83	
6	**2.361**	4.58	3.44	0.62	2.88	0.39	0.20	0.02	0.20	1.40	0.98	0.83	1.07	
7	**5.531**	9.49	5.56	1.73	5.59	0.70	0.68	0.34	0.57	2.41	2.15	2.09	2.22	
8	**7.982**	9.89	8.28	4.11	7.42	0.85	0.70	0.54	0.70	3.43	3.15	2.38	2.99	

Remark * Based on plant's wet weight.



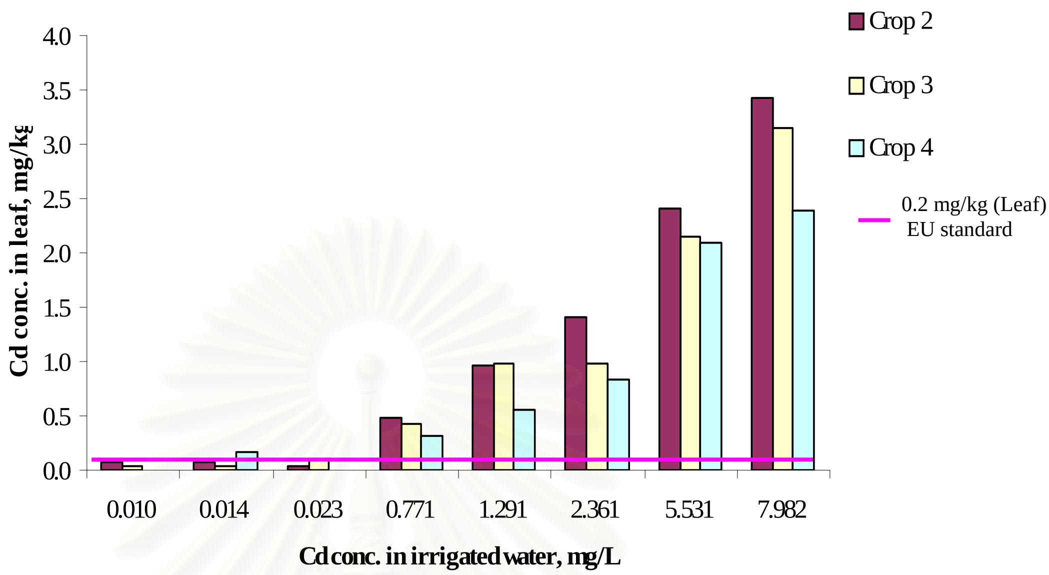
a) Root



b) Stem

Figure 4.9: Accumulation of cadmium in parts of kale:

a) root; b) stem; c) leaf



c) Leaf

Figure 4.8: Accumulation of cadmium in parts of kale (con't):

a) root; b) stem; c) leaf

4.4 Mass Balance of Kale Cultivation

Based on the amount of cadmium added in kale cultivation, the large part was adsorbed to the soil while small part was taken up by kale and leached out in infiltrated water. In plots irrigated with low cadmium concentration; i.e. plot 1 to 3, cadmium accumulation in all media was rather low. In plot irrigated with high cadmium concentration, i.e. plot 4 to 8, the most cadmium accumulation was in the soil. For example, it could be calculated that the amount of added cadmium remaining in the soil from the fourth cultivation was 1.3, 2.1, 3.8, 127.3, 216.4, 395.9, 927.1, and 1339.7 mg, respectively as shown in Table 4.9. If 7.982 mg Cd/L of irrigated water was still used for cultivation, this soil will be further polluted with cadmium.

According to Table 4.10, mass of cadmium was compared between the total accumulation in soil/ unaccounted and in soil at 0.15 m depth from soil surface. In this study, cadmium accumulation at depth 15 cm represented the total cadmium at root zone. The result obtained showed that mass of cadmium in total soil/ unaccounted and at 0.15 m depth from soil surface had the increasing trend under the higher cadmium concentration of irrigated water. However, mass of cadmium in total soil/unaccounted was different from cadmium at root zone. Mass of cadmium in total soil/ unaccounted was calculated from cadmium in irrigated water subtracted by cadmium in kale and infiltrated water while cadmium at root zone was computed from cadmium in soil at 0.15 m depth, i.e. position of soil sampling, multiplied with weight of soil. Mass of cadmium at depth 0.15 m was a part of mass of cadmium in total soil/ unaccounted. Thus, mass of cadmium at depth 0.15 m should not exceed mass of cadmium in soil/ unaccounted. In the case of mass of cadmium at depth 0.15 m higher than mass of cadmium in soil/ unaccounted, the macropore of soil may be result. While, mass of cadmium at 0.15 m had the negative values, i.e. plot 1 to 3, resulting in possible error. In this study, mass of cadmium at other depth did not know.

Table 4.9: Mass balance of cadmium concentration in kale, soil, irrigated water and infiltrated water.

Crop	Plot number	Actual concentration in irrigated water, mg/L	Input of Cd in Irrigated water, mg	Output of Cd, mg					Accumulation in soil and unaccounted, mg
				Kale				Infiltrated water	
				Root	Stem	Leaf	Total		
2	**1**	**0.010**	1,620	0.002	0.001	0.012	0.015	0.085	1.5
	2	**0.014**	2,268	0.001	0.001	0.008	0.010	0.576	1.7
	3	**0.023**	3,726	0.002	0.001	0.003	0.006	0.052	3.7
	4	**0.771**	124,902	0.014	0.008	0.067	0.089	0.147	124.7
	5	**1.291**	209,142	0.040	0.003	0.133	0.176	0.126	208.8
	6	**2.361**	382,482	0.080	0.014	0.215	0.309	0.195	382.0
	7	**5.531**	896,022	0.146	0.023	0.304	0.473	0.546	895.0
	8	**7.982**	1293,084	0.143	0.023	0.507	0.673	1.479	1290.9
3	**1**	**0.010**	1,320	0.001	0.001	0.003	0.005	0.068	1.2
	2	**0.014**	1,848	0.000	0.000	0.002	0.002	0.042	1.8
	3	**0.023**	3,036	0.002	0.000	0.004	0.006	0.035	3.0
	4	**0.771**	101,772	0.003	0.001	0.019	0.023	0.254	101.5
	5	**1.291**	170,412	0.026	0.003	0.125	0.154	0.274	170.0
	6	**2.361**	311,652	0.036	0.003	0.085	0.124	0.891	310.6
	7	**5.531**	730,092	0.046	0.006	0.169	0.221	0.711	729.2
	8	**7.982**	1053,624	0.076	0.010	0.297	0.383	2.527	1050.7
4	**1**	**0.010**	1,680	0.002	0.003	0.000	0.005	0.346	1.3
	2	**0.014**	2,352	0.001	0.001	0.034	0.036	0.244	2.1
	3	**0.023**	3,864	0.003	0.002	0.002	0.007	0.103	3.8
	4	**0.771**	129,528	0.015	0.009	0.075	0.099	2.091	127.3
	5	**1.291**	216,888	0.015	0.015	0.117	0.147	0.317	216.4
	6	**2.361**	396,648	0.018	0.001	0.175	0.194	0.583	395.9
	7	**5.531**	929,208	0.038	0.016	0.373	0.427	1.659	927.1
	8	**7.982**	1340,976	0.087	0.025	0.405	0.517	0.789	1339.7

Table 4.10: Mass of cadmium in soil.

Crop	Plot	Actual concentration in irrigated water, mg	In soil and unaccounted, mg	Accumulation at 0.15 m depth, mg
2	1	0.010	1.5	-115.8
	2	0.014	1.7	-193.9
	3	0.023	3.7	-40.3
	4	0.771	124.7	219.5
	5	1.291	208.8	6.1
	6	2.361	382.0	97.6
	7	5.531	895.0	-664.6
	8	7.982	1290.9	250.0
3	1	0.010	1.2	146.3
	2	0.014	1.8	224.3
	3	0.023	3.0	70.8
	4	0.771	101.5	54.9
	5	1.291	170.0	298.8
	6	2.361	310.6	85.4
	7	5.531	729.2	1487.7
	8	7.982	1050.7	603.6
4	1	0.010	1.3	-115.8
	2	0.014	2.1	-132.9
	3	0.023	3.8	-9.8
	4	0.771	127.3	67.1
	5	1.291	216.4	554.8
	6	2.361	395.9	1530.3
	7	5.531	927.1	585.3
	8	7.982	1339.7	4700.8

CHAPTER V

CONCLUSIONS

The major objective of this research was to assess the cadmium distribution in soil, kale and infiltrated water when irrigated with cadmium contaminated water at different concentration. Based on the experimental results, the following conclusions can be drawn.

1. The discrepancy in preparation of the cadmium concentrations in irrigated water resulted in some variations. The actual concentrations were different from the target concentrations but still within acceptable limit ($R^2 = 0.988$).

2. Cadmium in infiltrated water of any plot, when compared with irrigated water, varied without distinct pattern under long term cultivation. The relationship between cadmium concentrations in irrigated and infiltrated water of all cultivation was not found. At cadmium concentration in irrigated water of 0.023 mg/L, the infiltrated water had cadmium concentration exceeding.

3. Cadmium contamination in soil when irrigated with high cadmium concentration water showed the increasing trend under long term cultivation. The relationship between cadmium concentrations in irrigated water and soil was not found. At cadmium concentration in irrigated water of 2.361 mg/L, the cadmium contamination in soil had exceeded EU standard.

4. Cadmium in irrigated water up to 7.982 mg/L had no adverse effect on kale growth and yield. Toxicity on plant was not found during cultivation. Cadmium contamination in kale was highest in root, leaf, and stem, respectively. The relationship between cadmium concentrations in irrigated water and kale was not found. At cadmium concentration in irrigated water of 0.023 mg/L, the cadmium accumulation in leaf and stem exceeded EU standard for consumption.

5. Mass balance of kale cultivation showed that soil adsorbed most cadmium, much higher than absorbed in kale and leached out in infiltrated water.

CHAPTER VI

RECOMMENDATIONS FOR FUTURE WORK

Based on the results of this study, some recommendations for further studies can be proposed.

1. In this study, cadmium was distributed into kale, infiltrated water and soil without distinct pattern. The form of cadmium that accumulated in kale, infiltrated water and soil is important as well as the mechanism of cadmium distribution. Therefore, the form of cadmium should be investigated in the further study.

2. The distribution and accumulation of cadmium in kale did not affect the growth of kale. Similar study should be conducted in other vegetable.

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APPENDICES

APPENDIX A

MICROWAVE DIGESTION

A. Microwave digestion

A.1 Soil digestion (EPA 3051)

This method is provided for the acid digestion of the EPA 3051 in a closed vessel device using temperature control microwave heating for the metal determination by spectroscopic methods. The microwave used was Milestone ETHOS PLUS model lab station with HPR-1000/10S high pressure segmented rotor

Sample: 0.5 g.

Reagent: 10 mL of HNO_3 65%

Procedure:

1. Place a Tetrafluoro methoxil (TFM) vessel on the balance plate, tare it and weight 0.5 gram of sample.
2. Introduce the THM vessel into the HTC safety shield.
3. Add the acids then gently swirl the solution to homogenize the sample with the acid.
4. Close the vessel and introduce it into the rotor segment, then tighten by using the torque wrench.
5. Insert the segment into the microwave cavity and connect the temperature sensor.
6. Run the microwave program to completion, 2 steps as presented in Table A.1.
7. Cool the rotor by air and by water until the solution reaches room temperature.

8. Open the vessel and transfer the solution to a marked flask.

Table A.1: Microwave program for soil digestion

Step	Time	Temperature	Microwave power
1.	5.5 min.	175° C	Up to 1000 watt.
2.	10 min.	175° C	Up to 1000 watt.

A.2 Leave digestion

This method described the acid digestion of a leaf sample in a closed vessel microwave sample preparation work station.

Sample: 0.5 g.

Reagent: 8 mL of HNO_3 65%

2 mL of H_2O_2 30%

Procedure:

1. Place a TFM vessel on the balance plate, tare it and weight 0.5 gram of sample.
2. Introduce the THM vessel into the HTC safety shield.
3. Add 8 mL of HNO_3 65 % and 2 mL of H_2O_2 30%; swirl the solution to homogenize it.
4. Close the vessel and introduce it into the rotor segment, then tighten by using the torque wrench.
5. Insert the segment into the microwave cavity and connect the temperature sensor.

6. Run the microwave program to completion, 2 steps as presented in Table A.2.
7. Cool the rotor by air and by water until the solution reaches room temperature.
8. Open the vessel and transfer the solution to a marked flask.

Table A.2: Microwave program for leave digestion

Step	Time	Temperature	Microwave power
1.	5 min.	180° C	Up to 1000 watt.
2.	10 min.	180° C	Up to 1000 watt.

A.3 Root and stem digestion

This method described the acid digestion of a Wood Chips sample in a closed vessel microwave sample preparation work station.

Sample: 0.5 g.

Reagent: 8 mL of HNO_3 65%

2 mL of H_2O_2 30%

Procedure:

1. Place a TFM vessel on the balance plate, tare it and weight 0.5 gram of sample.
2. Introduce the THM vessel into the HTC safety shield.
3. Add the acids and swirl the solution to homogenize it.

4. Close the vessel and introduce it into the rotor segment, then tighten by using the torque wrench.
5. Insert the segment into the microwave cavity and connect the temperature sensor.
6. Run the microwave program to completion, 2 steps as presented in Table A.3.
7. Cool the rotor by air and by water until the solution reaches room temperature.
8. Open the vessel and transfer the solution to a marked flask.

Table A.3: Microwave program for root and shoot digestion

Step	Time	Temperature	Microwave power
1.	2 min.	85° C	Up to 1000 watt.
2.	5 min.	145° C	Up to 1000 watt.
3.	3 min.	200° C	Up to 1000 watt
4.	20 min.	200° C	Up to 1000 watt

APPENDIX B

ANALYTICAL METHODS

B. Analytical Methods

B.1 pH.

The pH was directly measured by Horiba pH-meter, Model F-21 with an accuracy of ± 0.01. The pH meter was calibrated daily with buffer solution at pH 4.00, 7.00 and 9.00, respectively.

B.2 Atomic Absorption Spectroscopy

Cadmium concentration was directly measured by flame and graphite furnace atomic absorption spectroscopy.

B.2.1 Flame atomic absorption

Lamp current: 3.0 mA.

Flame type: Air- Acetylene (oxidizing)

Flame emission:

Wavelength: 228.8 nm.

Slit width: 0.2 nm.

B.2.2 Graphite Furnace atomic absorption

Wavelength: 228.8 nm

Slit: 0.5 nm.

Lamp current: 3 mA.

Table B.1: Atomic absorption spectroscopy condition for cadmium analysis

Element	Max Ash in HNO_3	Atomize Temp	Characteristic concentration		Characteristic Mass	Typical respond (conc. for 20 µL to give approx. 0.3 abs) Ar ng/mL
			Ar	N_2	Ar	
	˚C	˚C	ng/mL	ng/mL	pg	
Cadmium	300	1800	0.013	0.013	0.25	1.0

Remark: Final volume was diluted to be 50 mL.

B.2.3 Data interpretation

Standard solution at desire concentration was measured for absorbance to create standard calibration curve. The absorbance of the sample gave the concentration by using the standard calibration curve. The example of data interpretation is presented as follows.

Concentration of heavy metal from standard calibration curve is x µg/ml

The total volume of sample is 50 ml equal to heavy metal 50 x µg.

The samples 50 ml prepare from soil dry weight 0.5 g.

Thus, soil dry weight 0.5 g has heavy metal 50x µg.

Soil dry weight 1.0 g has heavy metal 50x/0.5 µg/g.

APPENDIX C

EXPERIMENT DATA

Table C.1 Amount of infiltrated water in the first cultivation

Day	Date	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7		Plot 8	
		Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%
1	5 Aug. 04	2.8	23.3	0.4	3.3	0.0	0.0	3.1	25.8	7.4	61.7	4.5	37.5	4.0	33.3	1.9	15.8
2	7 Aug. 04	5.9	49.2	5.4	45.0	2.5	20.8	6.7	55.8	7.5	62.5	6.6	55.0	6.3	52.5	6.7	55.8
3	9 Aug. 04	4.3	35.8	4.7	39.2	4.6	38.3	4.9	40.8	5.4	45.0	5.2	43.3	4.0	33.3	4.8	40.0
4	11Aug. 04	3.1	25.8	3.8	31.7	4.0	33.3	4.0	33.3	5.2	43.3	4.0	33.3	3.3	27.5	4.3	35.8
5	13 Aug. 04	4.8	40.0	5.0	41.7	4.8	40.0	4.9	40.8	4.8	40.0	4.9	40.8	4.3	35.8	4.8	40.0
6	15 Aug. 04	4.9	40.8	5.4	45.0	5.3	44.2	5.4	45.0	4.4	36.7	5.1	42.5	4.4	36.7	5.4	45.0
7	17 Aug. 04	6.1	50.8	6.7	55.8	6.7	55.8	6.7	55.8	6.5	54.2	6.0	50.0	5.6	46.7	6.4	53.3
8	19 Aug. 04	5.4	45.0	5.4	45.0	5.3	44.2	5.2	43.3	4.4	36.7	5.2	43.3	4.5	37.5	5.1	42.5
9	21 Aug. 04	5.4	45.0	5.9	49.2	5.5	45.8	5.6	46.7	5.3	44.2	5.8	48.3	5.2	43.3	5.5	45.8
10	23 Aug. 04	3.2	26.7	4.0	33.3	3.9	32.5	4.0	33.3	3.5	29.2	3.7	30.8	4.0	33.3	3.6	30.0
11	25 Aug. 04	2.5	20.8	3.7	30.8	4.0	33.3	4.0	33.3	2.9	24.2	3.5	29.2	3.5	29.2	4.0	33.3
12	27 Aug. 04	2.6	21.7	3.5	29.2	3.7	30.8	4.0	33.3	3.0	25.0	3.5	29.2	3.7	30.8	4.2	35.0
13	29 Aug. 04	2.8	23.3	3.6	30.0	4.0	33.3	4.2	35.0	2.3	19.2	3.0	25.0	2.8	23.3	3.1	25.8
14	31 Aug. 04	5.4	45.0	6.1	50.8	5.8	48.3	6.0	50	5.3	44.2	5.3	44.2	5.2	43.3	5.5	45.8
15	2 Sep. 04	5.7	47.5	6.6	55.0	6.7	55.8	7.0	58.3	6.0	50.0	6.3	52.5	6.0	50.0	6.5	54.2
16	4 Sep. 04	5.3	44.2	5.7	47.5	5.8	48.3	5.5	45.8	6.8	56.7	5.7	47.5	4.9	40.8	5.2	43.3
17	6 Sep. 04	5.7	47.5	6.4	53.3	6.0	50.0	6.3	52.5	6.7	55.8	5.8	48.3	5.6	46.7	6.0	50.0
Average		4.5	37.2	4.8	40.3	4.6	38.5	5.1	42.9	5.1	42.8	4.9	41.2	4.5	37.9	4.9	40.7
SD		1.32	10.98	1.57	13.10	1.65	13.73	1.15	9.59	1.58	13.20	1.08	8.99	0.99	8.28	1.27	10.62

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Table C.2 Amount of infiltrated water in the second cultivation

Day	Date	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7		Plot 8	
		Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%
1	**25 Sep. 04**	0.3	2.5	1.8	15.0	-	-	1.8	15.0	1.3	10.8	2.2	18.3	1.5	12.5	1.7	14.2
2	**27 Sep.04**	2.8	23.3	4.2	35.0	3.7	30.8	3.8	31.7	3.3	27.5	4.3	35.8	4.8	40.0	4.6	38.3
3	**29 Sep. 04**	4.4	36.7	4.9	40.8	4.6	38.3	4.9	40.8	3.8	31.7	4.7	39.2	5.8	48.3	4.9	40.8
4	**1 Oct. 04**	3.8	31.7	3.5	29.2	3.5	29.2	2.9	24.2	2.6	21.7	3.3	27.5	3.7	30.8	3.6	30.0
5	**3 Oct. 04**	5.5	30.6	7.3	40.6	6.5	36.1	7.2	40.0	5.5	30.6	6.8	37.8	6.4	35.6	6.6	36.7
6	**6 Oct. 04**	4.4	24.4	5.3	29.4	4.9	27.2	4.4	24.4	3.7	20.6	4.5	25.0	4.1	22.8	4.3	23.9
7	**9 Oct. 04**	3.7	20.6	5.4	30.0	4.5	25.0	4.0	22.2	3.5	19.4	4.1	22.8	6.9	38.3	4.9	27.2
8	**12 Oct. 04**	5.9	32.8	7.9	43.9	7.4	41.1	7.2	40.0	6.2	34.4	6.4	35.6	6.9	38.3	7.0	38.9
9	**15 Oct. 04**	4.3	23.9	6.0	33.3	5.3	29.4	4.4	24.4	4.0	22.2	3.9	21.7	5.6	31.1	5.7	31.7
10	**19 Oct. 04**	3.0	16.7	4.5	25.0	4.4	24.4	3.3	18.3	3.1	17.2	3.6	20.0	3.4	18.9	3.5	19.4
11	**21 Oct. 04**	4.3	23.9	6.8	37.8	6.9	38.3	5.0	27.8	5.0	27.8	5.0	27.8	5.5	30.6	5.9	32.8
Average		3.9	24.3	5.2	32.7	4.7	26.1	4.4	24.4	3.8	24.0	4.4	28.3	5.0	31.6	4.8	30.4
SD		1.50	9.31	1.76	8.29	1.34	6.01	1.57	8.96	1.37	7.06	1.31	7.56	1.67	10.31	1.52	8.52

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Table C.3 Amount of infiltrated water in the third cultivation

Day	Date	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7		Plot 8	
		Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%
1	7 Dec. 04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	10 Dec. 04	1.6	8.9	1.9	10.6	-	-	1.3	7.2	-	-	-	-	-	-	-	-
3	13 Dec. 04	3.7	20.6	4.1	22.8	2.0	11.1	4.5	25.0	0.9	5.0	0.5	2.8	-	-	2.9	16.1
4	16 Dec. 04	4.8	26.7	6.9	38.3	5.8	32.2	6.9	38.3	2.4	13.3	2.8	15.6	2.3	12.8	5.2	28.9
5	19 Dec. 04	6.7	37.2	6.8	37.8	5.1	28.3	6.8	37.8	5.2	28.9	6.4	35.6	5.9	32.8	5.5	30.6
6	22 Dec. 04	6.4	35.6	8.0	44.4	8.3	46.1	8.9	49.4	5.2	28.9	6.1	33.9	5.9	32.8	7.1	39.4
7	25 Dec. 04	6.1	33.9	8.3	46.1	7.8	43.3	8.4	46.7	4.4	24.4	5.9	32.8	5.8	32.2	6.2	34.4
8	28 Dec. 04	4.8	26.7	5.8	32.2	5.9	32.8	5.6	31.1	3.0	16.7	4.5	25.0	4.6	25.6	4.3	23.9
Average		4.9	27.1	6.0	33.2	5.8	32.3	6.1	33.7	3.5	19.5	4.4	24.3	4.9	27.2	5.2	28.9
SD		1.79	9.96	2.28	12.67	2.24	12.47	2.59	14.36	1.72	9.56	2.32	12.89	1.55	8.63	1.47	8.16

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Table C.4 Amount of infiltrated water in the fourth cultivation

Day	Date	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7		Plot 8	
		Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%	Vol.,L/d	%
1	15 Jan 05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	18 Jan 05	1.1	6.1	1.5	8.3	-	-	0.5	-	-	-	1.5	-	-	-	-	-
3	21 Jan 05	3.6	20.0	4.1	22.8	5.0	27.8	4.3	23.9	0.6	3.3	2.0	11.1	1.8	10.0	2.6	14.4
4	24 Jan 05	6.0	33.3	6.8	37.8	6.8	37.8	6.2	34.4	3.5	19.4	4.8	26.7	5.0	27.8	5.6	31.1
5	27 Jan 05	5.6	31.1	6.4	35.6	6.8	37.8	5.9	32.8	3.3	18.3	4.8	26.7	5.1	28.3	5.3	29.4
6	30 Jan 05	5.8	32.2	6.1	33.9	6.1	33.9	6	31.1	2.7	15.0	4.4	24.4	4.5	25.0	5.0	27.8
7	2 Feb 05	3.9	21.7	4.4	24.4	4.5	25.0	9	21.7	1.3	7.2	3.0	16.7	3.3	18.3	3.2	17.8
8	5 Feb 05	2.0	11.1	2.6	14.4	2.5	13.9	4	7.8	0.8	4.4	2.2	12.2	1.8	10.0	2.2	12.2
9	8 Feb 05	0.4	2.2	1.5	8.3	1.4	7.8	3	7.2	-	-	0.8	4.4	1.6	8.9	-	-
10	11 Feb 05	0.4	2.2	1.5	8.3	1.3	7.2	1.2	6.7	-	-	0.8	4.4	0.6	3.3	-	-
Avg.		3.2	17.8	3.9	21.5	4.3	23.9	3.4	20.7	2.0	11.3	2.7	15.8	3.0	16.5	4.0	22.1
SD		2.31	12.81	2.20	12.23	2.30	12.76	2.28	11.95	1.29	7.16	1.63	9.29	1.75	9.70	1.49	8.27

Table C.5 pH of irrigated and infiltrated water in the first cultivation

Day	Date	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7		Plot 8	
		Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated
1	5 Aug. 04	6.15	7.60	6.56	7.58	7.26	7.93	7.35	8.59	6.66	7.81	7.31	7.59	7.23	8.78	7.22	7.99
2	7 Aug. 04	7.84	7.61	7.73	7.64	7.70	8.34	7.62	7.94	7.50	7.73	7.50	7.69	7.31	8.96	7.39	8.16
3	9 Aug. 04	8.00	7.73	7.77	8.05	7.69	8.62	7.53	8.54	7.60	8.01	7.54	8.52	7.42	8.85	7.38	8.24
4	11Aug. 04	7.95	7.73	7.90	7.86	7.89	8.43	7.82	7.77	7.82	8.20	7.73	7.88	7.59	8.62	7.57	7.99
5	13 Aug. 04	7.89	7.37	7.67	7.78	7.86	8.08	7.87	8.03	7.83	7.83	7.70	8.11	7.61	8.77	7.44	8.13
6	15 Aug. 04	8.03	7.36	8.09	7.74	8.10	8.05	8.09	8.02	8.08	8.01	8.04	8.70	7.89	9.08	7.75	8.27
7	17 Aug. 04	8.03	8.47	7.97	8.39	8.01	8.28	8.00	8.42	8.02	8.15	7.96	8.40	7.79	8.95	7.79	8.57
8	19 Aug. 04	8.12	9.30	8.08	8.93	7.99	8.81	7.99	9.33	7.90	8.12	7.83	8.81	7.71	9.41	7.48	8.48
9	21 Aug. 04	7.95	8.18	7.99	8.26	8.06	9.10	7.99	8.63	8.22	8.38	7.90	7.84	7.75	8.88	7.68	8.23
10	23 Aug. 04	7.91	8.14	7.99	8.65	7.96	8.31	7.89	8.86	8.01	8.99	7.78	8.52	7.66	9.00	7.50	8.62
11	25 Aug. 04	7.85	8.00	7.77	8.30	7.68	7.91	7.64	8.97	7.55	8.70	7.58	8.54	7.36	8.87	7.25	8.57
12	27 Aug. 04	7.66	8.74	7.51	8.79	7.45	7.92	7.41	9.28	7.35	8.88	7.27	9.10	7.15	9.17	7.03	8.86
13	29 Aug. 04	7.82	7.71	7.68	7.91	7.62	8.52	7.49	8.66	7.49	7.61	7.44	7.52	7.31	7.90	7.22	7.78
14	31 Aug. 04	7.94	7.86	7.76	8.34	7.73	8.85	7.70	8.76	7.68	8.42	7.64	8.48	7.55	8.86	7.49	8.43
15	2 Sep. 04	7.98	7.77	7.81	8.49	7.64	8.81	7.59	8.91	7.49	8.77	7.44	8.73	7.33	9.09	7.24	8.27
16	4 Sep. 04	7.96	8.06	7.74	8.40	7.64	8.81	7.57	8.84	7.53	8.57	7.45	8.40	7.34	9.23	7.21	8.52
17	6 Sep. 04	8.15	8.11	7.94	8.39	7.79	8.79	7.85	8.54	7.85	8.68	7.81	8.45	7.84	9.01	7.63	8.59
Avg.		7.84	7.98	7.76	8.21	7.77	8.44	7.73	8.59	7.68	8.29	7.64	8.31	7.52	8.91	7.43	8.34
SD		0.45	0.50	0.35	0.40	0.22	0.38	0.23	0.45	0.36	0.43	0.23	0.46	0.23	0.32	0.21	0.28

Table C.6 pH of irrigated and infiltrated water in second cultivation

Day	Date	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7		Plot 8	
		Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated
1	25 Sep. 04	6.75	7.15	6.81	7.24	6.86	-	6.88	7.49	6.25	7.45	6.85	7.50	6.80	7.52	6.80	-
2	27 Sep. 04	7.00	7.05	7.03	7.27	7.08	7.47	7.14	7.67	7.15	7.66	7.15	7.71	7.08	7.84	7.08	7.82
3	29 Sep. 04	6.44	7.13	6.71	7.58	6.82	7.61	7.10	7.94	7.15	7.84	7.16	7.93	7.14	7.96	7.11	7.99
4	1 Oct. 04	7.02	6.75	6.92	7.46	6.93	7.59	6.93	7.78	6.96	7.88	6.97	7.88	6.93	7.98	6.89	7.92
5	3 Oct. 04	7.87	7.44	7.79	8.41	7.69	8.47	7.60	8.69	7.55	8.64	7.50	8.55	7.41	8.79	7.30	8.50
6	6 Oct. 04	7.90	6.56	7.71	6.91	7.62	7.82	7.53	8.36	7.47	8.42	7.42	8.64	7.30	8.51	7.23	8.50
7	9 Oct. 04	7.96	7.75	7.73	7.83	7.61	8.13	7.54	8.18	7.49	8.20	7.44	8.18	7.33	8.12	7.25	8.06
8	12 Oct. 04	7.81	6.41	7.72	6.86	7.60	6.96	7.49	7.44	7.48	7.53	7.40	7.61	7.33	7.77	7.27	7.90
9	15 Oct. 04	7.82	6.54	7.64	6.74	7.50	6.91	7.44	7.33	7.41	7.61	7.33	7.68	7.26	7.62	7.20	7.47
10	18 Oct. 04	7.62	7.30	7.49	7.08	7.33	7.31	7.30	7.72	7.32	7.81	7.27	7.87	7.15	7.72	7.12	7.69
11	21 Oct. 04	7.80	6.96	7.61	7.28	7.36	7.03	7.34	7.35	7.22	7.42	7.17	7.52	7.07	7.58	6.99	7.59
Avg.		7.45	7.00	7.38	7.33	7.31	7.53	7.30	7.81	7.22	7.86	7.24	7.92	7.16	7.95	7.11	7.94
SD		0.54	0.41	0.42	0.48	0.33	0.51	0.25	0.44	0.37	0.40	0.20	0.39	0.19	0.40	0.16	0.34

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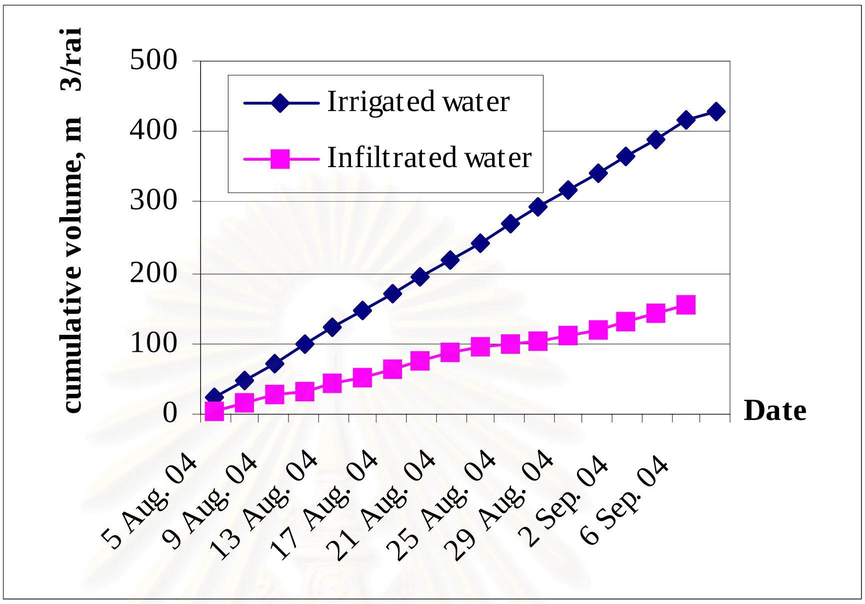
Table C.7 pH of irrigated and infiltrated water in the third cultivation

Day	Date	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7		Plot 8	
		Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated
1	7 Dec. 04	7.41	-	7.10	-	7.24	-	7.27	-	7.16	-	7.02	-	6.91	-	6.97	-
2	10 Dec. 04	7.47	7.31	7.46	7.23	7.44	-	7.41	7.19	7.40	-	7.40	-	7.42	-	7.19	-
3	13 Dec. 04	7.61	7.81	7.49	7.04	7.48	7.51	7.44	8.01	7.39	7.81	7.31	8.07	7.21	-	7.20	7.77
4	16 Dec. 04	7.66	7.62	7.44	6.97	7.76	7.72	7.26	8.25	7.30	7.70	7.05	7.92	6.99	7.52	6.93	7.76
5	19 Dec. 04	7.14	7.41	7.35	7.36	7.30	7.15	7.09	7.40	7.04	7.58	7.03	7.18	6.94	7.34	6.93	7.29
6	22 Dec. 04	7.80	7.94	7.61	7.46	7.66	7.94	7.52	8.52	7.56	8.11	7.53	8.48	7.46	8.36	7.45	8.39
7	25 Dec. 04	8.00	7.33	7.74	7.01	7.73	7.04	7.62	8.08	7.54	7.25	7.49	7.73	7.35	8.05	7.31	7.61
8	28 Dec. 04	7.84	8.37	7.63	8.18	7.53	8.29	7.40	8.75	7.40	8.51	7.39	8.37	7.28	8.65	7.37	8.59
Avg.		7.62	7.68	7.48	7.32	7.52	7.61	7.38	8.03	7.35	7.83	7.28	7.96	7.20	7.98	7.17	7.90
SD		0.27	0.39	0.20	0.42	0.19	0.48	0.17	0.56	0.18	0.44	0.21	0.47	0.22	0.55	0.21	0.49

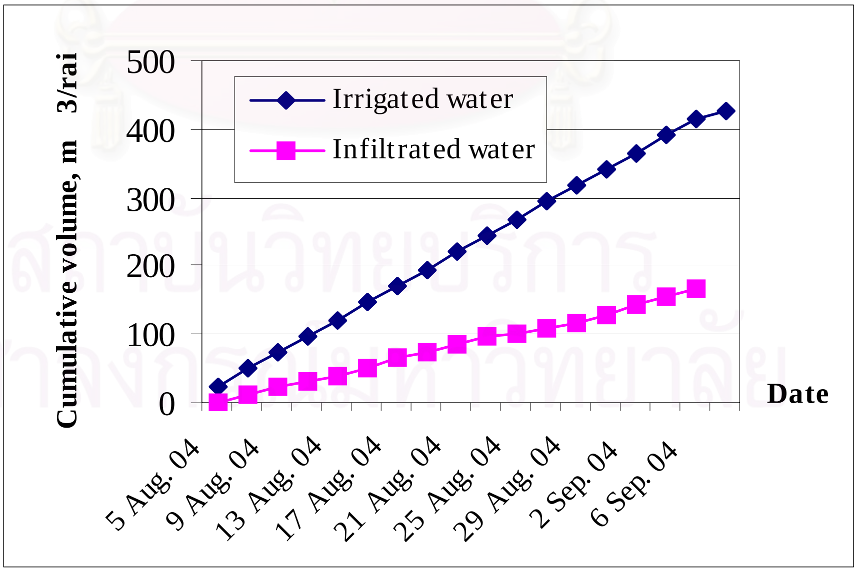
Table C.8 pH of irrigated and infiltrated water in the fourth cultivation

Day	Date	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7		Plot 8	
		Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated	Irrigated	Infiltrated
1	15-Jan-05	7.50	-	7.55	-	7.59	-	7.48	-	7.49	-	7.40	-	7.35	-	7.30	-
2	18-Jan-05	7.40	7.62	7.46	7.59	7.42	-	7.43	7.87	7.33	-	7.22	7.77	7.16	-	7.22	-
3	21-Jan-05	7.91	7.97	7.79	7.87	7.68	7.82	7.60	7.98	7.51	7.72	7.52	8.24	7.43	7.99	7.40	7.92
4	24-Jan-05	8.11	7.90	7.97	7.64	7.90	7.78	7.86	8.43	7.80	8.02	7.73	8.20	7.64	7.90	7.58	7.97
5	27-Jan-05	7.88	8.38	7.71	8.51	7.67	8.36	7.57	8.94	7.53	8.76	7.43	8.82	7.32	8.59	7.30	8.59
6	30-Jan-05	8.31	8.30	8.11	7.83	8.02	8.07	7.94	8.83	7.85	8.34	7.81	8.51	7.70	8.10	7.62	8.29
7	2-Feb-05	7.90	8.01	7.81	8.25	7.73	8.35	7.66	8.73	7.62	8.43	7.58	8.40	7.48	8.11	7.42	8.30
8	5-Feb-05	8.26	8.16	8.07	8.66	7.97	8.52	7.88	8.94	7.64	8.66	7.50	8.71	7.46	8.40	7.45	8.56
9	8-Feb-05	8.36	8.09	8.14	8.32	8.05	8.21	7.92	8.46	7.80	-	7.76	8.13	7.71	8.03	7.64	-
10	11-Feb-05	7.83	8.50	7.86	8.93	7.83	8.60	7.73	8.92	7.63	-	7.62	8.67	7.46	8.35	7.47	-
Avg.		7.95	8.10	7.85	8.18	7.79	8.21	7.71	8.57	7.62	8.32	7.56	8.38	7.47	8.18	7.44	8.27
SD		0.32	0.27	0.23	0.47	0.20	0.30	0.19	0.41	0.16	0.39	0.18	0.33	0.17	0.24	0.14	0.28

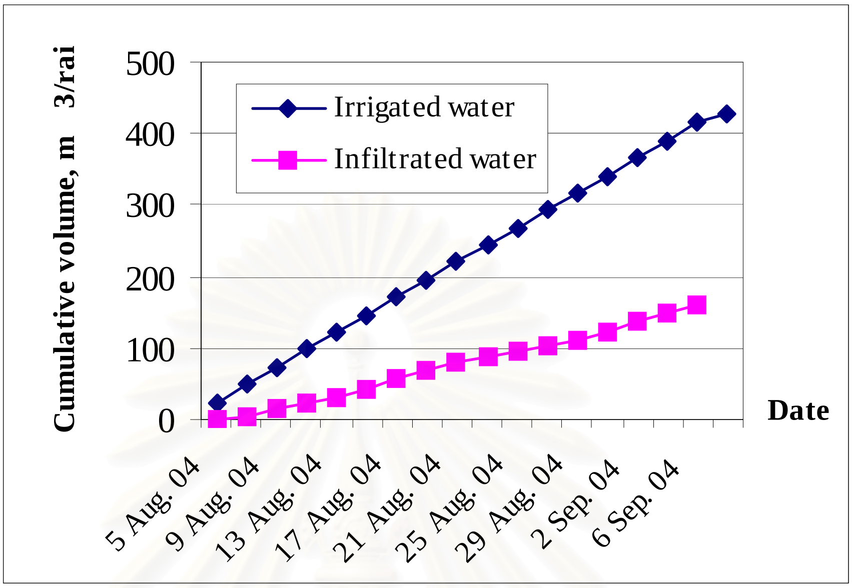
Table C.9 Cumulative volume of irrigated and infiltrated water in the first kale cultivation



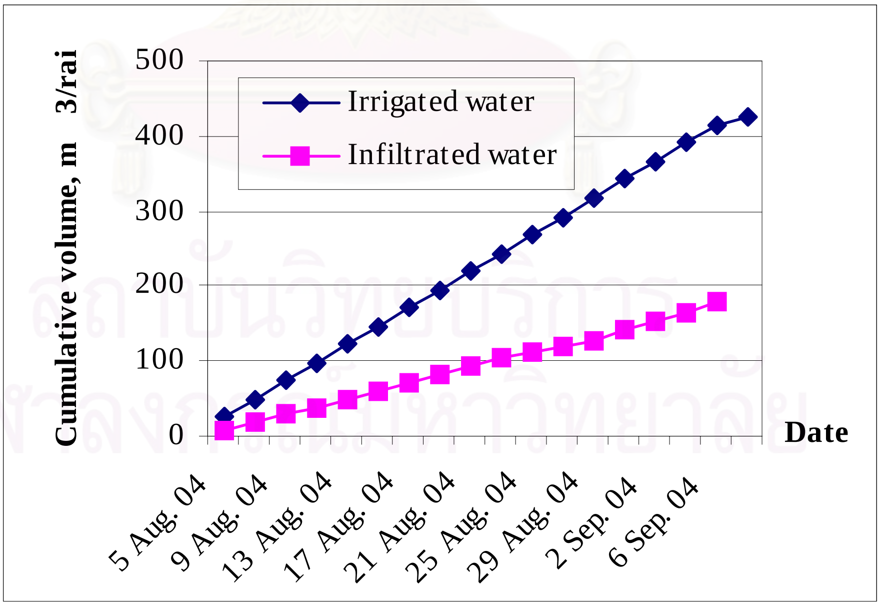
a) Plot 1(0.010 mg Cd/L)



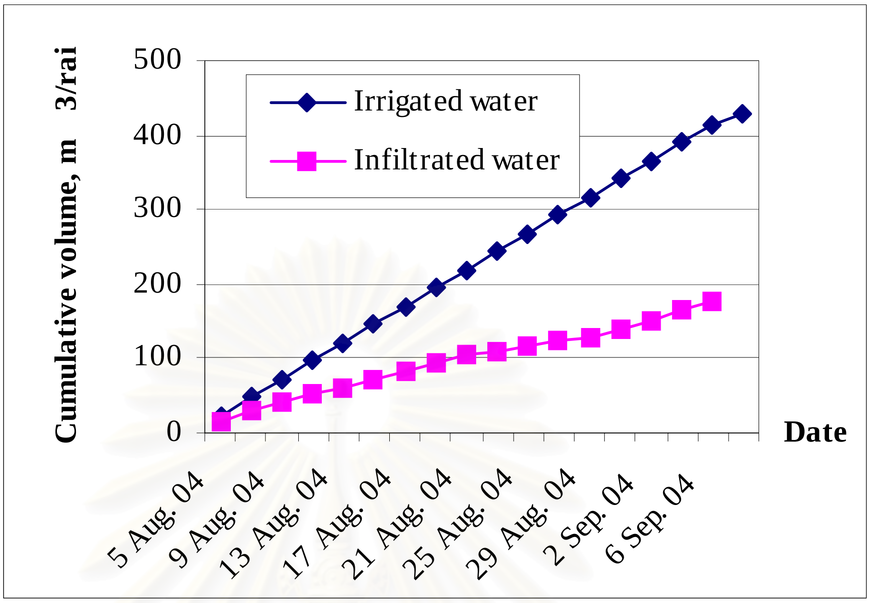
b) Plot 2 (0.014 mg Cd/L)



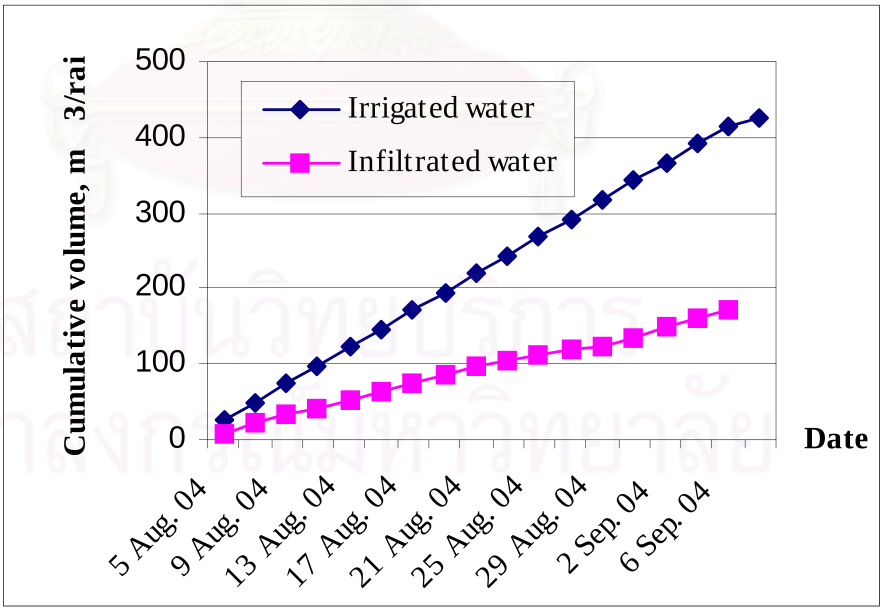
c) Plot 3 (0.023 mg Cd/L)



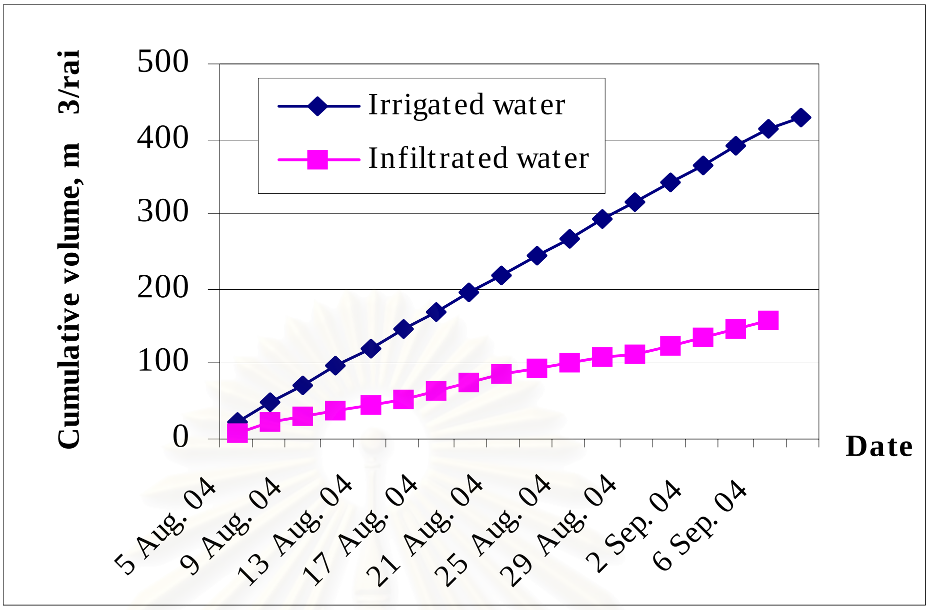
d) Plot 4 (0.771 mg Cd/L)



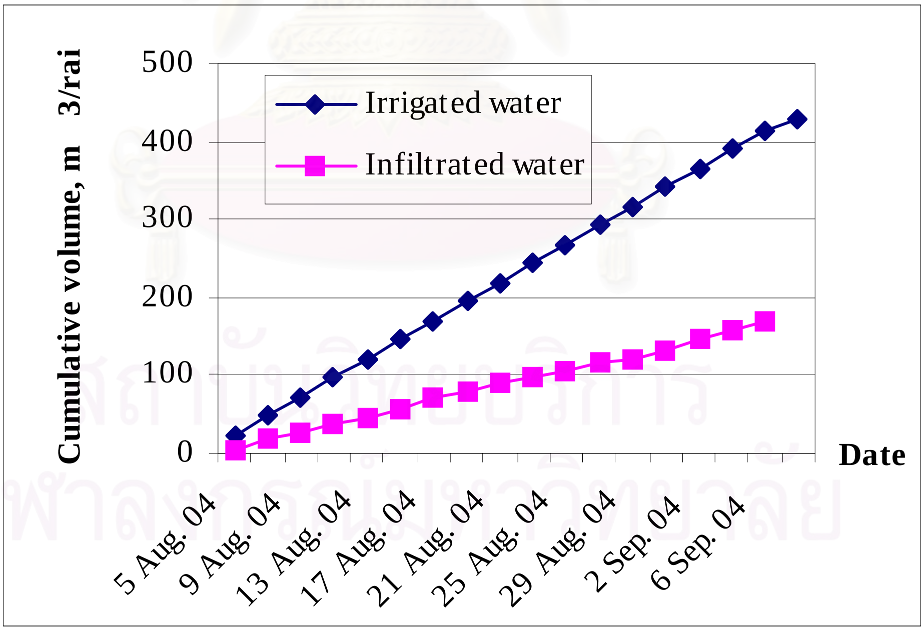
e) Plot 5 (1.291 mg Cd/L)



f) Plot 6 (2.361 mg Cd/L)

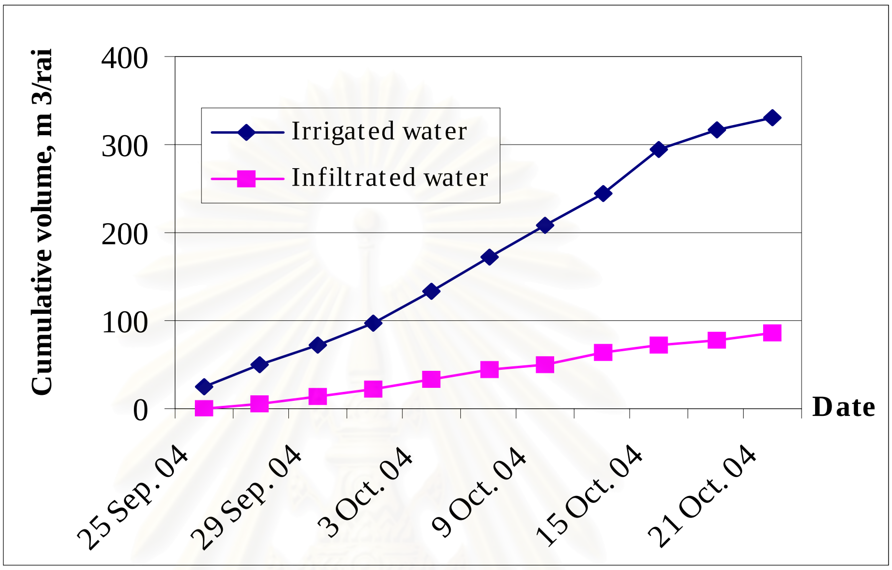


g) Plot 7 (5.531 mg Cd/L)

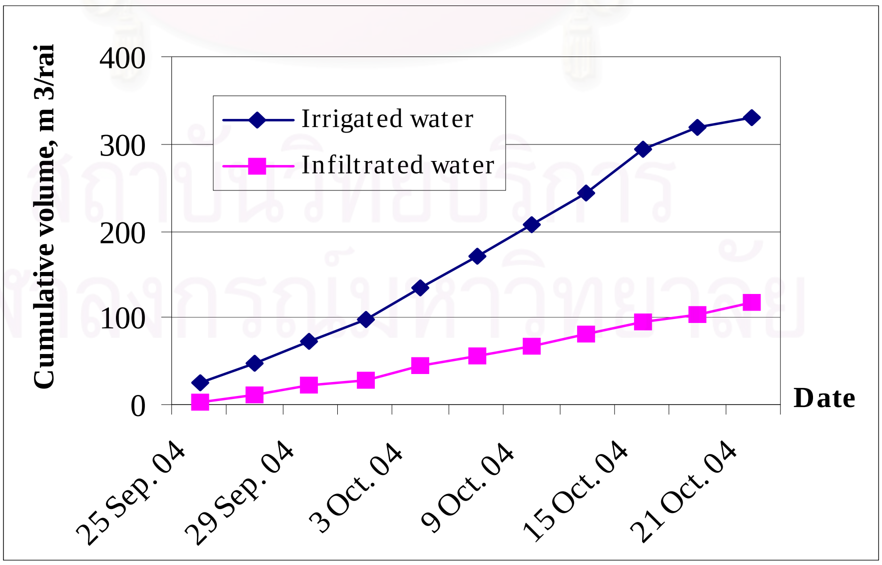


h) Plot 8 (7.982 mg Cd/L)

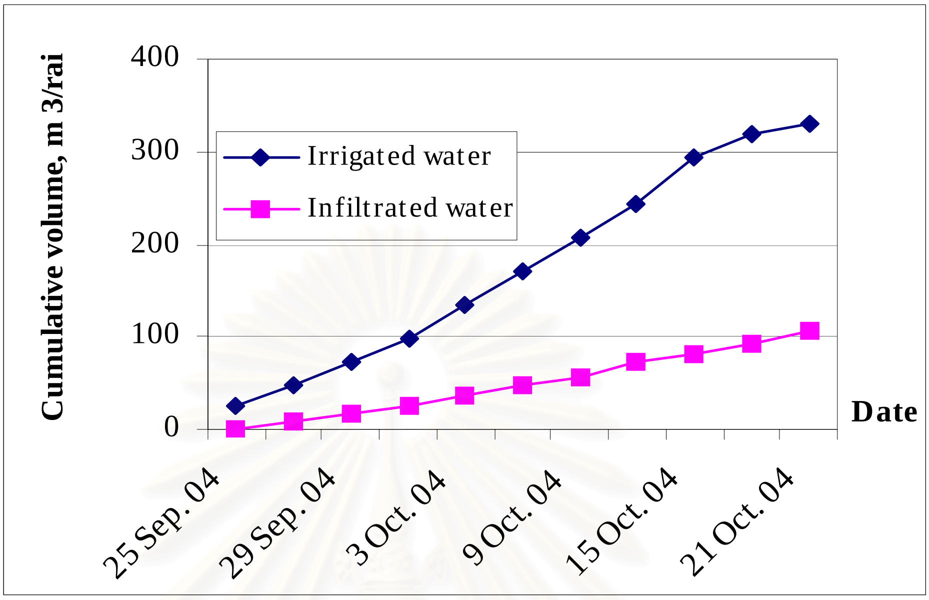
Table C.10 Cumulative volume of irrigated and infiltrated water in the second kale cultivation



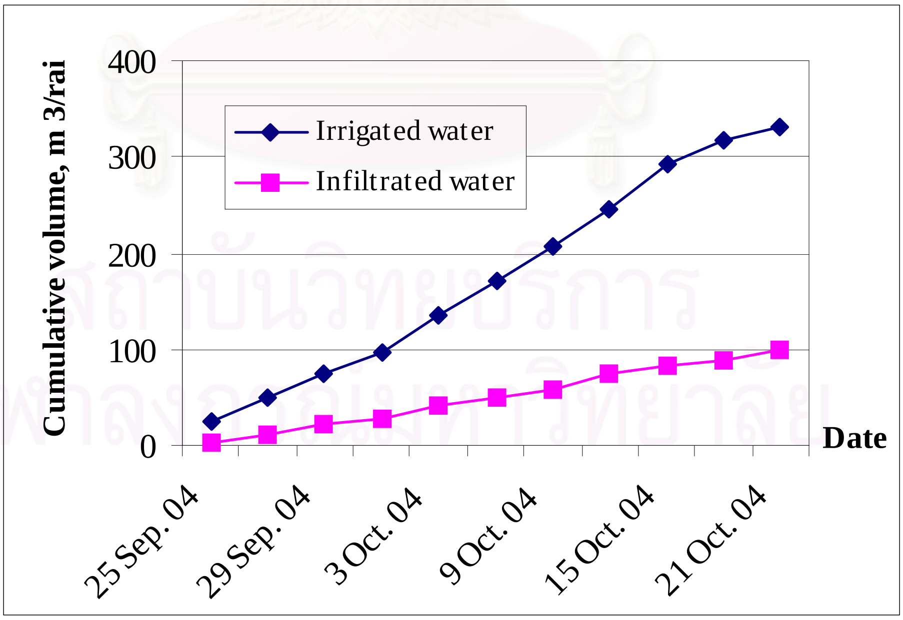
a) Plot 1(0.010 mg Cd/L)



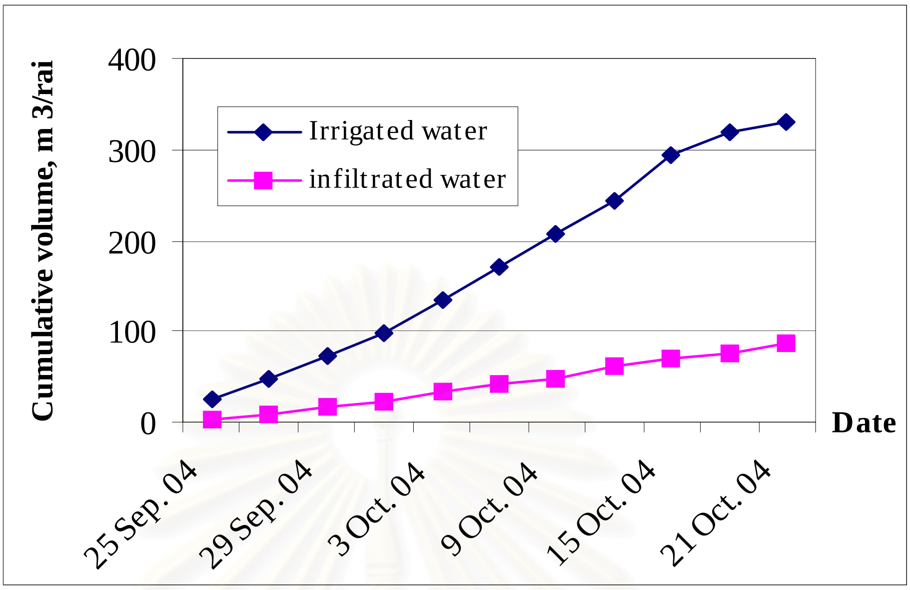
b) Plot 2 (0.014 mg Cd/L)



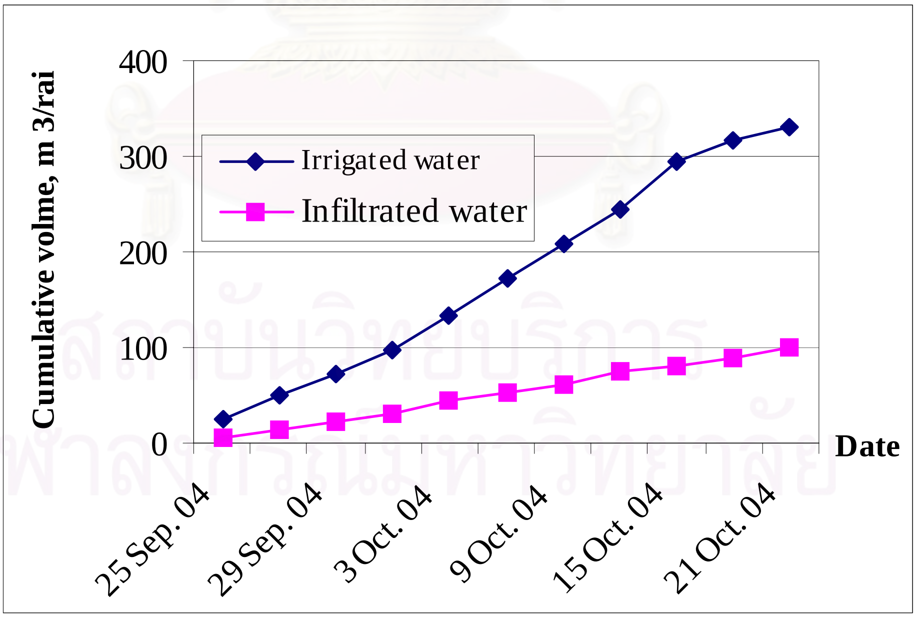
c) Plot 3 (0.023 mg Cd/L)



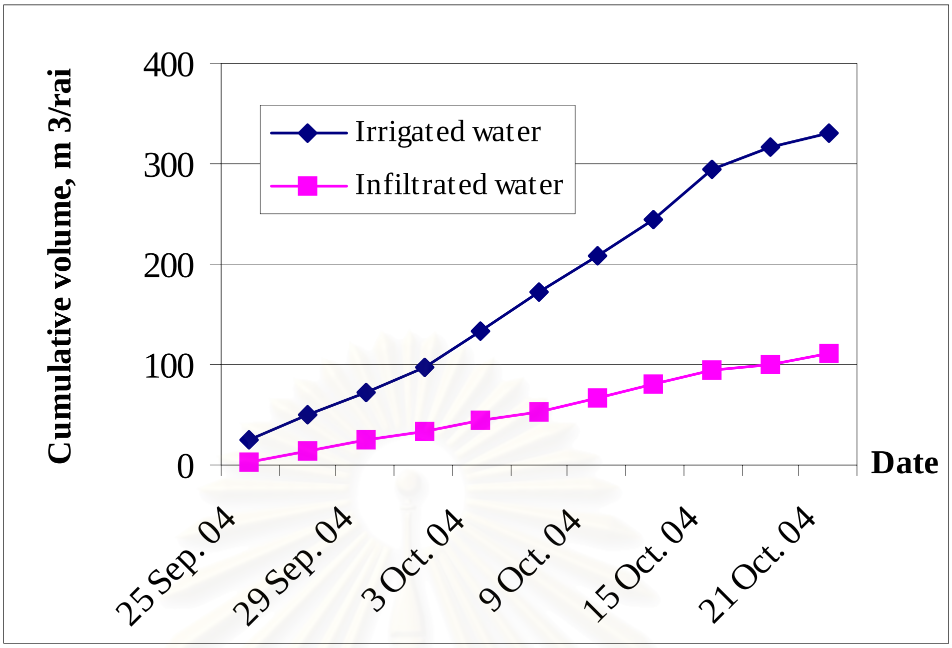
d) Plot 4 (0.771 mg Cd/L)



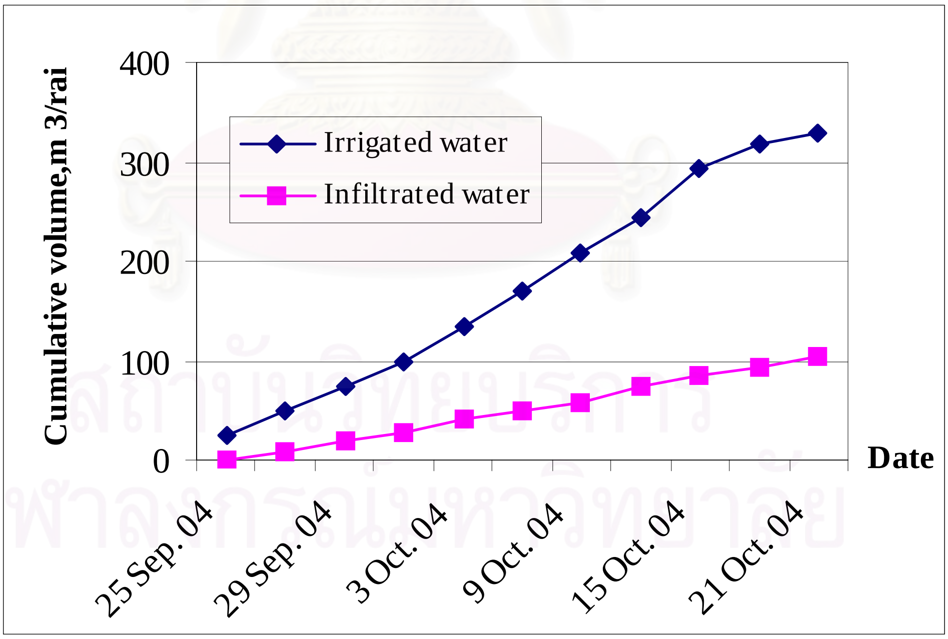
e) Plot 5 (1.291 mg Cd/L)



f) Plot 6 (2.361 mg Cd/L)

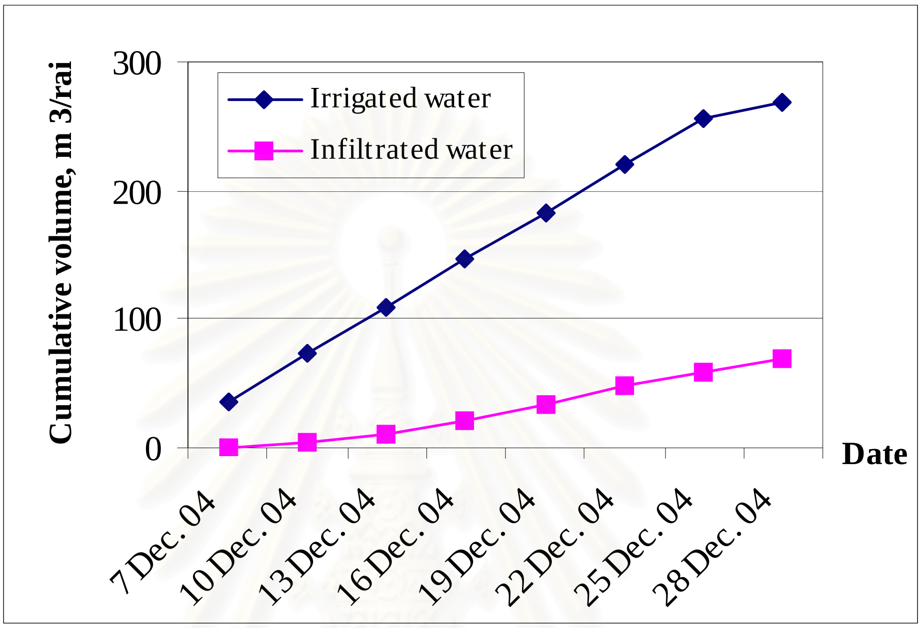


g) Plot 7 (5.531 mg Cd/L)

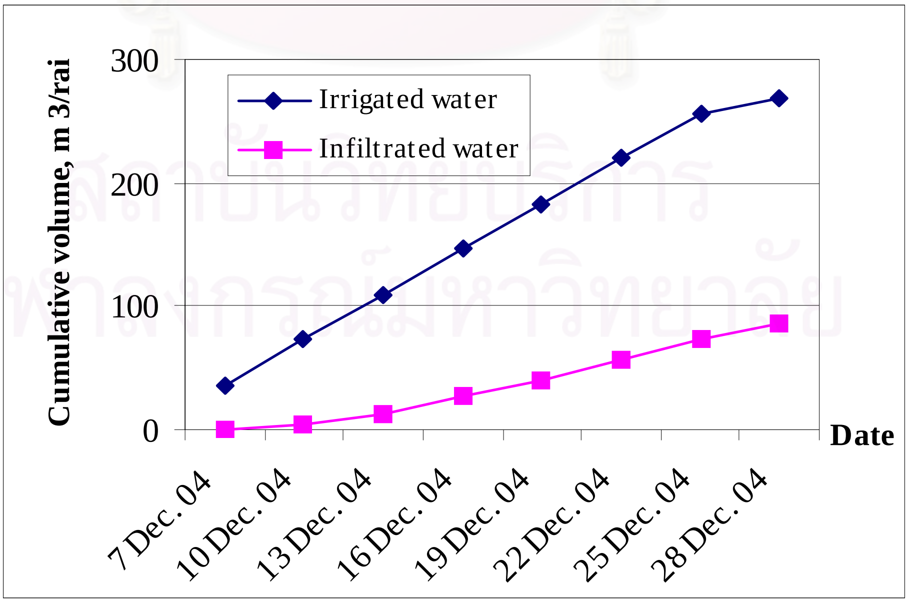


h) Plot 8 (7.982 mg Cd/L)

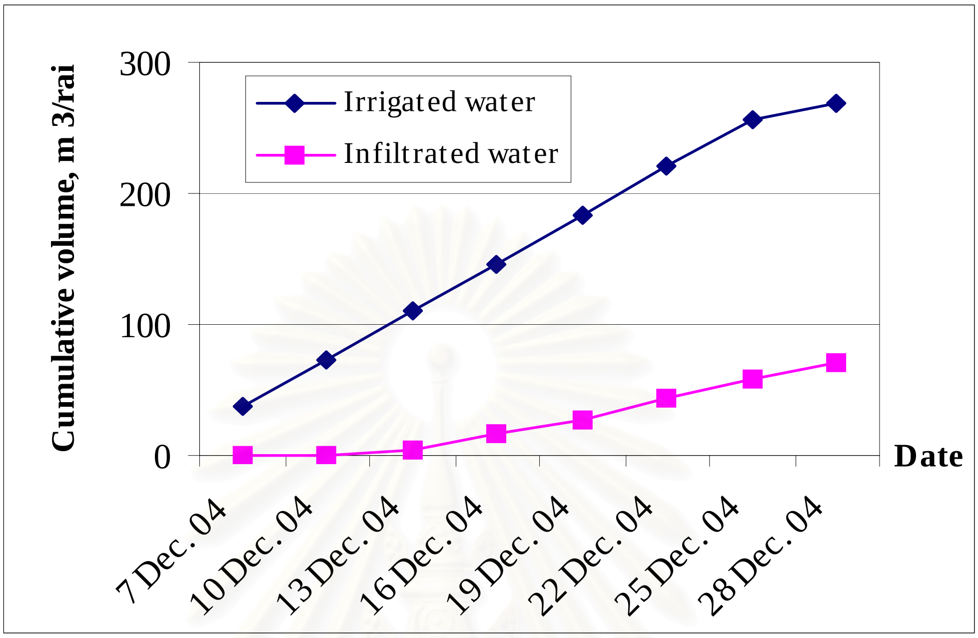
Table C.11 Cumulative volume of irrigated and infiltrated water in the third kale cultivation



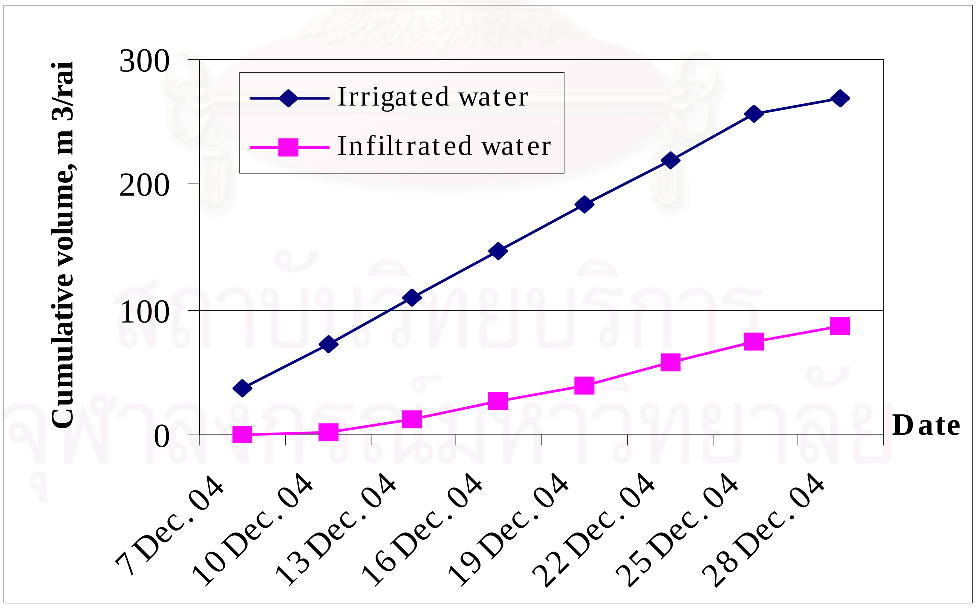
a) Plot 1(0.010 mg Cd/L)



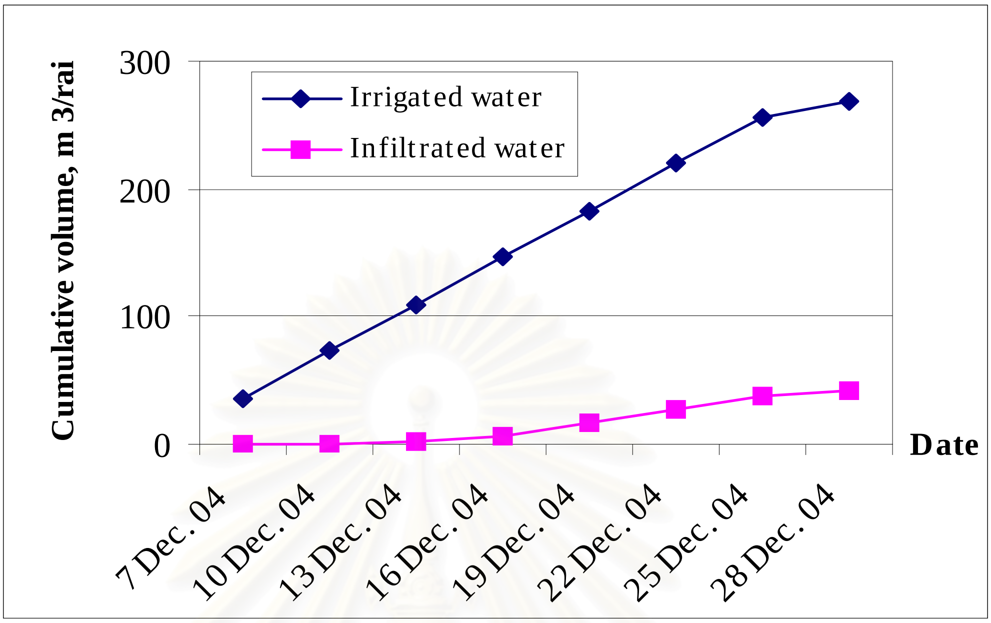
b) Plot 2 (0.014 mg Cd/L)



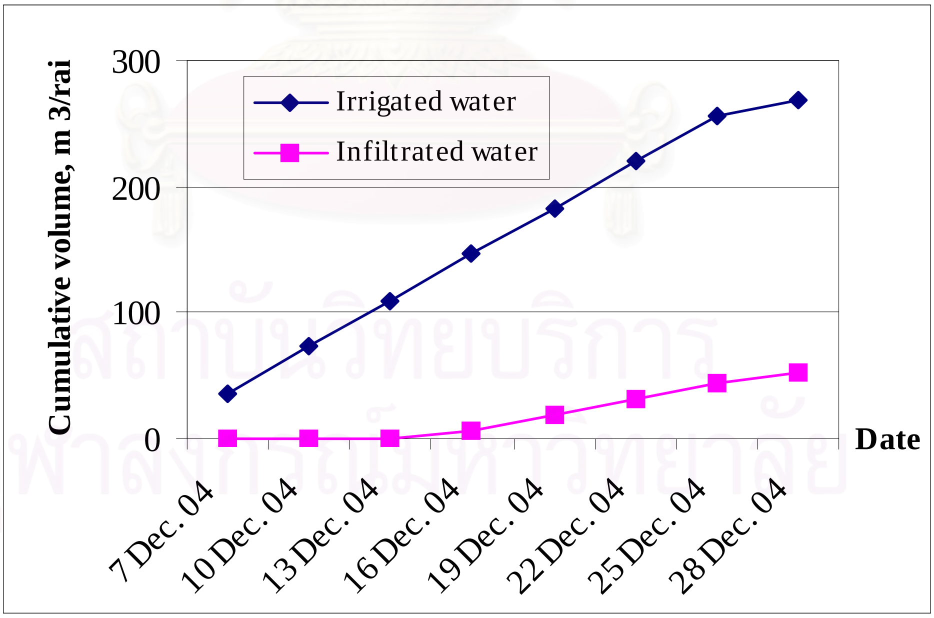
c) Plot 3 (0.023 mg Cd/L)



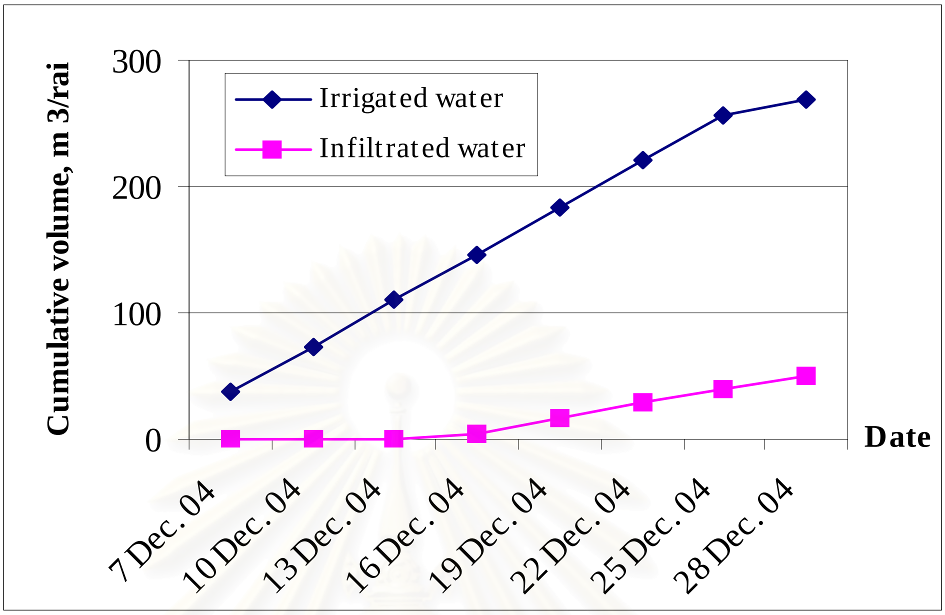
d) Plot 4 (0.771 mg Cd/L)



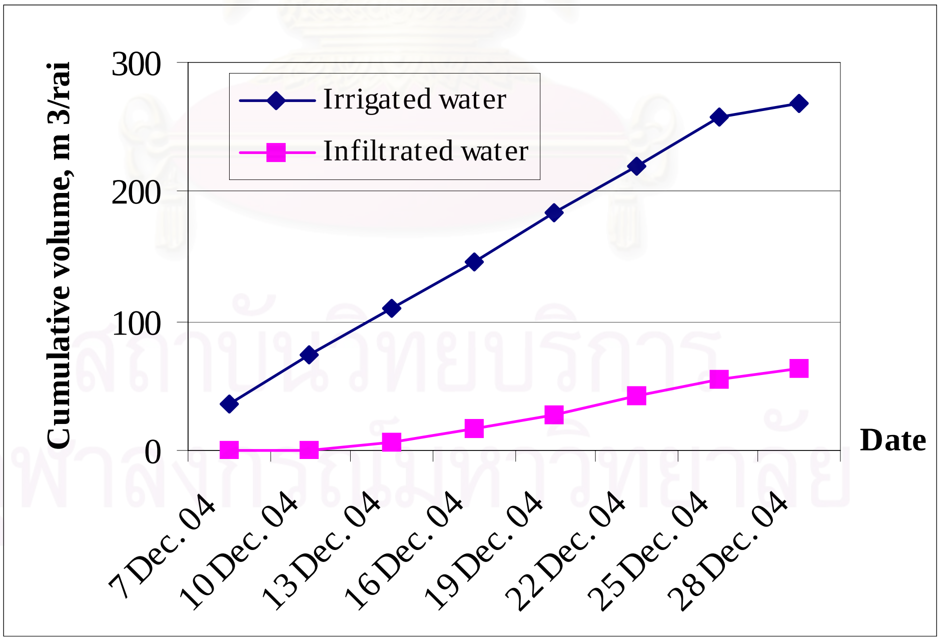
e) Plot 5 (1.291 mg Cd/L)



f) Plot 6 (2.361 mg Cd/L)

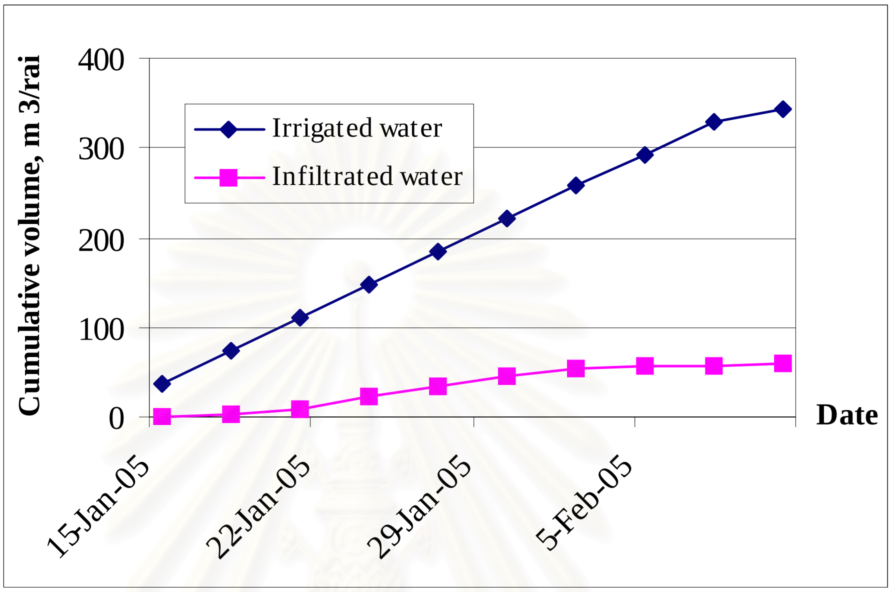


g) Plot 7 (5.531 mg Cd/L)

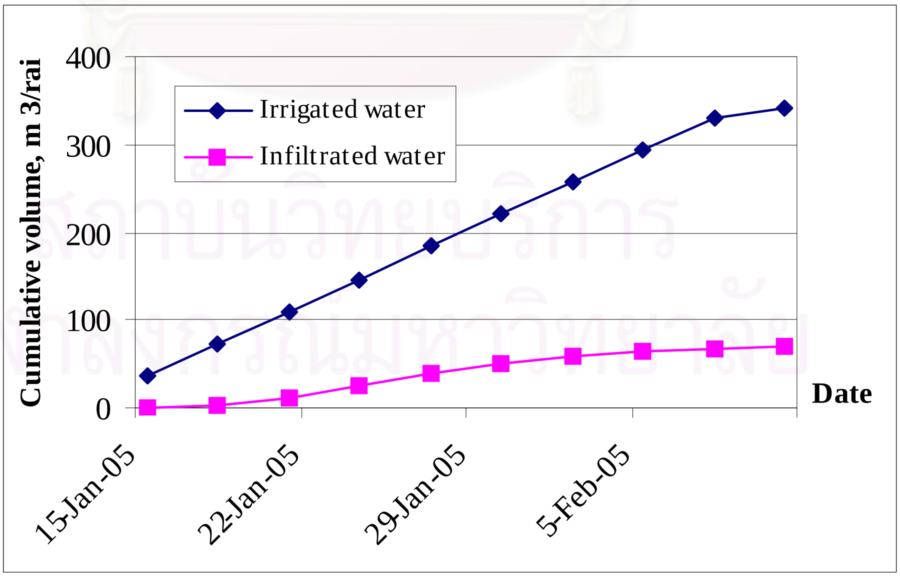


h) Plot 8 (7.982 mg Cd/L)

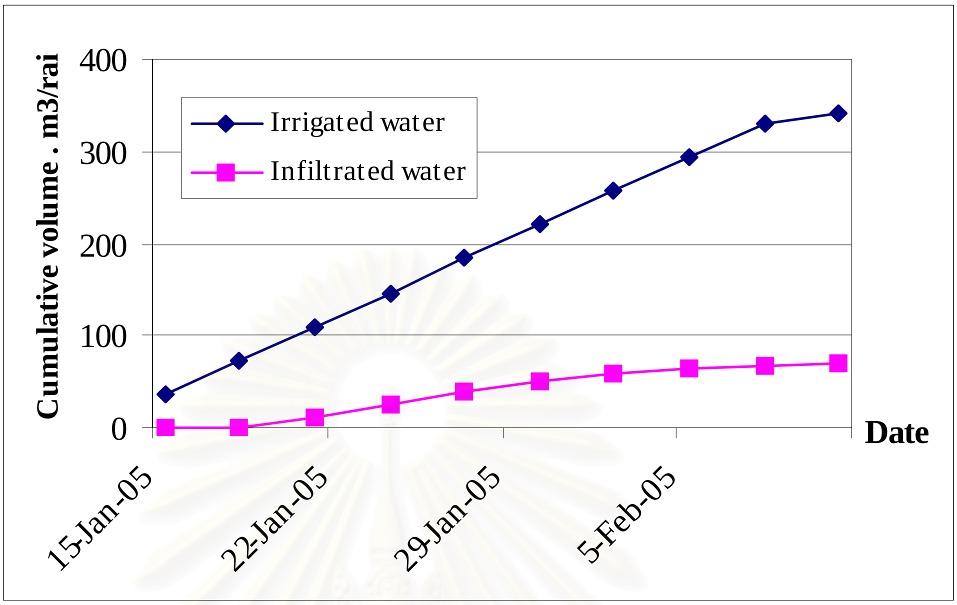
Table C.12 Cumulative volume of irrigated and infiltrated water in the fourth kale cultivation



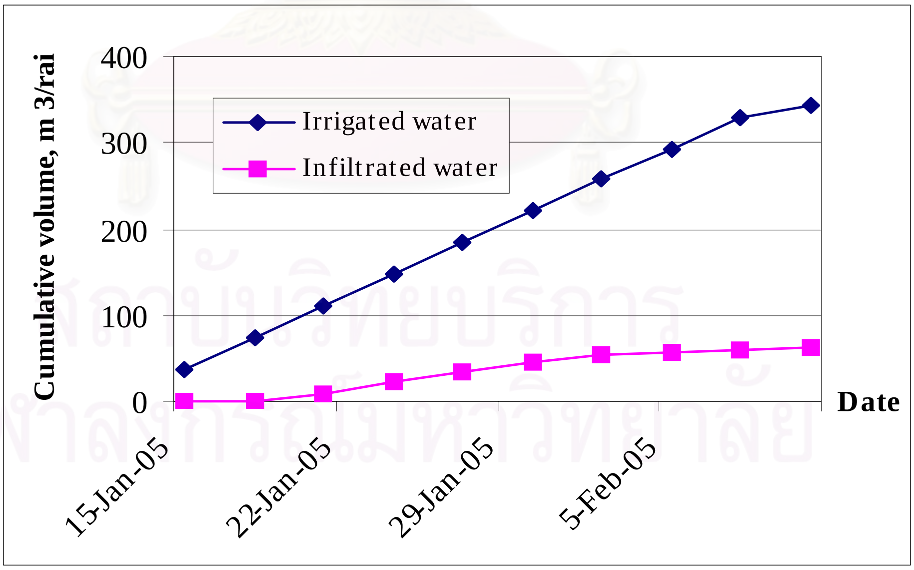
a) Plot 1(0.010 mg Cd/L)



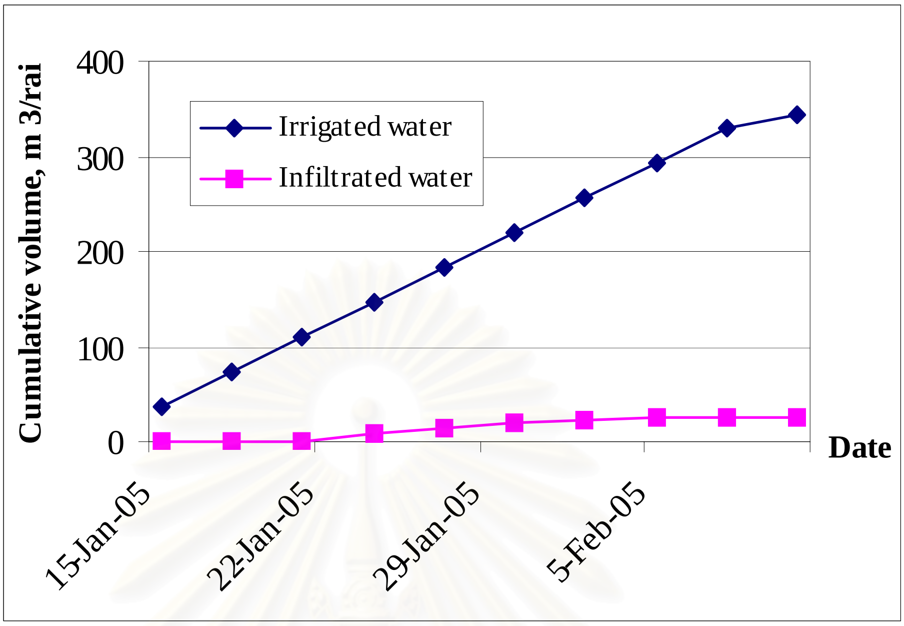
b) Plot 2 (0.014 mg Cd/L)



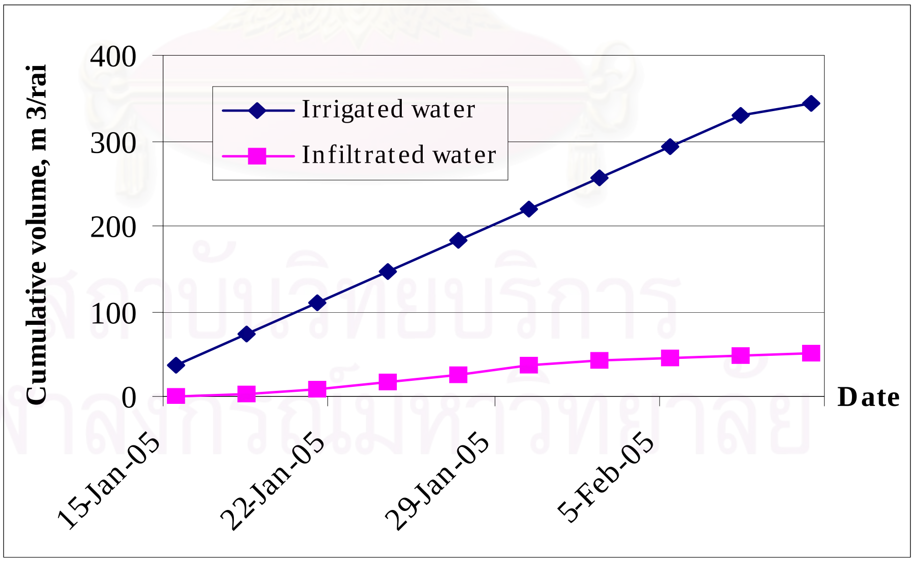
c) Plot 3 (0.023 mg Cd/L)



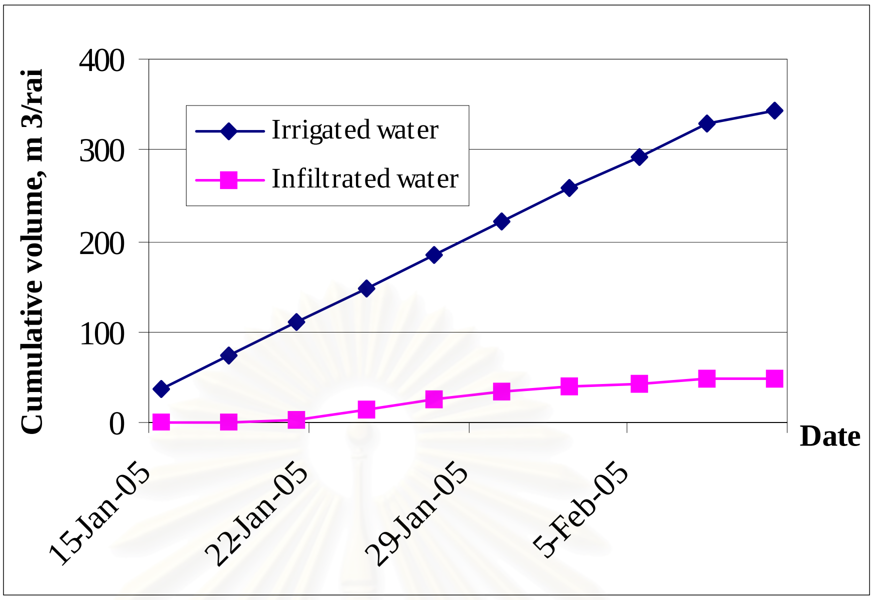
d) Plot 4 (0.771 mg Cd/L)



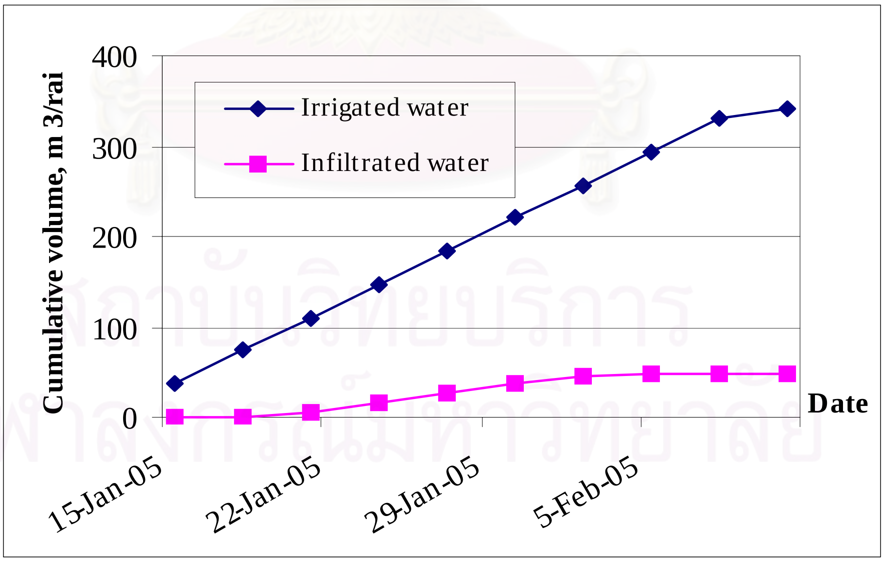
e) Plot 5 (1.291 mg Cd/L)



f) Plot 6 (2.361 mg Cd/L)



g) Plot 7 (5.531 mg Cd/L)



h) Plot 8 (7.982 mg Cd/L)

Table C.13 Cadmium concentration of irrigated and infiltrated water in the first cultivation

Day	Date	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7		Plot 8	
		Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate
1	5 Aug. 04	-	-	-	-	-	-	-	-	-	0.032	-	-	-	0.080	-	0.020
2	7 Aug. 04	0.044	0.008	0.010	0.004	0.034	0.008	0.390	0.011	0.837	0.009	1.875	0.013	4.578	0.002	6.904	0.001
3	9 Aug. 04	0.050	0.009	0.031	0.006	0.038	0.009	0.036	0.007	0.793	0.006	1.909	0.034	4.596	0.007	6.498	0.035
4	11Aug. 04	0.001	0.007	0.005	0.012	0.008	0.006	0.116	0.010	0.602	0.009	1.545	0.019	4.445	0.010	5.750	0.023
5	13 Aug. 04	0.003	0.160	0.004	0.130	0.009	0.110	0.231	0.070	0.638	0.050	1.400	0.070	3.920	0.040	5.680	0.020
6	15 Aug. 04	0.005	0.060	0.017	0.180	0.015	0.280	0.464	0.120	0.620	0.014	1.280	0.016	4.100	0.027	5.870	0.031
7	17 Aug. 04	0.006	0.024	0.024	0.028	0.015	0.224	0.529	0.090	0.697	0.108	1.480	0.096	4.080	0.035	5.960	0.088
8	19 Aug. 04	0.005	0.190	0.021	0.190	0.022	0.080	0.605	0.060	0.651	0.130	1.390	0.100	4.050	0.015	5.920	0.021
9	21 Aug. 04	0.002	0.004	0.002	0.004	0.030	0.006	0.341	0.003	0.704	0.080	1.380	0.029	3.710	0.008	5.290	0.025
10	23 Aug. 04	0.002	0.110	0.002	0.110	0.020	0.130	0.358	0.080	0.704	0.090	1.530	0.100	4.070	0.070	5.190	0.110
11	25 Aug. 04	0.007	0.003	0.011	0.023	0.030	0.002	0.415	0.002	0.757	0.004	1.640	0.009	3.780	0.011	5.130	0.017
12	27 Aug. 04	0.002	0.001	0.002	0.002	0.004	0.001	0.383	0.001	0.783	0.007	1.250	0.009	3.880	0.002	5.930	0.013
13	29 Aug. 04	0.004	0.070	0.004	0.060	0.013	0.050	0.355	0.020	0.760	0.010	1.110	0.030	3.400	0.010	5.550	0.030
14	31 Aug. 04	0.003	0.005	0.005	0.003	0.018	0.004	0.517	0.006	0.650	0.012	1.510	0.014	4.550	0.010	6.330	0.031
15	2 Sep. 04	0.002	0.005	0.011	0.004	0.033	0.004	0.655	0.006	1.091	0.010	1.960	0.010	5.050	0.010	7.040	0.020
16	4 Sep. 04	0.004	0.005	0.003	0.004	0.020	0.003	0.643	0.005	1.420	0.007	2.100	0.009	4.680	0.008	7.350	0.003
17	6 Sep. 04	0.005	0.004	0.004	0.003	0.018	0.003	0.838	0.002	1.490	0.003	2.240	0.011	5.290	0.007	7.340	0.018
Avg.		0.009	0.042	0.010	0.048	0.020	0.058	0.430	0.031	0.825	0.034	1.600	0.036	4.261	0.021	6.108	0.030
SD		0.015	0.061	0.009	0.066	0.010	0.087	0.205	0.039	0.272	0.042	0.325	0.035	0.508	0.023	0.730	0.028

Table C.14 Cadmium concentration of irrigated and infiltrated water in the second cultivation

Day	Date	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7		Plot 8	
		Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate
1	25 Sep. 04	0.017	0.002	0.013	0.000	0.039	-	0.933	0.003	1.710	0.002	2.770	0.006	6.020	0.008	8.080	-
2	27 Sep. 04	0.002	0.001	0.003	0.000	0.011	0.000	1.060	0.004	1.360	0.004	2.430	0.002	5.760	0.006	8.000	0.011
3	29 Sep. 04	0.002	0.002	0.004	0.001	0.005	0.001	1.053	0.006	1.280	0.006	2.480	0.009	5.780	0.003	8.100	0.012
4	1 Oct. 04	0.017	0.003	0.025	0.007	0.040	0.001	0.720	0.006	1.530	0.002	2.680	0.002	5.870	0.003	8.530	0.015
5	3 Oct. 04	0.013	0.000	0.010	0.000	0.032	0.000	0.700	0.001	1.550	0.000	2.840	0.002	5.340	0.002	9.060	0.004
6	6 Oct. 04	0.006	0.001	0.003	0.000	0.025	0.001	0.680	0.002	1.430	0.001	2.550	0.002	5.820	0.011	7.980	0.011
7	9 Oct. 04	0.005	0.001	0.009	0.001	0.015	0.001	0.640	0.002	1.400	0.006	2.430	0.008	5.740	0.018	8.080	0.013
8	12 Oct. 04	0.010	0.000	0.024	0.000	0.012	0.001	0.720	0.003	1.330	0.002	2.540	0.002	6.110	0.003	8.830	0.034
9	15 Oct. 04	0.005	0.006	0.005	0.006	0.006	0.002	0.680	0.003	1.280	0.002	2.320	0.006	5.620	0.016	7.510	0.044
10	18 Oct. 04	0.004	0.001	0.007	0.003	0.002	0.001	0.760	0.002	1.270	0.002	2.290	0.003	5.680	0.015	8.090	0.073
11	21 Oct. 04	0.007	0.001	0.005	0.002	0.007	0.001	0.900	0.002	1.520	0.002	2.800	0.005	6.390	0.022	8.700	0.071
Avg.		0.008	0.002	0.010	0.002	0.018	0.001	0.804	0.003	1.424	0.003	2.557	0.004	5.830	0.010	8.269	0.029
SD		0.005	0.002	0.008	0.002	0.014	0.001	0.154	0.002	0.140	0.002	0.191	0.003	0.274	0.007	0.454	0.026

Table C.15 Cadmium concentration of irrigated and infiltrated water in the third cultivation

Day	Date	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7		Plot 8	
		Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate
1	7 Dec. 04	0.004	-	0.012	-	0.017	-	0.933	-	1.780	-	2.630	-	6.310	-	8.380	-
2	10 Dec. 04	0.005	0.002	0.006	0.001	0.011	-	0.940	0.014	1.260	-	2.580	-	6.030	-	9.880	-
3	13 Dec. 04	0.001	0.001	0.008	0.000	0.011	0.001	0.970	0.014	1.480	0.032	2.560	0.044	6.020	-	8.950	0.164
4	16 Dec. 04	0.006	0.001	0.021	0.001	0.013	0.000	0.820	0.006	1.360	0.014	2.510	0.041	6.060	0.042	8.800	0.085
5	19 Dec. 04	0.011	0.002	0.011	0.001	0.013	0.001	0.870	0.005	1.570	0.023	2.620	0.086	5.540	0.058	9.020	0.116
6	22 Dec. 04	0.003	0.000	0.005	0.000	0.011	0.000	1.046	0.002	1.410	0.003	2.480	0.014	6.160	0.019	8.550	0.047
7	25 Dec. 04	0.005	0.003	0.009	0.002	0.012	0.001	0.878	0.002	1.350	0.003	2.360	0.012	5.670	0.014	8.320	0.048
8	28 Dec. 04	0.002	0.003	0.003	0.003	0.004	0.001	0.821	0.003	1.620	0.001	2.450	0.005	5.620	0.011	6.400	0.028
Avg.		0.005	0.002	0.009	0.001	0.012	0.001	0.910	0.006	1.479	0.013	2.524	0.034	5.926	0.029	8.538	0.081
SD		0.003	0.001	0.006	0.001	0.004	0.000	0.078	0.005	0.170	0.013	0.092	0.030	0.280	0.020	0.994	0.051

Table C.16 Cadmium concentration of irrigated and infiltrated water in the fourth cultivation

Day	Date	Plot 1		Plot 2		Plot 3		Plot 4		Plot 5		Plot 6		Plot 7		Plot 8	
		Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate	Irrigated	Infiltrate
1	15-Jan-05	0.019	-	0.024	-	0.055	-	1.083	-	1.270	-	2.400	-	5.270	-	7.600	-
2	18-Jan-05	0.008	0.058	0.019	0.043	0.012	-	0.088	0.063	1.400	-	2.550	0.017	5.210	-	7.500	-
3	21-Jan-05	0.015	0.036	0.030	0.005	0.006	0.005	1.078	0.049	1.260	0.073	2.230	0.084	4.810	0.014	7.290	0.030
4	24-Jan-05	0.019	0.003	0.030	0.003	0.060	0.003	0.660	0.052	1.030	0.045	2.010	0.012	5.420	0.014	7.360	0.026
5	27-Jan-05	0.024	0.002	0.030	0.002	0.049	0.002	0.570	0.428	0.710	0.004	1.940	0.006	4.970	0.031	7.640	0.036
6	30-Jan-05	0.002	0.001	0.004	0.002	0.018	0.001	0.380	0.005	0.850	0.012	1.980	0.016	4.940	0.074	7.290	0.052
7	2-Feb-05	0.045	0.003	0.042	0.002	0.067	0.002	0.360	0.004	0.610	0.008	1.790	0.019	5.360	0.044	8.640	0.024
8	5-Feb-05	0.034	0.002	0.047	0.002	0.084	0.004	0.260	0.004	0.550	0.013	1.440	0.026	4.170	0.066	6.340	0.032
9	8-Feb-05	0.006	0.001	0.008	0.003	0.016	0.003	0.530	0.013	0.670	-	1.160	0.022	2.470	0.179	3.480	-
10	11-Feb-05	0.008	0.004	0.012	0.001	0.028	0.002	0.990	0.005	1.360	-	2.530	0.014	5.750	0.141	8.250	-
Avg.		0.018	0.012	0.025	0.007	0.040	0.003	0.600	0.069	0.971	0.026	2.003	0.024	4.837	0.070	7.139	0.033
SD		0.013	0.021	0.014	0.014	0.027	0.001	0.351	0.137	0.332	0.027	0.455	0.023	0.934	0.060	1.422	0.010

Table C.17 Meteorology report of the first cultivation

Day	Date	Temperature (°C)	Humidity (%)	Rain Intensity(mm.)	Sunlight(Hr)
1	5 Aug 04	24.9	90	0.7	2.4
2	6 Aug 04	25.8	89	13.8	4.4
3	7 Aug 04	26.7	83	0.0	5.3
4	8 Aug 04	26.7	85	12.0	4.3
5	9 Aug 04	26.5	85	4.2	4.7
6	10 Aug 04	25.1	93	11.0	5.3
7	11 Aug 04	25.8	85	4.9	4.4
8	12 Aug 04	25.8	87	0.8	1.4
9	13 Aug 04	26.3	84	0.0	5.0
10	14 Aug 04	26.7	82	2.0	3.2
11	15 Aug 04	26.1	86	2.4	3.1
12	16 Aug 04	26.5	85	0.0	3.9
15	17 Aug 04	27.3	81	0.0	3.8
16	18 Aug 04	27.0	83	T	3.9
17	19 Aug 04	26.6	85	1.8	3.7
18	20 Aug 04	26.5	87	21.7	4.9
19	21 Aug 04	27.4	82	0.0	5.8
20	22 Aug 04	27.9	83	0.0	4.3
21	23 Aug 04	28.7	79	0.0	4.5
22	24 Aug 04	27.8	81	0.0	3.5
23	25 Aug-04	28.5	75	0.0	5.9
24	26 Aug 04	28.4	75	0.0	5.7
25	27 Aug 04	27.8	76	0.0	4.3
26	28 Aug 04	27.0	82	0.0	3.4
27	29 Aug 04	27.3	81	T	2.8
28	30 Aug 04	26.4	86	5.4	1.3
29	31 Aug 04	26.6	86	0.0	3.1
30	1 Sep 04	27.1	85	T	4.0
31	2 Sep 04	27.4	85	17.2	5.2
32	3 Sep 04	26.1	88	14.7	4.1
33	4 Sep 04	25.0	93	4.0	2.0
34	5 Sep 04	27.7	78	0.0	4.8
35	6 Sep 04	27.3	79	0.0	5.6
36	7 Sep 04	26.8	81	0.0	3.4

Table C.18 Meteorology report of the second cultivation

Day	Date	Temperature (˚C)	Humidity (%)	Rain Intensity(mm.)	Sunlight(Hr)
1	25 Sep 04	27.3	82	0.0	4.7
2	26 Sep 04	26.9	84	0.0	4.2
3	27 Sep 04	27.7	78	0.0	4.8
4	28 Sep 04	26.1	88	T	2.5
5	29 Sep 04	25.9	86	0.0	3.1
6	30 Sep 04	25.9	80	0.0	5.1
7	1 Oct 04	27.4	77	3.0	4.9
8	2 Oct 04	26.2	82	0.7	3.7
9	3 Oct 04	26.1	83	0.0	3.8
10	4 Oct 04	26.5	81	0.0	3.9
11	5 Oct 04	27.0	79	0.0	6.1
12	6 Oct 04	26.9	81	0.0	4.5
13	7 Oct 04	26.4	80	0.0	4.8
14	8 Oct 04	26.6	80	0.0	4.1
15	9 Oct 04	27.0	80	0.0	4.5
16	10 Oct 04	26.9	84	1.9	3.7
17	11 Oct 04	26.4	86	T	1.8
18	12 Oct 04	24.9	88	T	1.1
19	13 Oct 04	25.6	84	0.0	3.3
20	14 Oct 04	25.8	80	0.0	3.7
21.	15 Oct 04	25.8	82	0.0	3.3
22	16 Oct 04	26.1	79	0.0	4.2
23	17 Oct 04	26.8	78	0.2	4.6
24	18 Oct 04	25.1	87	22.0	4.2
25	19 Oct 04	26.0	82	0.0	3.8
26	20 Oct 04	25.6	82	0.0	3.9
27	21 Oct 04	26.1	79	7.0	4.0
28	22 Oct 04	22.5	96	4.0	1.3
29	23 Oct 04	24.0	85	0.0	3.0
30	24 Oct 04	24.6	80	0.0	3.4
31	25 Oct 04	24.6	77	0.0	3.9

Table C.19 Meteorology of the third cultivation

Day	Date	Temperature (˚C)	Humidity (%)	Rain Intensity(mm.)	Sunlight(Hr)
1	7 Dec04	21.4	72	0.0	1.4
2	8 Dec 04	18.9	74	0.0	3.0
3	9 Dec 04	18.2	73	0.0	2.7
4	10 Dec 04	18.7	75	0.0	2.5
5	11 Dec 04	19.0	75	0.0	3.7
6	12 Dec 04	19.2	77	0.0	2.7
7	13 Dec 04	18.3	71	0.0	2.1
8	14 Dec 04	18.6	75	0.0	3.9
9	15 Dec 04	19.5	73	0.0	2.5
10	16 Dec 04	19.5	71	0.0	3.6
11	17 Dec 04	18.7	74	0.0	2.5
12	18 Dec 04	18.8	75	0.0	3.8
13	19 Dec 04	18.6	74	0.0	2.0
14	20 Dec 04	18.3	74	0.0	2.2
15	21 Dec 04	18.8	76	0.0	3.6
16	22 Dec 04	19.0	76	0.0	3.0
17	23 Dec 04	19.3	77	0.0	1.7
18	24 Dec 04	20.2	76	0.0	2.7
19	25 Dec 04	20.4	77	0.0	2.4
20	26 Dec 04	20.5	75	0.0	3.5
21	27 Dec 04	20.9	78	0.0	2.2
22	28 Dec 04	20.6	78	0.0	2.4
23	29 Dec 04	20.5	77	0.0	2.8
24	30 Dec 04	20.1	73	0.0	3.1

Table C.20 Meteorology report of the fourth cultivation

Day	Date	Temperature (˚C)	Humidity (%)	Rain Intensity(mm.)	Sunlight(Hr)
1	15 Jan 04	19.9	75	0.0	6.0
2	16 Jan 04	20.2	79	0.0	5.4
3	17 Jan 04	20.7	78	0.0	8.4
4	18 Jan 04	22.2	73	0.0	8.5
5	19 Jan 04	22.7	72	0.0	8.7
6	20 Jan 04	23.6	73	0.0	8.0
7	21 Jan 04	23.9	74	0.0	9.2
8	22 Jan 04	24.0	70	0.0	9.0
9	23 Jan 04	23.9	67	0.0	9.1
10	24 Jan 04	24.0	66	0.0	8.6
11	25 Jan 04	22.9	65	0.0	9.3
12	26 Jan 04	22.2	66	0.0	9.1
13	27 Jan 04	22.3	63	0.0	8.8
14	28 Jan 04	22.6	66	0.0	9.0
15	29 Jan 04	23.9	65	0.0	8.8
16	30 Jan 04	24.0	62	0.0	9.2
17	31 Jan 04	23.7	65	0.0	9.1
18	1 Feb 04	24.1	67	0.0	8.8
19	2 Feb 04	24.8	66	0.0	8.8
20	3 Feb 04	25.7	62	0.0	9.1
21	4 Feb 04	25.0	60	0.0	9.4
22	5 Feb 04	26.0	61	0.0	9.1
23	6 Feb 04	26.3	58	0.0	9.4
24	7 Feb 04	24.9	58	0.0	9.3
25	8 Feb 04	24.4	54	0.0	9.4
26	9 Feb 04	23.9	52	0.0	9.2
27	10 Feb 04	23.3	56	0.0	9.0
28	11 Feb 04	23.8	63	0.0	7.7
29	12 Feb 04	26.5	60	0.0	8.4
30	13 Feb 04	24.1	56	0.0	9.1
31	14 Feb 04	25.0	47	0.0	9.3
32	15 Feb 04	26.2	47	0.0	9.3

Table C.21 pH of soil in the whole cultivation

Plot (mg/L)	pH of Soil					Average after cultivation
	Before cultivation	After harvesting crop 1	After harvesting crop 2	After harvesting crop 3	After harvesting crop 4	
0.005	6.47	5.18	5.06	5.05	5.49	5.20
0.01	6.20	5.08	5.16	5.03	5.04	5.08
0.03	5.97	5.06	4.95	4.84	5.91	5.19
0.5	5.87	4.96	5.27	5.01	5.57	5.20
1.0	6.11	6.64	5.39	5.97	6.32	6.08
2.0	6.21	5.34	5.33	5.13	6.04	5.46
5.0	5.95	5.39	5.09	5.05	5.55	5.27
7.0	5.85	5.01	5.34	4.88	6.13	5.34
Average	6.08	5.33	5.20	5.12	5.76	

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Table C.22 Percent moisture of soil in the first cultivation

Plot	Fresh Weight (g.)	Dry Weight (g.)	% Moisture
0.005 mg/l	107.70	85.71	20.42
0.01 mg/l	112.66	89.83	20.26
0.03 mg/l	101.95	82.52	19.06
0.5 mg/l	107.84	86.25	20.02
1.0 mg/l	84.86	69.71	17.85
2.0 mg/l	108.57	86.10	20.70
5.0 mg/l	110.85	88.58	20.09
7.0 mg/l	103.28	82.24	20.37

Table C.23 Percent moisture of soil in the second cultivation

Plot	Fresh Weight (g.)	Dry Weight (g.)	% Moisture
0.005 mg/l	128.76	108.68	15.59
0.01 mg/l	120.35	98.36	18.27
0.03 mg/l	96.28	79.77	17.15
0.5 mg/l	112.09	91.41	18.45
1.0 mg/l	124.30	102.20	17.78
2.0 mg/l	107.67	87.86	18.40
5.0 mg/l	122.79	99.75	18.76
7.0 mg/l	128.20	103.03	19.63

Table C.24 Percent moisture of soil in the third cultivation

Plot	Fresh Weight (g.)	Dry Weight (g.)	% Moisture
0.005 mg/l	84.38	69.18	18.01
0.01 mg/l	108.61	86.18	20.65
0.03 mg/l	79.40	64.75	18.45
0.5 mg/l	88.74	72.69	18.09
1.0 mg/l	93.07	76.38	17.93
2.0 mg/l	84.50	68.62	18.79
5.0 mg/l	84.70	68.53	19.09
7.0 mg/l	94.81	76.09	19.74

Table C.25 Percent moisture of soil in the fourth cultivation

Plot	Fresh Weight (g.)	Dry Weight (g.)	% Moisture
0.005 mg/l	91.15	80.91	11.23
0.01 mg/l	119.59	105.57	11.72
0.03 mg/l	91.28	79.12	13.32
0.5 mg/l	97.64	86.67	11.24
1.0 mg/l	106.25	95.50	10.12
2.0 mg/l	87.57	77.13	11.92
5.0 mg/l	108.65	95.19	12.39
7.0 mg/l	90.94	79.18	12.93

Table C.26 Percent moisture of the part of kale in the first cultivation

Plot	Fresh Weight			Dry Weight			% Moisture		
	Root (g.)	Stem (g.)	Leaves (g.)	Root (g.)	Stem (g.)	Leaves (g.)	Root	Stem	Leaves
0.005 mg/l	7.04	11.47	86.05	1.42	1.24	9.29	79.83	89.19	89.20
0.01 mg/l	5.15	8.38	77.51	1.03	0.96	8.05	80.00	88.54	89.61
0.03 mg/l	7.71	11.86	97.13	1.65	1.34	10.63	78.60	88.70	89.06
0.5 mg/l	6.21	8.11	71.98	1.30	0.98	7.87	79.07	87.92	89.07
1.0 mg/l	8.26	18.80	135.84	1.49	1.86	13.96	81.96	90.11	89.72
2.0 mg/l	7.11	13.99	99.18	1.38	1.49	9.73	80.59	89.35	90.19
5.0 mg/l	6.70	15.37	96.88	1.21	1.45	9.33	81.94	90.57	90.37
7.0 mg/l	7.87	17.69	109.81	1.35	1.65	10.16	82.85	90.67	90.75

Table C.27 Percent moisture of the part of kale in the second cultivation

Plot	Fresh Weight			Dry Weight			% Moisture		
	Root (g.)	Stem (g.)	Leaves (g.)	Root (g.)	Stem (g.)	Leaves (g.)	Root	Stem	Leaves
0.005 mg/l	34.28	159.31	492.54	5.95	11.48	45.69	82.64	92.79	90.72
0.01 mg/l	21.15	108.41	341.47	4.00	7.24	31.74	81.09	93.32	90.70
0.03 mg/l	23.16	76.06	322.11	3.65	5.23	29.92	84.24	93.12	90.71
0.5 mg/l	25.77	146.23	426.79	4.27	10.18	39.15	83.43	93.04	90.83
1.0 mg/l	23.73	109.27	416.16	4.46	7.38	38.68	81.21	93.25	90.71
2.0 mg/l	29.04	138.05	429.81	4.84	9.86	42.65	83.33	92.86	90.08
5.0 mg/l	31.83	143.61	394.78	4.28	9.01	35.06	86.55	93.73	91.12
7.0 mg/l	25.35	112.96	424.70	4.03	7.52	41.11	84.10	93.34	90.32

Table C.28 Percent moisture of the part of kale in the third cultivation

Plot	Fresh Weight			Dry Weight			% Moisture		
	Root (g.)	Stem (g.)	Leaves (g.)	Root (g.)	Stem (g.)	Leaves (g.)	Root	Stem	Leaves
0.005 mg/l	21.99	69.03	312.50	2.88	4.16	23.76	86.90	93.97	92.40
0.01 mg/l	13.44	43.47	216.71	1.85	2.71	16.78	86.24	93.77	92.26
0.03 mg/l	12.97	30.63	168.81	1.82	1.88	12.97	85.97	93.86	92.32
0.5 mg/l	11.93	27.85	161.27	1.43	1.73	12.55	88.01	93.79	92.22
1.0 mg/l	35.32	86.53	482.28	4.20	5.21	35.18	88.11	93.98	92.71
2.0 mg/l	27.23	61.12	319.04	2.91	3.63	24.14	89.31	94.06	92.43
5.0 mg/l	22.37	42.23	287.15	2.32	2.64	21.88	89.63	93.75	92.38
7.0 mg/l	24.32	69.04	354.80	2.55	4.13	26.21	89.51	94.02	92.61

Table C.29 Percent moisture of the part of kale in the fourth cultivation

Plot	Fresh Weight			Dry Weight			% Moisture		
	Root (g.)	Stem (g.)	Leaves (g.)	Root (g.)	Stem (g.)	Leaves (g.)	Root	Stem	Leaves
0.005 mg/l	34.85	165.87	602.28	6.18	12.91	57.00	82.27	92.22	90.54
0.01 mg/l	38.69	184.12	620.57	6.26	12.89	55.74	83.82	93.00	91.02
0.03 mg/l	44.38	218.40	677.85	7.60	16.25	59.44	82.88	92.56	91.23
0.5 mg/l	51.42	196.82	666.31	8.10	15.29	68.17	84.25	92.23	89.77
1.0 mg/l	44.36	204.90	577.06	8.24	18.03	58.32	81.42	91.20	89.89
2.0 mg/l	49.92	238.62	691.28	8.16	18.15	58.53	83.65	92.39	91.53
5.0 mg/l	40.02	182.19	538.8	6.03	13.06	49.57	84.93	92.83	90.80
7.0 mg/l	40.38	183.91	567.66	5.86	12.81	47.25	85.49	93.03	91.68

BIOGRAPHY

Name	Jutamas Suppradid
Date of Birth	February 12, 1981
Place of Birth	Burirum, Thailand
Institute Attended	Burirum Phittayakhom School, Burirum
	Certificate of Mathayomsuksa 6
	Faculty of Science
	Chulalongkorn University, Bangkok
	B.Sc. (General Science)