COAL COMBUSTION PRODUCTS UTILIZATION FOR SOIL AMENDMENT

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ตรัง ถี อาน ทเวียต : การใช้ประโยชน์ผลิตภัณฑ์จากการเผาไหม้ถ่านหินเพื่อการปรับปรุงดิน (COAL COMBUSTION PRODUCTS UTILIZATION FOR SOIL AMENDMENT) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: เกรียงไกร มณีอินทร์, 89 หน้า.

ปัจจุบันถ่านหินได้เข้ามามีบทบาทสำคัญในการผลิตพลังงานทั่วโลกเป็นผลทำให้การใช้ถ่านหินก่อให้เกิดผลิตภัณฑ์จากการเผาไหม้ถ่านหินในปริมาณมากซึ่งจะประกอบด้วยเถ้าหนักและเถ้าลอย ในเถ้าถ่านหินนั้นยังมีคุณลักษณะที่มีศักยภาพเป็นไปตามความต้องการจึงกลายมาเป็นแหล่งวัตถุดิบในการเกษตร เช่น เนื้อสัมผัส ความสามารถในการอุ้มน้ำ ความหนาแน่นรวม ความเป็นกรด - เบส เป็นต้น และยังมีสารอาหารที่จำเป็นสำหรับพืชเกือบทั้งหมด อย่างไรก็ตามปริมาณเถ้าถ่านหินที่เกิดขึ้นมามากนั้นจะถูกจัดการด้วยวิธีการฝังกลบซึ่งหากปล่อยทิ้งไว้จะส่งผลกระทบต่อทางด้านสิ่งแวดล้อม ดังนั้นการวิจัยนี้จึงได้นำเถ้าถ่านหินมาใช้ในการเกษตรเพื่อต้องการกำจัดเถ้าถ่านหิน และในทำนองเดียวกันยังต้องการเพิ่มผลผลิตให้แก่พืชและคุณสมบัติทางเคมี - กายภาพของดินอีกด้วย ซึ่งการวิจัยนี้จะประกอบด้วยกันสองส่วนที่สำคัญ คือ (1) เป็นการวัดผลกระทบของเถ้าถ่านหินที่ส่งผลต่อคุณสมบัติของดิน เช่น เนื้อดิน ความเป็นกรด - เบส ความเค็ม และความหนาแน่นรวม ส่วน (2) เป็นการประเมินค่าการเจริญเติบโตของพืชโดยการวัดความสูงของลำต้นและขนาดของใบ จากผลการวิจัยคุณสมบัติของดินพบว่าการใช้เถ้าหนักและเถ้าลอยส่งผลกระทบมากต่อเนื้อดิน ความเป็นกรด - เบส ความเค็ม และความหนาแน่นรวมของดิน ยกตัวอย่างเช่น การใช้เถ้าถ่านหินที่อยู่ในช่วงร้อยละ 5 ถึง 30 โดยน้ำหนักนั้นจะสามารถปรับปรุงความหนาแน่นรวมของดินเพื่อให้เหมาะสมกับสภาพการเจริญเติบโตของพืชได้ การวิจัยนี้จึงขอแนะนำว่าควรใช้เถ้าถ่านหินที่มีความเข้มข้นน้อยกว่าร้อยละ 5 โดยน้ำหนัก เพื่อไม่ให้เสี่ยงต่อการเกิดดินเค็มได้ และจากผลการวิจัยการปลูกพืชพบว่ากรณีที่ใช้เถ้าหนักร้อยละ 5 โดยน้ำหนักจะช่วยเพิ่มการเจริญเติบโตของต้นพริกขี้หนูได้ตลอดช่วงระยะเวลาสามเดือนแรกของการวิจัยนี้ ส่วนการผสมของเถ้าหนักและปุ๋ยในส่วนผสมของดิน ปุ๋ย และเถ้าหนัก ที่ร้อยละ 90 5 และ 5 โดยน้ำหนัก ตามลำดับ จะแสดงให้เห็นว่าการเจริญเติบโตของต้นพริกขี้หนูสูงกว่าการผสมปุ๋ยที่ร้อยละ 10 และ 20 โดยน้ำหนักตลอดระยะเวลาที่ทำการวิจัยมา ซึ่งหมายความว่าเถ้าหนักสามารถใช้ร่วมกับปุ๋ยเพื่อลดราคาต้นทุนการผลิตและอีกทั้งยังช่วยเพิ่มผลผลิตให้แก่พืชได้ ส่วนการใช้เถ้าลอยนั้นไม่สามารถช่วยให้พืชเจริญเติบโตได้ทั้งในต้นพริกขี้หนูและต้นใบกะเพรา จากผลการวิจัยทั้งหมดนี้สามารถสรุปได้ว่าเถ้าหนักสามารถนำไปใช้ในการเกษตรได้อย่างมากเพื่อก่อให้เกิดประโยชน์สูงสุดและยังสามารถลดปัญหาผลกระทบต่อทางด้านสิ่งแวดล้อมได้อีกด้วย

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TRAN THI ANH TUYET: COAL COMBUSTION PRODUCTS UTILIZATION FOR SOIL AMENDMENT. ADVISOR: ASST. PROF. KREANGKRAI MANEEINTR, Ph.D., 89 pp.

Nowadays, coal has a crucial role in generating energy all over the world. As a result, the consumption of coal creates a huge amount of coal combustion products, including bottom ash and fly ash. The coal ash has the potential characteristics to become a resource material in agriculture such as its texture, water holding capacity, bulk density, pH etc., and contains almost all the essential plant nutrients. However, most of the coal ash created is dumped into the landfill, which is a contributing factor in the environmental degradation. This study wants to use coal ash in agriculture as a way to dispose of coal ash and at the same time, it improves crops yield and physicochemical properties of soil.

This research contains two main parts. The first part measures the effect of coal ash on soil properties of soil such as soil texture, pH, salinity, and bulk density. The second part is to evaluate the plant growth by measuring height and leaf size.

The results of the experiment on soil properties show that the application of bottom ash and fly ash has a significant effect on soil texture, pH, salinity and bulk density of soil. For instance, the using of coal ash ranging from 5% wt. to 30% wt. improves bulk density of soil to a suitable condition for plant growth. This research recommends that this coal ash should be used with concentration less 5% wt. to avoid the soil become saline.

From the result of growing plant, it is found that the case of bottom ash used at 5% wt. help to increase significantly the growth of Bird Pepper during the first three months of the study time.

The combination of bottom ash and fertilizer in the mixture of soil, fertilizer and bottom ash by 90% wt., 5% wt., 5% wt., respectively shows the plant growth of Bird Peppers higher than that of the mixtures of fertilizer at 10% wt., 20% wt. in most of the study period. It means that bottom ash could be combined used with fertilizer to reduce production cost and increase crop yield. Furthermore, the application of fly ash does not help plants growing of both Bird Peppers and Holy Basil.

From the results of this research, it is expected that bottom ash could be used wider in agriculture to bring more benefit and reduce environmental problems when disposes of coal ash.

Department:	Mining and Petroleum Engineering	Student's Signature	....
		Advisor's Signature	....
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ABBREVIATIONS

CCPs	Coal combustion products
CBA	Coal bottom ash
BA	Bottom ash
CFA	Coal fly ash
FA	Fly ash
FGD	Flue gas desulfurization
Mtoe	Million Tons of Oil Equivalent
Mt	Million metric tons (Mt)

CHAPTER 1
INTRODUCTION

1.1. Background

Today coal is the main source of energy generation in the world. It provides about 30% of the global energy demand. A significant increase in global coal consumption by 64% from 2000 to 2014 (Council, 2016) makes coal now the fastest growing sector of fuel. About 40% globally generated powers depend on coal. As shown in Figure 1.1, coal ranks second in the global energy consumption (29%) over the past 15 years.

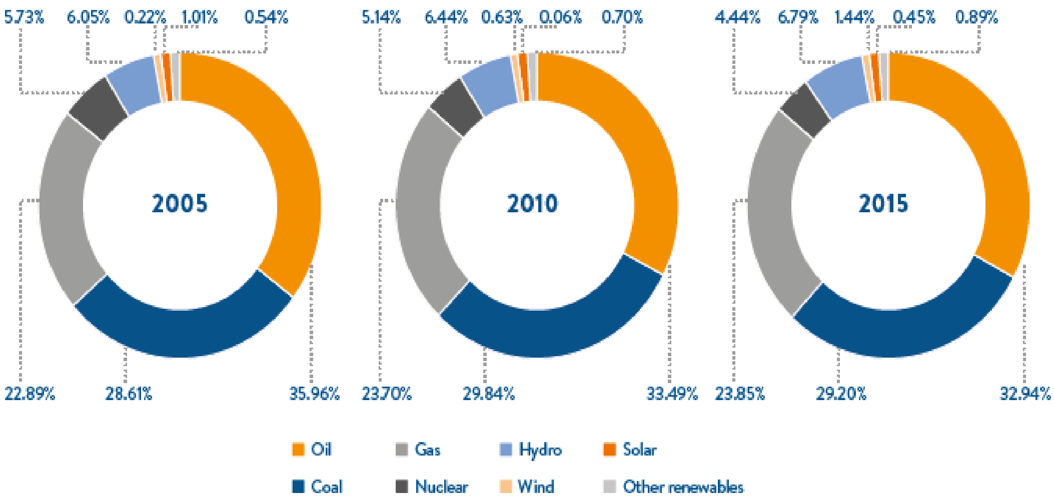

Figure 1.1 The comparative primary energy consumption over the past 15 years (Council, 2016)

Asia is known as the biggest market for coal with 66% of global coal consumption. In 2016, China contributed 50% of the global coal consumption with 1887.6 Mtoe larger than 5.3 times the second largest consumer market (The United States) with 358.4 Mtoe. In Thailand, the coal consumption was reported at 17.57 Mtoe in 2015 and 17.74 Mtoe in 2016 (Dudley, 2017).

A large quantity of coal combustion products (CCPs) is generated from the coal combustion process for the electricity generation purpose.

In previous research, CCPs are also used as materials for construction, mining, waste treatment, agriculture etc. However, it is the fact that the number of CCPs being produced is larger than that of the current CCPs utilization. The difference between the CCPs generation and utilization in different countries in 2010 is shown in Table 1.1. It shows that the worldwide production of coal combustion products is nearly 780 Mt. Meanwhile, the CCPs utilization rate is only equal to about 50% of the total CCPs production.

Table 1.1 Generation and utilization of CCPs in different countries 2010 (Heidrich et al., 2013)

Country/region	CCPs production (Mt)	CCPs utilization (Mt)	Utilization rate (%)
Australia	13.1	6.0	45.8
Canada	6.8	2.3	33.8
China	395.0	265.0	67.1
Europe (EU 15)	52.6	47.8	90.9
India	105.0	14.5	13.8
Japan	11.1	10.7	96.4
Middle East & Africa	32.2	3.4	10.6
United State of America	118.0	49.7	42.1
Other Asia	16.7	11.1	66.5
Russian Federation	26.6	5.0	18.8
Overall	777.1	415.5	53.5

1.2. Type of Coal Combustion Products

Fly ash, bottom ash, boiler slag, and FGD materials are four main types of CCPs that are collected in emission control processes (Tharaniyil, 2013). While fly ash and bottom ash are the main products of the combustion, boiler slag, on the other hand, is only produced when a wet-bottom furnace is used. Boiler slag is noncombustible minerals kept in a molten state and tapped off as a liquid. The CCPs production process is shown in Figure 1.2.

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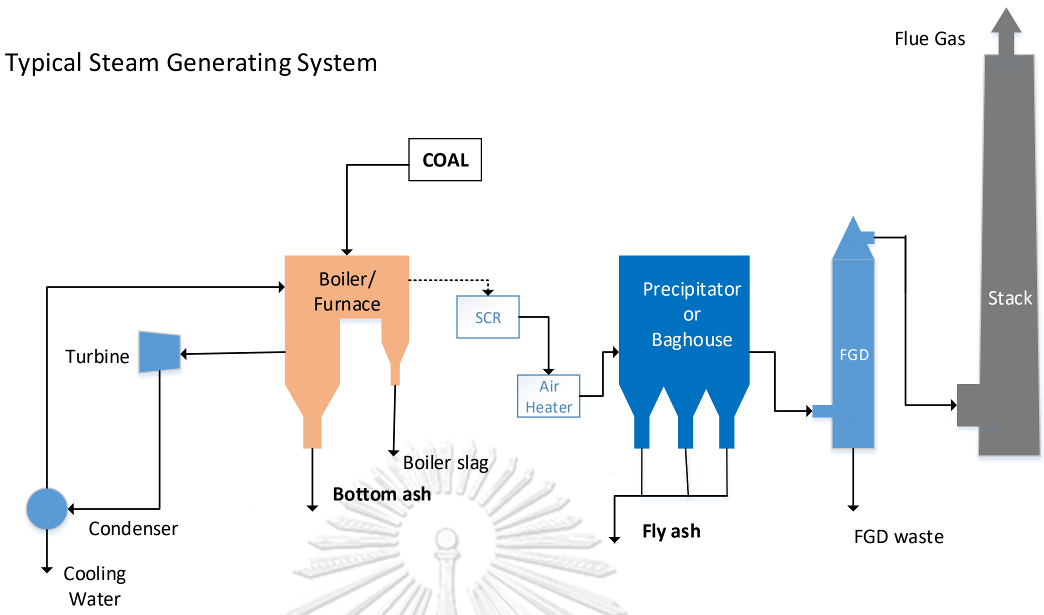


Figure 1.2 Production of coal combustion products (CCPs) (Skousen et al., 2013)

In the coal combustion process, CCPs are generated in direct proportion to quantity content of coal consumed. First, heat is created by burning coal in a furnace. Then, the hot gases pass around the bank of tubes in the boiler and are eventually cleaned and discharged through the plant chimney. Fly ash is the fine particle residue in electrostatic precipitators (ESP) or baghouses.

Fly ash is a main component of by-product, which is the most difficult to handle. Fly ash takes more than 58% of CCPs production, followed by flue gas desulfurization (FGD) material (24%), bottom ash (16%), and boiler slag (2%) (Kalyoncu and Olson, 2001).

Bottom ash is formed by the agglomeration of ash particles melting during the coal combustion process (Tharaniyil, 2013). These particles fall by themselves into the bottom of the furnace. Normally, the particle size of bottom ash is larger than fly ash.

Flue gas desulfurization (FGD) material is formed in the process of removing sulfur dioxide gas (SO_2). The slurried limestone or lime in the flue gas scrubbers reacts with sulfur dioxide gas to generate calcium sulfite ($CaSO_3$). Calcium sulfate ($CaSO_4$), the basis of FGD gypsum, is then formed by oxidized calcium sulfite ($CaSO_3$).

According to the American Coal Ash Association (ACAA), about 130 million tons of CCPs are generated in 2010 in the United States in which there are approximate 68 million tons of fly ash, 18 million tons of bottom ash, 32 million tons of flue gas desulfurization (FGD) materials, and 2 million tons of boiler slag (Tharaniyil, 2013). Figure 1.3 shows the typical proportions of different constituents of CCPs produced for 2010 in the United States.

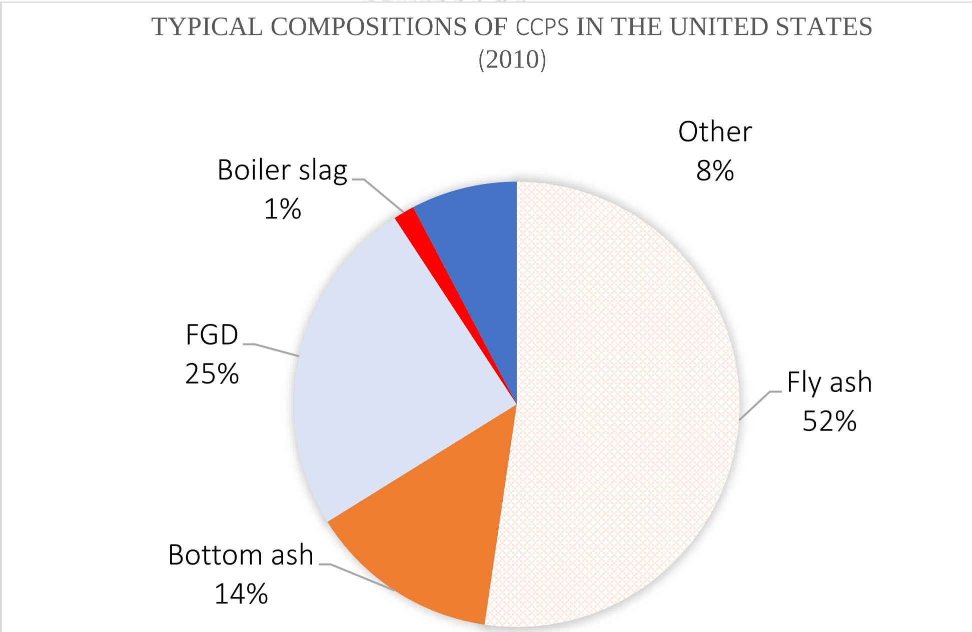


Figure 1.3 Typical compositions of CCPs in the United States in 2010; total production 130 million tons (Tharaniyil, 2013)

In Thailand, there are approximately 3 million tonnes of fly ash generated per year with 95% from the Mae Moh generating plant of the Electricity Generating Authority of Thailand at Lampang province, in the north of Thailand. Moreover, Thailand is the number one user of fly ash in cement and concrete with almost 100% of fly ash is used in cement and concrete in 2004 (Tangtermsirikul, 2005). However, bottom ash still has not been utilized much. Almost of bottom ash is disposed to landfilling creating the negative environmental impacts. Improperly constructed or managed coal ash disposal units could lead to harm groundwater and air pollution.

1.3. Coal Combustion Products Utilization

It is found that CCPs are non-hazardous. Although CCPs contain trace elements of mercury, it is proven that mercury retained in CCPs do not leach at levels of environmental concern (Tharaniyil, 2013).

CCPs in general and coal ash in particular, have many applications such as in civil engineering (road base, embankment, flowable fill etc.), mining, waste treatment etc. It is estimated that CCPs produced worldwide annually range from 500 Mt to 780 Mt (Fu, 2010, Heidrich *et al.*, 2013). However, only a small amount of the total CCPs produced is beneficially used. The most common method for CCPs disposal is landfilling causing significant environmental and economic burden to the ecology and society.

In 2007, the overall CCPs production of the European Union (EU15) was approximately 61 Mt with a utilization rate of 89.3%, according to European Coal Combustion Products Association (ECOBA) in 2009, as shown in Figure 1.4. The main reuse of the CCPs is in civil engineering such as road base, embankment, flowable fill, etc. with 52.7% of the CCPs produced, 36.5% are used in the restoration of open cast mines, 2.5% are temporarily stockpiled for future use and 8.3% are disposed (Fu, 2010).

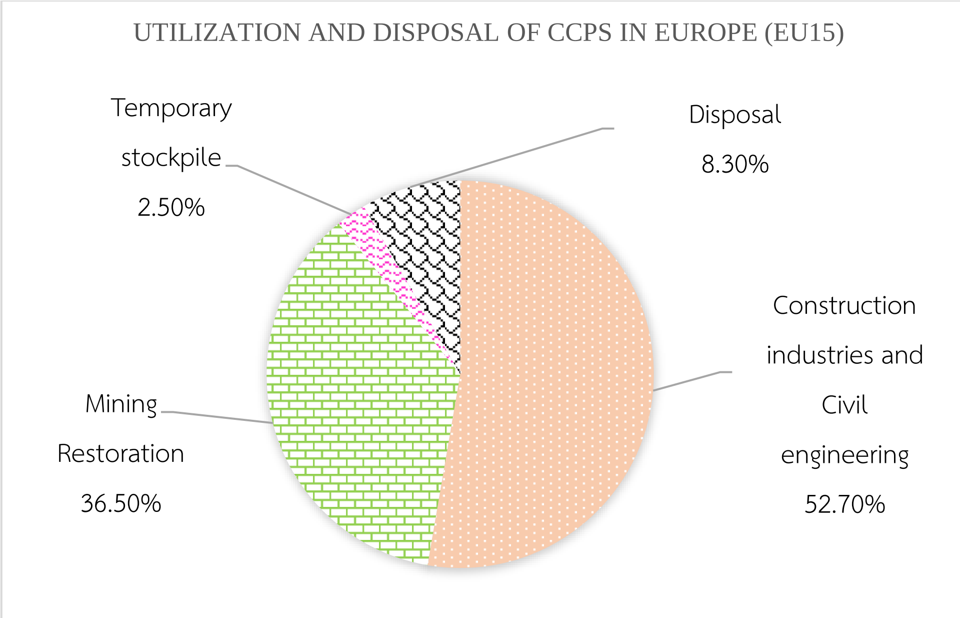


Figure 1.4 Utilization and disposal of CCPs in Europe (EU15); total amount 61 million tons (based on ECOBA, 2009) (Fu, 2010)

The report by The America Coal Ash Association (ACAA) presents that the CCPs production in the United States 2008 is approximately 136.1 million tons. There are about 44.5% of total CCPs production used in a number of applications such as construction industries and civil engineering leading the way at 32.1%, followed by mining applications with 7.7% and other applications with 4.7%. Meanwhile, about 55.5% of the total CCPs is still being stockpiled or disposed of in landfills. (Fu, 2010). Figure 1.5 illustrates the CCPs utilization and disposal for 2008 in the United States.

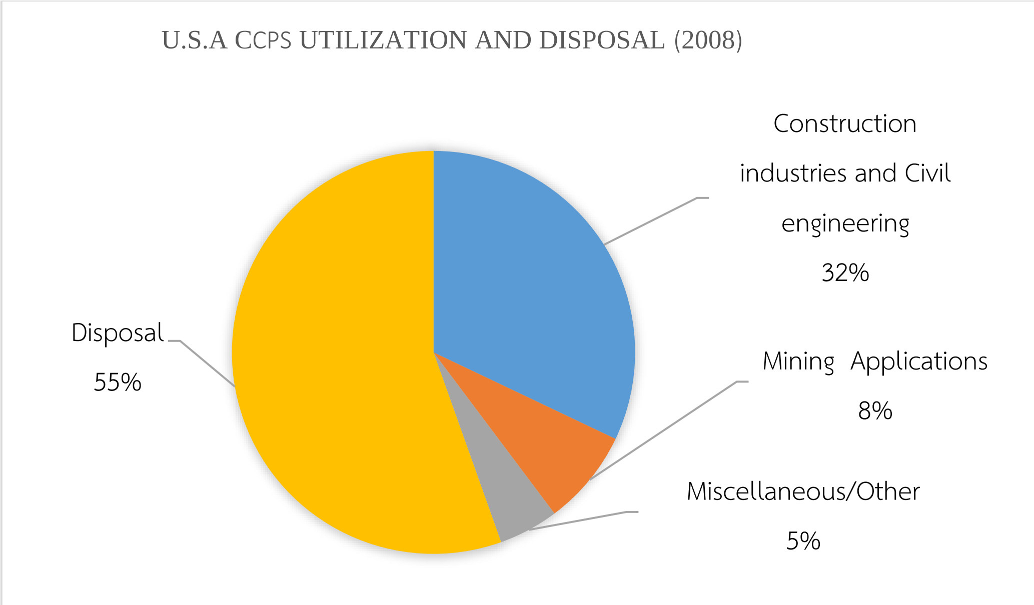


Figure 1.5 U.S.A Coal Combustion Products utilization and disposal in 2008; total amount 136.1 million tonnes (based on ACAA, 2009) (Fu, 2010)

Coal ash is the main component of CCPs produced. To generates 1 megawatt of electricity, there need 4.3–11 tons of coal ash produced by burning of 15–18.75 tons of coal (Jayaranjan *et al.*, 2014). In Figure 1.6, coal ash is used in various sectors, such as concrete products (37.13%), embankment (18.06%), blended cement (10.40%), cement raw material (8.29%), and agriculture (0.05%), etc. (Jayaranjan *et al.*, 2014). Also, concrete/concrete products, structural fills/embankments, roads in civil engineering are main applications of coal ash.

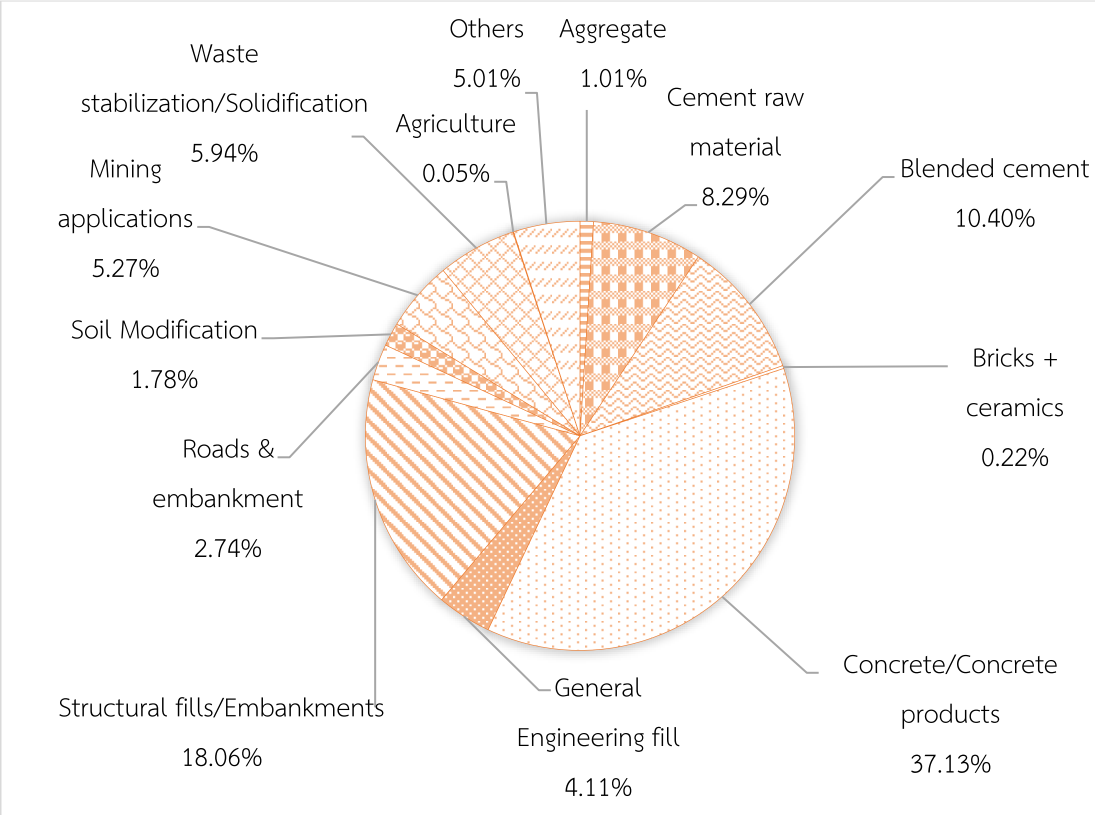


Figure 1.6 Use of coal ash in various sectors (Jayaranjan et al., 2014)

In agriculture, the main application of coal ash is a soil amendment. Soil amendments are anything mixed into soil to improve soil properties and promote healthy plant growth. Some of the soil amendments are presented in Table 1.2. Coal ash is also known as a material used to amendment soil. Some coal ash properties such as soil texture, soil pH, the electrical conductivity of the extract of a soil-saturated paste (ECse), bulk density help to improve soil properties. Moreover, coal ash contains essential elements and micronutrients for plant growth. The application of coal ash to soil is to supply nutrients for plant growth as P, K, Ca, Mg, S, Zn, Fe, Cu, Mn (Arenas *et al.*, 2011, Singh *et al.*, 2010, Wearing *et al.*, 2004).

Table 1.2 Some of the various soil amendments

Material used for soil amendment	Purpose
Lime	Make soil less acidic
Fertilizers	Supply nutrients for soil
Gypsum	Releases nutrients and improves structure of soil
Clay	Allows water to reach the plant root
Bottom ash and Fly ash	Supply nutrients for soil, improve soil properties

It is found that Arsenic in coal fly ash did not lead out at all in a basic environment for either sample (Seshadri *et al.*, 2011). However, coal ash also contains some toxic element, assessing the coal ash absorbed in growing plant when using coal ash as soil amendments are a necessity.

Nowadays, coal is known as the main energy in the world. A huge amount of coal ash is generated from coal combustion lead to concern in environmental. Although coal ash is suitable to utilize as a soil amendment in agriculture due to unique properties of them, they are used quite less than the quantity of production by agriculture now. Especially, bottom ash is rare reuse or sell, although a huge amount of bottom ash is generated annually. The most common method for coal ash disposal is landfilling causing significant environmental and economic burden to the ecology and society. Moreover, the disposal cost of coal ash has escalated significantly during the last couple of decades due to significant changes in landfill design regulations. Thus, the coal ash utilization like soil amendment is a better way to manage the waste as well as to reduce the environmental impacts and increase the profit for the manufacturer. On the other hand, it also conserves these manufacture materials. This study expects to use coal ash as a soil amendment in order to minimize waste, decrease environmental impacts, and increase the profit for the manufacturers.

1.4. Research Objective

This thesis has two main objectives. First is to evaluate the effects of bottom ash or fly ash as a soil amendment on soil qualities such as soil texture, soil pH, ECse, bulk density. Secondly, it is to investigate the effects of bottom ash or fly ash on plant growth by measuring height and leaf size.

1.4.1. Scope of study

Bottom ash and fly ash are obtained from the pulp and paper industry in Thailand. Soil is collected in Saraburi province, Thailand. This study also uses cow manure fertilizer to grow plants in order to compare with the other conditions. Two plants are selected, including Bird Peppers *(Capsicum annuum)* and Holy Basil *(Ocimum sanctum)*.

This thesis includes two parts. Part 1 is the experiments on soil properties such as soil texture, soil pH, ECse, bulk density in order to understand the effect of coal ash on soil properties. Part 2 is to evaluate growth plant by measuring plant height and leaf size.

1.4.2. Contribution

According to unique properties of coal ash, this study is expected to use ashes as a source of material in agriculture to improve soil quality, reduce costs associated with coal ash disposal, increase revenue from the sale of coal ash and reduce environmental impact.

1.4.3. Thesis organization

This thesis consists of five chapters. **Chapter 1** provides the background, objectives, scope, contribution of this study, and a summary outline of the research. **Chapter 2** summarizes the literature review, theory of using coal ash as a soil amendment, and previous research relevant to this study. The experimental work is provided in **Chapter 3**. **Chapter 4** presents the research results and discussion of using coal ash to improve soil properties and plant growth. Conclusions on the effects of using coal ash as a soil amendment, followed by the recommendation of using coal ash in agriculture are presented in **Chapter 5.**

CHAPTER 2
THEORIES AND LITERATURE REVIEW

This chapter presents the overall picture of literature reviews, the previous research related to this study, and the theory of using coal ash as a soil amendment in agriculture.

2.1. Definition and Characteristics of Coal Combustion Products (CCPs)

2.1.1. Characteristics of fly ash

The largest part of coal combustion products is fly ash with more than 58% of CCPs production (Kalyoncu and Olson, 2001). The raw coal source, size, type of coal burner and the operating conditions significantly affect physiochemical properties of fly ash. (Tharaniyil, 2013).

2.1.1.1. Physical properties of fly ash

The color of fly ash particles is dependent on unburned carbon content and combustion technology use. It is generally grey or dark grey. According to the Unified Soil Classifications System, the particle size of fly ash is primarily in silt range with the lower bound is the clay category and the upper one is the sand category. (Tharaniyil, 2013). Generally, fly ash is mostly alkaline, abrasive, and refractory in nature (Ahmaruzzaman, 2010).

Fly ash is popularly used in civil construction engineering or in agriculture due to its particle size distribution, bulk density, porosity, etc. Those properties are shown in Table 2.1.

Table 2.1 Typical value of fly ash properties (Jayaranjan et al., 2014)

Parameters	Fly ash	Unit
Color	Gray to black	-
Shape	Spherical	
Specific gravity	2.10–2.81	-
Particle size distribution	0.001–0.075	mm
Bulk density	1.12–1.28	g/cm^3
Specific surface area	1.0–9.44	m^2/g

2.1.1.2. Chemical properties of fly ash

Fly ash has two categories: Class F and Class C, according to ASTM C618. Class F (low calcium) is normally originated from the bituminous or anthracite coal combustion, while the lignite or sub-bituminous coal combustion produces Class C (high calcium) (Tharaniyil, 2013).

The typical range of the fly ash chemical composition produced from various coal types is shown in Table 2.2. The main composition of fly ash is presented in Table 2.3.

Table 2.2 Normal range of chemical composition of fly ash (%) produced from different coal types (Tharaniyil, 2013)

Compounds	Bituminous	Sub-bituminous	Lignite
SiO_2	20-60	40-60	15-45
Al_2O_3	5-35	20-30	10-25
Fe_2O_3	10-40	4-10	4-15
CaO	1-12	5-30	15-40
MgO	0-5	1-6	3-10
SO_3	0-4	0-2	0-10
Na_2O	0-4	0-2	0-6
K_2O	0-3	0-4	0-4

Table 2.3 Trace elements concentrations in coal fly ash (Jayaranjan et al., 2014)

Trace	Trace element composition of fly ash (mg/kg dry basis)			
	Lignite	Sub-bituminous	Bituminous	Anthracite
As	13.5-172	-	110-141	-
B	-	-	386-400	-
Ba	-	-	-	-
Cd	1-312	-	18-35	-
Co	16-57	18-53	21-25	8-12
Cr	31-160	69-95	98-128	80-498
Cu	24-71.8	63-66	64-64	77-109
Hg	0.01-8.8	-	-	-
Li	-	-	113-119	-
Mn	182-566	-	460-588	-
Mo	-	-	162-386	-
Ni	36-242	74-174	49-61	41-72
Pb	9-847	29-32	20-1192	36-103
Sn	-	-	101-109	-
Zn	59.6-249	93	3500-5800	43-167

2.1.1.3. Use of fly ash in agriculture

There are many reasons to fly ash used. A few of these reasons are given. The use of fly ash to save land is reserved for disposal and disposal costs are minimized. Coal fly ash can replace some natural resources and decrease environmental impact.

Fly ash physical properties such as texture, water holding capacity, bulk density, and enrichment with nutrients for plant growth make it suitable to be utilized in agriculture (Singh *et al.*, 2010).

Adding fly ash to soil decreases soil bulk density and improves soil porosity as well as workability. Furthermore, the fly ash addition can also enhance water retention capacity (Page *et al.*, 1979).

Table 2.4 shows the effect of fly ash on soil physical and chemical properties.

Table 2.4 Effect of fly ash on soil physical and chemical properties (Singh et al., 2010)

Properties	Effect	References
Physical		
pH	Decrease	Pathan et al. (2003), Sinha and Gupta (2005), Gupta and Sinha (2006)
	Increase	Pandey et al. (2008), Wong and Lai (1996), Jala and Goyal (2006), Sharma et al. (1989)
Soil aggregate stability	Increase	Campbell et al. (1983), Sharma et al. (1989)
Bulk density	Decrease	Pandey et al. (2008), Page et al. (1979)
Water holding capacity	Increase	Campbell et al. (1983), Pandey et al. (2008), Page et al. (1979), Chang et al. (1977)
Porosity	Increase	Pandey et al. (2008), Page et al. (1979)
Chemical		
Nutrients (Fe, Cu, Zn, Mn…)	Increase	Tripathi et al. (2004), Gupta and Sinha (2006, 2008), Jala and Goyal (2006), Basu et al. (2009)

Fly ash has been used to amend soil for growing *Cajanus cajan L.* The experimental results determined that using fly ash with a dose lower than 25% wt. is safe for *C.cajan* crop, and ensured the absorption of heavy metal to crops within the safety limits (Pandey *et al.*, 2009).

Fly ash is used at a dose of 200 tons/ha in the croplands of maize and rice grains in Odisha, India. It is found that the yield of maize grains significantly increases by 28% and 34% at Malud and Dhenkanal, respectively. Meanwhile, the application of fly ash helps to increase the yield of rice grains by 40% and 13% at Malud and Dhenkanal, respectively (Patra *et al.*, 2012).

A study has used fly ash as a soil amendment for *Vicia faba L*. The study reveals that using fly ash with a dose lower than 10% wt. can enhance the germination of seed up to 68%. Meanwhile, the seed germination is inhibited when a dose of 30% wt. of fly ash is used. In addition, a dose of 20% wt. of fly ash used delays the germination of seed by 4 days. This study confirmed that fly ash should be used with a dose lower than 10% is suitable for *Vicia faba* growth (Singh *et al.*, 1997) .

In another study, fly ash is used for growing rice. The study result shows that the use of fly ash can improve the soil quality and increase the germination of rice seeds. The shoot length, pigment composition, leaf area, and yield of rice increase as the dose of fly ash increases (Mishra *et al.*, 2007).

Fly ash is also use to apply for growing mung bean (*Vigna radiata L.)* with different concentrations of fly ash. It is found that fly ash improves the growth and yield of crops. When applying 10% wt. of fly ash leads to increases in all the growth parameters (Singh *et al.*, 2010).

Mahale *et al.* study the effect of fly ash on plant growth and accumulation of heavy metals in wheat (*Triticum aestivum*), mung bean *(Vigna radiata)*, and urad beans *(Vigna mungo)*. They show that the use of fly ash up to 60% for the wheat, 10-20% for mung bean, and 20% for urad beans is suitable to maximize the growth and yield. The heavy metals were accumulated in plant, but below permissible limits provided for human consumption (Mahale *et al.*, 2012).

Coal fly ash and sewage sludge have been used to amend sandy soils in China. The poplar *(Populus spp.)* trees grown in these amended soils are 55% higher than those in the unamended soils (Shen *et al.*, 2008).

Using a combination of 10 tons/ha fly ash and organic sources such as farm manure, paper mill sludge, chemical fertilizers, and crop residues causes an increase in the grain yield of rice *(Oryza sativa L.)* and pod yield of peanut *(Arachis hypogaea L.)* from 25% to 30% (Mittra *et al.*, 2005).

However, some applications of fly ash are not beneficial. For instance, the use of fly ash with concentration ranging from 0 to 20% for growing palak *(Beta vulgaris L.)* slows the growth and reduces the biomass and yield of the plants. Singh *et al.* recommend that the palak is not a suitable crop to grown with amended soil by fly ash. (Singh *et al.*, 2008).

2.1.2. Characteristics of bottom ash

2.1.2.1. Physical properties of bottom ash

The botom ash size is bigger than fly ash. The grain size of bottom ash ranges from fine sand to gravel. The chemical composition of bottom ash is almost the same as that of fly ash but typically contains greater quantities of carbon (Tharaniyil, 2013).

The typical values of bottom ash properties are showed in Table 2.5 below.

Table 2.5 Typical values of bottom ash properties (Jayaranjan et al., 2014)

Parameters	Bottom ash	Unit
Color	Dark grey	-
Specific gravity	2.3-3.0	-
Particle size distribution	0.1-10	mm
Moisture content	11.74-52.24	wt%
Bulk density	1.15-1.76	g/cm^3
Specific surface area	0.17-1.0	m^2/g

2.1.2.2. Chemical properties of bottom ash

Bottom ash contains silicate, carbonate, aluminate, ferrous materials and several of heavy metals.

Tables 2.6 and 2.7 show the typical chemical composition and trace elements of bottom ash obtained from the combustions of bituminous coal and sub-bituminous coal.

Table 2.6 Chemical Composition of bottom ash (Tharaniyil, 2013)

Compounds	Bottom ash from Bituminous coal (%)	Bottom ash from Sub-bituminous coal (%)
SiO_2	61	46.7
Al_2O_3	25.4	18.8
Fe_2O_3	6.6	5.9
CaO	1.5	17.8
MgO	1	4
Na_2O	0.9	1.3
K_2O	0.2	0.3

Table 2.7 Trace elements concentrations in coal bottom ash (Jayaranjan et al., 2014)

Trace	Trace element composition of bottom ash (mg/kg dry basis)			
	Lignite	Sub-bituminous	Bituminous	Anthracite
As	-	25-30	1.7	<5
B	-	321-467	15.3	-
Ba	62-109	428-523	-	-
Cd	<5	0.5-0.6	0.3	<2
Co	3-7	10-13	17.5	-
Cr	47-194	65-99	47	21-30
Cu	18-121	33-49	32	42-80
Hg	0.4-1.6	-	-	<0.8
Li	4-30	93-147	28	-
Mn	97-328	295-402	991	-
Ni	30-293	34-53	30	-
Pb	5-33	16-29	2.6	62-80
Zn	33-226	59-99	47	1250-2000

2.1.2.3. Bottom ash utilization in soil reclamation and agriculture

Wearing *et al.* show that bottom ash added at a dose of 150 tons/ha increases water holding capacities of soil, provides some mineral ingredients for plant growth, and increases the yield of peanut (Wearing *et al.*, 2004).

It is found that bottom ash may be used as an alternative source for lime to amend pH of soil (Korcak, 1998).

When bottom ash is blended to soil, the soil structure can be improved and soil pH increases. That helps soil to suitable for plant growth (Wearing *et al.*, 2004).

However, heavy metals containing in bottom ash may leach out under some environmental conditions that make a threat to water quality (Mukhtar *et al.*, 2008).

2.1.3. Characteristics of boiler slag

2.1.3.1. Physical properties of boiler slag

Boiler slag size varies from 0.5 to 5 mm. Boiler slag from the combustion of lignite or sub-bituminous coal tends to be more porous than that of the bituminous coals (Tharaniyil, 2013).

2.1.3.2. Chemical properties of boiler slag

The chemical composition of boiler slag, as shown in Table 2.8, is similar to that of bottom ash although the production process of boiler slag and bottom ash is relatively different.

Table 2.8 Chemical Composition of Selected Boiler Slag (Tharaniyil, 2013)

Compounds	Boiler Slag from Bituminous coal (%)	Boiler Slag from Sub-bituminous coal (%)
SiO_2	48.9	40.5
Al_2O_3	21.9	13.8
Fe_2O_3	14.3	14.2
CaO	1.4	22.4
MgO	5.2	5.6
Na_2O	0.7	1.7
K_2O	0.1	1.1

2.1.3.3. Boiler slag utilization

Boiler slag has hard durable particles and high resistance to surface wear make it suitable for using in hot mix asphalt.

To achieve the target gradation used in hot mix asphalt, boiler slag is usually combined with other aggregates due to its uniform particle size.

2.1.4. Flue gas desulfurization (FGD) material

2.1.4.1. Properties of flue gas desulfurization (FGD) material

Flue gas desulfurization (FGD) materials are initially generated as calcium sulfite ($CaSO_3$) from the process of removing sulfur dioxide gas (SO_2). Calcium sulfate ($CaSO_4$) can be formed by utilizing calcium-based sorbents and forced oxidation that converts calcium sulfite ($CaSO_3$) to calcium sulfate ($CaSO_4$). The typical physical properties, including particle size and specific gravity of calcium sulfite and calcium sulfate as shown in Table 2.9 below. FGD gypsum is abrasive, sticky, compressive, and considerably finer (<0.2 mm).

Table 2.9 Typical Particle Size (%) Properties of FGD Material (Tharaniyil, 2013)

Property	Calcium Sulfite	Synthetic Gypsum (Calcium Sulfate)
Sand Size	1.3	16.5
Silt Size	90.2	81.3
Clay Size	8.5	2.2
Specific Gravity	2.57	2.36

2.1.4.2. Flue gas desulfurization (FGD) material utilization

The main utilization of FGD gypsum material produced from wet scrubbers are to use for wallboard manufacture and agricultural applications.

FGD gypsum has been also used for road base or structural fill construction by mixing it with quicklime and pozzolanic fly ash, cement, or self-cementitious fly ash.

2.2. Characteristics of Soil and Fertilizer

2.2.1. Soil

Soil is collected from the Learning Center Saraburi Chulalongkorn University, which is located in km.7 Kaeng Khoi- Bangna road, Cham Phak Pheo, Kaeng Khoi district, Saraburi province, Thailand. Figure 2.1 shows the location of the point in which soil is collected.

Saraburi province has a tropical savanna climate, which is arid with little rain from November to April and relatively high temperatures in summer. The average annual temperature is from 28 to 29 degrees Celsius (climate-data.org, 2018).

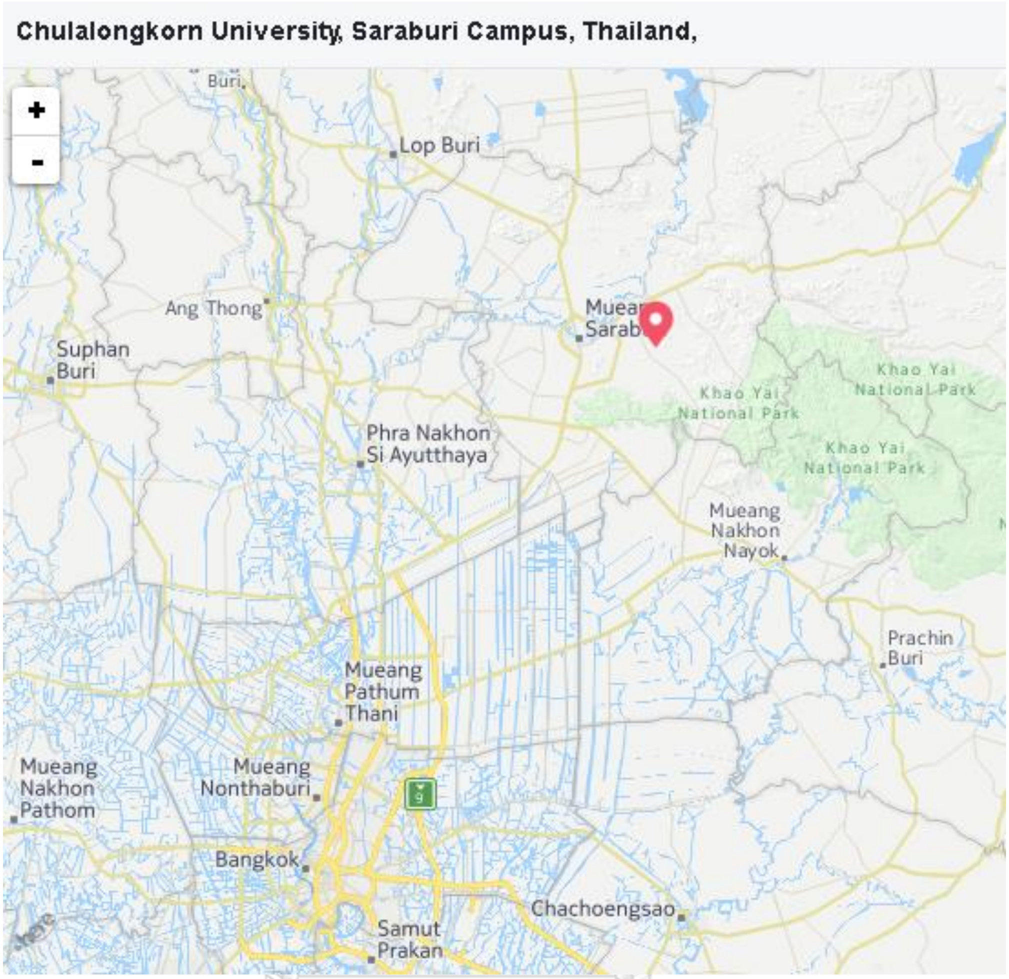


Figure 2.1 Learning Center Saraburi Chulalongkorn University in Saraburi province, Thailand was remarked on the map

According to the classification, the soil in Saraburi is a group of soil series No. 4, which is poorly drained, finely textured soils, which occur exclusively on a flood plain or alluvial plain. Soil texture is massive and cracking when dry which is difficult to be prepared (Land Develop Department, 2018)

2.2.2. Fertilizer

This study uses cow manure fertilizer to grow plants in order to compare with the other conditions.

This fertilizer can adjust the soil conditions to be able to increase water holding capacity and supply nutrients on plant growth.

2.3. Properties of Coal Ash as a Soil Amendment

The following are some main properties of soil that can be improved when applying coal ash as a soil amendment.

2.3.1. Soil texture

Soil texture reflects the particle size distribution of soil. It is an important parameter affecting the water content ability and draining speed of soil. For example, clay soils do not drain well but they hold water well. In contrast, sandy soils have quick water drainage and do not hold water well. Loam and other soils within sand and clay ranges have varied characteristics based upon the size of the particles.

Soil texture affects to plant growth indirectly. For example, it controls the pore space of soil that affects the movement of water, air, and temperature in soil, which in turn, affecting to plant growth.

Moreover, soil texture influences the available water in the soil, which directly affects to plant growth in soil. The available water in the soil is the difference between the maximum water content in soil (field capacity) and the amount of water that cannot be extracted by the plant (permanent wilting point). It also depends on the soil texture and soil organic matter content.

This study investigates the effect of coal ash on soil texture when using it as a soil amendment since soil texture is an important property for plant growth. As previous research results, applying coal ash to soil has some certain effects on soil texture. Using fly ash with a high concentration can change soil texture by increasing the silt content as the particle size of fly ash is primarily in silt range (Kishor et al., 2010). It is also found that the addition of fly ash at 70 tons/ha changes the texture of sandy and clayey soil to loamy (Fail and Wochok, 1977). Bottom ash improving the texture of soil for cultivating of the crop is also reported (Wearing *et al.*, 2004).

2.3.2. Soil pH, ECse

Soil pH is known as the acidity of soil represented by the negative logarithm of the hydrogen ion concentration in soil. It is divided into three ranges. They are acidic (pH 1-6) neutral (pH 7), and alkaline (pH 8-14).

Soil pH significantly affects the solubility of the nutrients in the soil so that it also affects proper plant growth and development. Different types of plant grow well over different ranges of soil pH values. Therefore, soil pH is a useful parameter to choose the type of crop suitable for soil.

Depending on coal source, coal ash can be acidic or alkaline that is useful to buffer the soil pH. The addition of fly ash in strip mine soils help to neutralize acid soil and enhance plant growth (Fail and Wochok, 1977). Fly ash may neutralize soil acidity and increase crop yield (Basu *et al.*, 2009). In the research of Korcak, bottom ash is used to amend soil. The research confirms that bottom ash can be used to alternate for lime in agriculture. (Korcak, 1998).

Furthermore, salinity is a critical parameter that affects the productivity of crop. In general, almost of crops are sensitive to salinity because of the high concentration of salt in soil. A high soil salinity can slow the plant growth such as shorter stature, smaller leaves, and sometimes fewer leaves (Shannon and Grieve, 1998). The soil salinity is estimated from the electrical conductivity (EC) of a soil solution.

The electrical conductivity can be divided into three categories: ECs, ECse, and $EC_{(1:5)}$. ECs is defined from soil that contains a maximum water content (approximately the field capacity). ECse is the electrical conductivity of the extract of a soil saturated paste. The water content of the saturated paste is about twice that of the soil moisture content at field capacity. Thus, the ECs of the in-situ soil solution is about twice that of the ECse because of the dilution effect (Hanson *et al.*, 1999). $EC_{(1:5)}$ is the electrical conductivity of a 1:5 soil-water suspension, which dilutes the salt concentration from that at field capacity by 5 to 40 times depending on the soil texture. Therefore, EC (1:5) is not an accurate parameter to show the concentration of salt in soil plant root can encounter in the field (Webb, 2011).

Nowadays, ECse is considered as the most dilute soil solution concentration, which plants can be encountered in the field. It is usually used to relate plant response to the soil salinity. Therefore, this study uses ECse as a parameter to explain the relationbetween plant growth and soil salinity. A high ECse soil restricts water uptake by plant roots, even if the soil has high water content.

As it is difficult to measure ECse in the laboratory, a more dilute extract is commonly used. For practical purpose, ECse is an estimated value from $EC_{(1:5)}$ that is easily measured by a conductivity meter and results are usually expressed in Deci Siemen per meter (dS/m).

The equation for converting $EC_{(1:5)}$ to ECse is:

$$\text{ECse (dS/m)} = EC_{(1:5)} \text{ (dS/m) x Conversion Factor}$$

Where:

The Conversion Factor depends on soil texture as shown in Table A.1.

2.3.3. Bulk density

Bulk density is a parameter used to indicate the compaction of soil. The higher the bulk density soil is the lower the soil porosity and the higher the soil compaction. Bulk density influences the root growth, available water in soil, soil porosity, nutrients for the plant growth, and soil microorganism activity. These affect the plant productivity. If bulk density increases, the available water capacity of soil reduces.

Bulk density is the proportion of dry soil mass in a given volume typically expressed in grams/cm^3. The main factors affecting bulk density are soil texture, soil organic matter, and the density of soil mineral. Additionally, bulk density increases in the deeper layers of soil since it is more compacted, less root grows, and less pore space in there as compared with surface layers. Table 2.10 shows the general relationship of soil bulk density to root growth based on soil texture.

Table 2.10 A Comparison of Root Limiting Bulk Density for Different Soil Types (Hanks and Lewandowski, 2003)

Soil Texture	Ideal bulk densities for plant growth (grams/cm^3)	Bulk densities that affect root growth (grams/cm^3)	Bulk densities that restrict root growth (grams/cm^3)
Sands, loamy sands	<1.6	1.69	>1.8
Sandy loams, loams	<1.4	1.63	>1.8
Sandy clay loams	<1.4	1.6	>1.75
Silts	<1.4	1.6	>1.75
Silt loams, silty clay loams	<1.4	1.55	>1.65
Sandy clays, silty clays, clay loams	<1.1	1.49	>1.58
Clays (> 45% clay)	<1.1	1.39	>1.47

Generally, bulk density of coarse-textured soils is higher than fine-textured soils. While bulk densities of sands and sandy loam soils may vary in from 1.2 to 1.8 g/cm^3, bulk densities of silt loam, clay loam, and clay soils may range from 1.0 to 1.6 g/cm^3.

Low bulk density values from 1.0 to 1.5 g/cm^3 generally indicate a suitable physical condition of soils for plant growth. A low bulk density soil has a good structure and high pore spaces for an optimum balance of air and water contents.

Conversely, soils with a high bulk density value from 1.8 to 2.0 g/cm^3 have a poor physical condition for plant growth due to the more compaction and relatively few pore spaces.

A soil in ideal condition for plant growth should have a bulk density that is not too low for adequate support, and not too high for proper porosity and aeration. Generally, a bulk density larger than 1.6 g/cm^3 can restrict root growth (McKenzie *et al.*, 2004). It is found that soil fly-ash mixture causes a lower bulk density than soil alone. The application of fly ash ranging from 0 to 15% wt. on clay soil significantly decreases the soil bulk density and increases saturated hydraulic conductivity as well as soil moisture. (Garg *et al.*, 2005).

2.3.4. Coal ash as a source of plant nutrients

It has been proven that coal ash can be used to buffer soil pH and provides some essential nutrients for plant growth such as Ca, S, B, Mo, Se.

Basu *et al.* confirm that fly ash contains almost the important nutrients for plant growth. Fly ash can be added to soil when nutrient concentrations in soil are deficient. Thus, fly ash can be considered as a soil amendment (Basu *et al.*, 2009). Bottom ash also contains trace element needed for plant growth (Tharaniyil, 2013).

2.4. Trace Element Uptake in Plants Growth

Heavy metals are the natural elements that have a high atomic weight and a density at least 5 times greater than that of water (Tchounwou *et al.*, 2012). In general, most coal ash contains the essential plant nutrients of Si, Al, Fe, Ca, Mg, K, Na, and S, as well as trace elements such as As, B, Se, Mo, Cd, Cr, Pb, Ni, V, and Zn (Brake *et al.*, 2004).

Heavy metal elements, such as lead, cadmium, arsenic, mercury, chromium etc., are known as the toxic elements. When the concentration of these heavy metals is over safety standard, it has toxic effects on human health. They accumulate and thereby disrupt function in vital organs and glands such as the heart, brain, kidneys, bone, liver, etc. There are several factors affect their toxicity such as the dose, route of exposure, as well as the gender, age, and nutritional status of exposed people (Tchounwou *et al.*, 2012). Lead can adversely influence the intellectual development of children, cause excessive lead in blood, and induce hypertension, nephropathy, and cardiovascular disease. Chronic Cadmium exposure can cause acute toxicity to the liver and lungs, induce nephrotoxicity and osteotoxicity, and impair function of the immune system. The element Arsenic is a metalloid and is associated with angiosarcoma and skin cancer (Zhou *et al.*, 2016). Mercury is well known as a hazardous metal. Mercury and its compounds are very toxic. The small dose is also hazardous to human health. The major effects of mercury poisoning manifest as neurological and renal disturbances as it can easily pass the blood-brain barrier and has effect on the brain. (Tangahu *et al.*, 2011).

Because they have a high degree of toxicity, lead, cadmium, arsenic, mercury, and chromium are concerned as the priority metal that effect on public health.

The absorption of coal ash by plants should be the most consideration in utilizing coal ash as a soil amendment in agriculture because the accumulation of coal ash in plants can increase the risk of exposure to the consumers affecting human health. Plants only need a small amount of some heavy metals for plant metabolism. The concentration of heavy metals in soil over a safety standard leads to negative effects for plants and soil ecosystem. Therefore, when using coal ash as a soil amendment, the uptake of heavy metals by plants should be measured in order to determine whether coal ash affects the absorption of heavy metals in plants.

Some previous research also concerned the effects of fly ash on trace element uptake in plants. For instance, an application of bottom ash as a soil amendment to grow peanut. The rates of bottom ash application were 0 tons/ha, 25 tons/ha, 50 tons/ha, 100 tons/ha and 150 tons/ha. The trace element contents in peanut are then analyzed. The result shows that either used bottom ash increase causes a decrease in the amount of heavy metals or no significant difference between the treated and untreated areas is found (Wearing *et al.*, 2004).

Another research has conducted which grow four crop plants, including tomato *(Heatwave II Hybrid)*, basil *(Genovese)*, dwarf sunflower *(Pacino)*, and zucchini *(Creamy Improved Hybrid)*, in amended soil with fly ash from 0 to 20% wt. The trace element absorped by these crops is then ivestigated. The leaves and stems from each plant are harvested and analyzed for heavy metals content during early, middle, and late growth. It is found that the application of fly ash does not significantly affect the heavy metals uptake by the plant, even though some concentrations decrease with time. (Jensen *et al.*, 2004).

According to the result of a previous research, soil pH is a crucial factor in determining the mobility of the trace element in soil. While some cations tend to leach out under acidic conditions, some oxyanionic elements such as As, B, Cr, Mo, V, and W tend to leach out under alkaline conditions (Izquierdo and Querol, 2012). Moreover, soil pH is one of the most crucial factors influencing trace element solubility and bioavailability in soils (Brake *et al.*, 2004). Thus, soil pH should be one of the first soil characteristics investigated when utilizing coal ash as a soil amendment. Since this study is conducted in pot experiments, this study does not focus on the leaching of trace elements to the environment. This study only investigates the effect of coal ash on soil pH with various concentrations of coal ash. However, in the future, the other studies will do the research about the leaching of trace elements from coal ash to the environment when utilizing coal ash as a soil amendment is expected.

The natural level of heavy metal in soil is different with each location which depending on the geologic history of the area. For soils, the average ranges of some heavy metals are: As (5-10 ppm), Cd (0.01-2.0 ppm), Cr (5-1,500 ppm), Cu (2-250 ppm), Pb (2-300 ppm), and Ni (2-750 ppm) (Gorospe, 2012).

The maximum permissible limit (MPL) values of the trace heavy metals in agricultural soil and vegetable by different sources are shown in Table 2.11.

Table 2.11 Recommended the maximum permissible limits of heavy metals for soil and vegetable

Parameters	Unit	The maximum permissible limit (MPL) values of the trace heavy metals in agricultural soil		The MPL standard values in vegetables
		Land Application of Biosolid of Home Vegetable Gardens (Gorospe, 2012)	Thailand standard (Pollution Control Department, 2004)	FAO/WHO, 2001 (Fite and Leta, 2015)
Nickel (Ni)	mg/kg	420	1600	
Chromium (Cr)	mg/kg	-	300	2.3
Cadmium (Cd)	mg/kg	39	37	0.2
Lead (Pb)	mg/kg	300	400	0.3
Arsenic (As)	mg/kg	41	3.9	0.43
Mercury (Hg)	mg/kg	17	23	0.03
Note:	MPL: maximum permissible limit			

CHAPTER 3
EXPERIMENT

This chapter presents the experimental work of this research. This study contains two main part, which are the experiments on soil properties and plant growth.

3.1. Materials

The coal ash, both bottom ash and fly ash, is obtained from the SCG pulp and paper plant in Thailand. The soil is collected in Saraburi province, Thailand. In addition, this study used cow manure fertilizer to grow plants in order to compare with the other conditions. The seeds of these plants are purchased from Chia Tai Co. Ltd.

The main compositions of soil, coal ash, and fertilizer are analyzed by the XRF equipment as presented in Table 3.1.

Table 3.1 Main composition of soil, fly ash, bottom ash and fertilizer

Parameters	Soil	Fly ash	Bottom ash	Fertilizer
SiO_2	61.00%	34.80%	75.00%	17.50%
CaO	0.28%	19.70%	5.42%	3.46%
Al_2O_3	9.80%	14.40%	6.48%	2.65%
Fe_2O_3	14.60%	12.10%	2.10%	1.20%
MgO	0.26%	7.96%	0.66%	1.31%
Na_2O	0.38%	2.33%	1.36%	0.29%
K_2O	1.23%	1.42%	2.91%	1.43%
TiO_2	0.75%	0.54%	0.11%	0.11%
As_2O_3	34.2ppm	76ppm	-	12.1ppm
MnO	0.247%	0.123%	231ppm	928ppm
P_2O_5	796ppm	0.195%	492ppm	1.6%
BaO	393ppm	0.163%	600ppm	109ppm
ZrO_2	338ppm	129ppm	80.6ppm	49.6ppm
SO_3	322ppm	5.77%	0.358%	0.811%
Cr_2O_3	253ppm	91ppm	0.198%	456ppm
CuO	73.4ppm	76ppm	30.7ppm	85.1ppm
ZnO	47.3ppm	156ppm	52.9ppm	171ppm
NiO	-	124ppm	40ppm	23.9ppm

According to Table 3.1, the main compositions of coal ash are the most of the oxides of Si, Al and Ca. Furthermore, coal ash also has some essential elements for plant growth, both macronutrients and micronutrients such as P, K, Ca, Mg, S, Zn, Fe, Cu, Mn exclude organic C and N. Thus, coal ash can be a suitable material used for agriculture in order to improve the chemical characteristics of soil.

For growing plants, the two plants Bird Peppers *(Capsicum annuum)* and Holy Basil *(Ocimum sanctum)* are selected. Bird pepper is known as a vegetable crop. It is used in fresh form to season foods. Furthermore, it is found that Bird pepper has medicinal properties against illnesses such as flu and asthma. Bird pepper should be grown in well-drained soils and rich in organic matter with pH range 6.0 to 6.5. However, it can also tolerate a wider soil pH range of 4.5 (acidic) to 8.0 (slightly alkaline). Soil for growing Bird pepper should be light sands, clay sandy, and sandy loams (Ashilenje, 2014).

Holy Basil is one of the popular herbs used for cooking. Holy basil should be grown in well-drained soil. The suitable pH level of the soil would be 6.5 to 7.5. (PlantWriter, 2018). It is found that most of the cultivars are tolerant of salt as well as of soils with pH from alkaline to moderately acidic but has a low tolerance for waterlogged soil (cabi.org, 2018).

Normal soil, coal ash and fertilizer are analyzed for heavy metal in the component by Inductively Coupled Plasma (ICP) method. The analysis result is shown in Table 3.2.

Table 3.2 The analysis result of trace elements in normal soil, coal ash, and fertilizer.

Parameters	Unit	Results by ICP			
		Normal soil	Bottom ash	Fly ash	Fertilizer
Nickel (Ni)	mg/kg	5.97	9.65	48.30	9.14
Chromium (Cr)	mg/kg	99.10	270.00	28.70	171.00
Cadmium (Cd)	mg/kg	0.21	0.06	0.47	0.17
Lead (Pb)	mg/kg	13.80	1.52	11.40	6.68
Arsenic (As)	mg/kg	6.10	3.57	26.10	5.06
Mercury (Hg)	mg/kg	0.15	0.11	0.15	0.32

From the analysis result, coal ash is quite clean with almost amount of heavy metal lower than the maximum permissible limit (MPL) values are shown in Table 2.11. Although fly ash contains amount of Arsenic (As) above the maximum permissible limit (MPL) values of Thailand, it is still considered "safe" levels when compared to Land Application of Biosolid of Home Vegetable Gardens standard.

3.2. Equipment and Procedure

3.2.1. Particle size distribution experiment

❖ **Equipment**

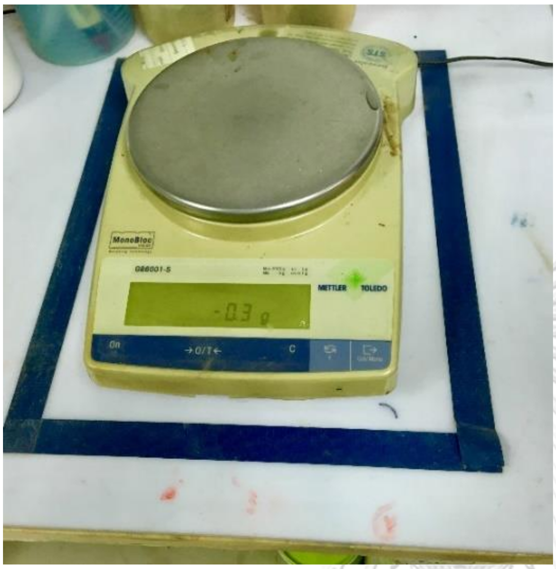


Figure 3.1 A balance

Figure 3.2 An ASTM 151H soil hydrometer

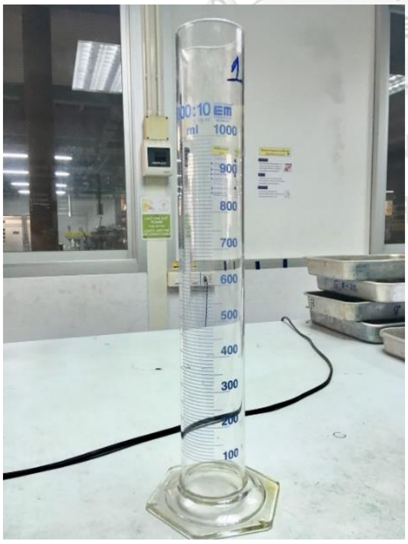


Figure 3.3 A sedimentation Cylinder 1000ml

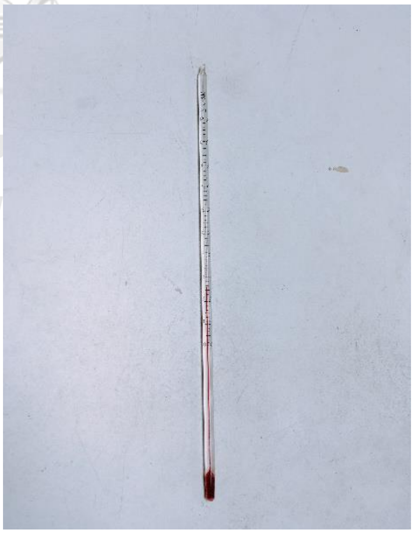


Figure 3.4 A thermometer

Figure 3.5 A series of sieves

Figure 3.6 Preparing Sodium Hexametaphosphate 4%

Figure 3.7 A drying oven

A GB6001-S balance from Mettler Toledo Company as shown in Figure 3.1 is used to weigh the samples in this experiment. This balance has a maximum capacity of 6,100g, a minimum weight of 5 g, and an accuracy of 0.1 g.

An ASTM 151H soil hydrometer as in Figure 3.2 is used to measure the fluid density and determine the quantity of particles in suspension at a specific time and position. It has a range of 0.995— 1.038 in 0.001 divisions at 68°F (20°C).

Two glass cylinders are used for the soil suspension and the other one can be used as the wash cylinder. Glass cylinders have an inside diameter is 58.2 mm, and a capacity of 1,000 ml as shown in Figure 3.3.

A thermometric device used is readable up to 0.5°C as in Figure 3.4.

Figure 3.5 is a series of sieves, conforming to the requirements of ASTM D422, which is the standard test method for particle-size analysis of soils.

A solution of sodium hexametaphosphate (sometimes called sodium metaphosphate) used as the dispersion agent (deflocculant) required to prevent the fine particles in suspension from coalescing or flocculating. Figure 3.6 illustrates the preparation of sodium hexametaphosphate 4%.

In Figure 3.7, a drying oven, which can maintain a uniform temperature of 110 ± 5°C, is used in this experiment.

All water used in the experiment is either distilled or demineralized water.

❖ **Procedure (Standard, 2007, Standard, 2017)**

Firstly, 200 g of air-dry soil sample is weighed out. Then, the sample is placed in the container and add sufficient water to cover it. Immediately pour the wash water containing the suspended and dissolve solids over the sieve no.10 (2.00-mm) as shown in Figure 3.8. The experiment continues with adding a second charge of water to the sample in the container, agitate. This operation is repeated until the wash water is clear.

In next step, all particles retained on the no.10 sieve are returned by flushing to the washed sample. These particles are dried to constant mass at a temperature of 110±5°C. The mass of the dried sample is then measured in order to calculate the percentages of particles retained on the No.10 sieve. The suspension which passing the no.10 sieve is transferred to sedimentation cylinder in order to do the hydrometer test.

Figure 3.8 Separate particle size larger No. 10 (2 mm)

Sieve analysis of portion retained on no. 10 (2.00-mm) sieve

The particles retained on the no. 10 (2.00-mm) sieve are separated into two parts for No. 4 (4.75-mm) and No. 10 sieves.

To conduct the sieving operation, a lateral and vertical motion of the sieve is performed, together with a jarring action that keeps the sample moving continuously over the surface of the sieve. The sieving operation is repeated until not more than 1 mass percentage of the residue on a sieve passes that sieve during 1 min of sieving. Then the mass of each fraction is determined on a balance.

Hydrometer and sieve analysis of portion passing the no.10 (2.00-mm) sieve

In next stages, the particles passing the no.10 (2.00 mm) is analyzed with hydrometer and wet sieve.

To beginning with hydrometer experiment, the particles passing the no.10 (2.00-mm) sieve is placed in the 250 ml beaker and cover with 125 ml of sodium hexametaphosphate solution 4%. The suspension is stirred until the soil is thoroughly wetted. It is kept for soaking for at least 16h.

After dispersion, the suspension which passing the no.10 sieve is transferred to the sedimentation cylinder, and add distilled water until the total volume is 1000 ml as in Figure 3.9.

Figure 3.9 Preparing the suspension for hydrometer test

Using the palm of the hand over the open end of the cylinder, turn the cylinder upside down and back for a period of 1 min to complete the agitation of the slurry. At the end of 1 min set the cylinder in a convenient location and take hydrometer readings at the following intervals of time (measured from the beginning of sedimentation): 1, 2, 5, 10, 15, 30, 60, 250, and 420 min. Figure 3.10 illustrates the step to agitating the slurry.

Figure 3.10 The agitation of the slurry for a period of 1 min

It is required to insert the hydrometer into the suspension before 20 to 25 seconds as take a reading. After reading, the hydrometer is taken out and placed in a clean cylinder filled by distilled water.

The temperature of the suspension is recorded at each reading by inserting the thermometer into the suspension.

Each reading value of hydrometer and temperature jotted down the experiment form will be used to calculate diameter and percentage passing of particle later, as shown in Appendix A.2.

Wet Sieves experiment

After completing hydrometer test, the suspension is transferred to a suitable container. A wet sieve analysis is conducted by using a series of sieves such as No. 40 (0.425-mm), No.80 (0.18-mm), No 120 (0.125-mm), as shown in Figure 3.11.

Figure 3.11 Making a wet sieve analysis

The process of experiment continues with pouring the wash water containing the suspended and dissolved solids over the sieves. Add a second charge of water to the sample in the container, agitate, and decant as before. This operation is repeated until the wash water is clear.

Then, return all particles retained on the each sieves by flushing to the washed sample. The particles retained on each sieve is dried to constant mass at a temperature of 110 ± 5°C. Then the mass of each fraction is weighed by a balance.

After finished with this experiment, the study applies data to determine soil texture of samples. Following to the United States Department of Agriculture (USDA), the particle size is divided four major groups including Gravel (>2 mm), Sand (2 to 0.05 mm), Silt (0.05 to 0.002 mm), Clay (<0.002 mm) as in Table 3.3 below.

Table 3.3 Particle size classification (Tan, 2005)

Name of organization	Grain size (mm)			
	Gravel	Sand	Silt	Clay
U.S.Department of Agriculture (USDA)	>2	2 to 0.05	0.05 to 0.002	<0.002

Soil texture refers to the relative proportions of the soil separates. A textural triangle is used to classify soil texture, as shown in Figure 3.12. Each side of the triangle represents the percentages of sand, silt, or clay. The soil texture is determined by the intersection points of three lines from each side of the triangle.

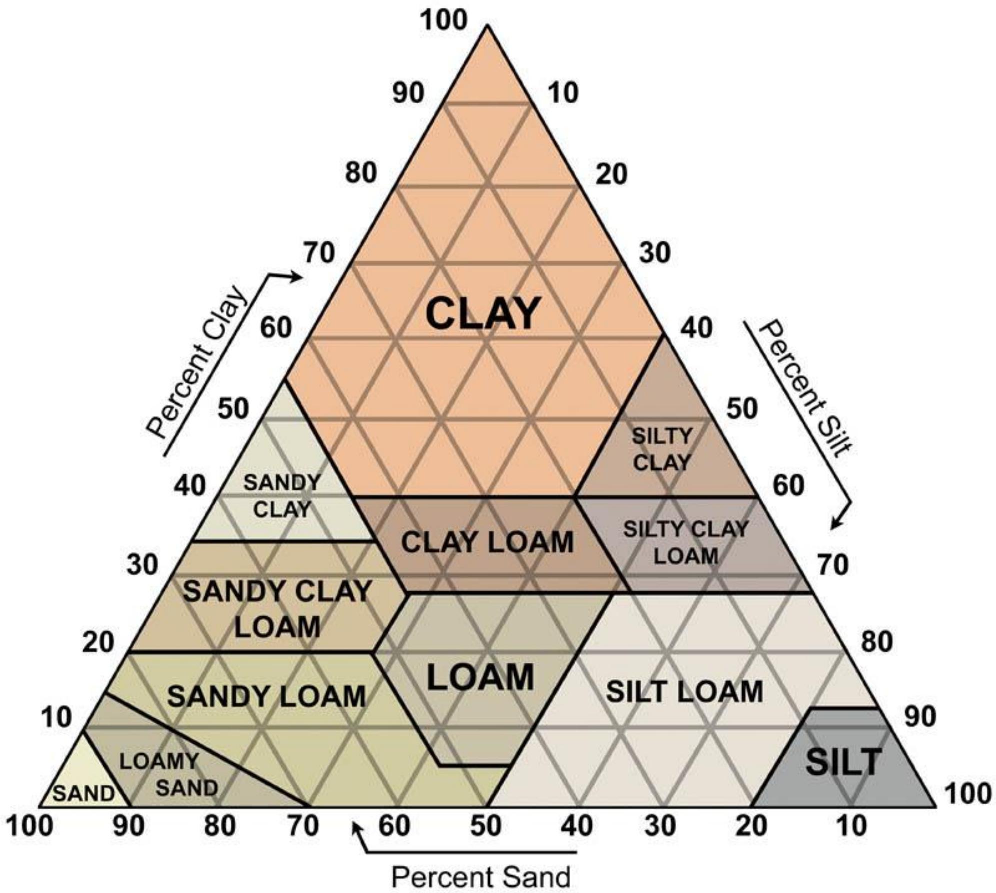


Figure 3.12 USDA guide for soil textural classification

3.2.2. Microscope

- **Equipment and materials**

A Binocular microscope used as shown in Figure 3.13. The microscope is the instrument used to see objects that too small for the naked eye. It is very important equipment in an ore dressing laboratory. It is used for identification the minerals especially determination the physical properties of minerals in ore which cannot be seen by naked eyes. Microscope geologist can identify own unique physical properties and determine the name of the mineral. The microscope can help us to separate type of minerals and analysis their distribution, their concentration, and other properties.

A laptop used in this experiment was set up S-Viewer program as shown in Figure 3.13, and all samples used is the oven-dried specimens.

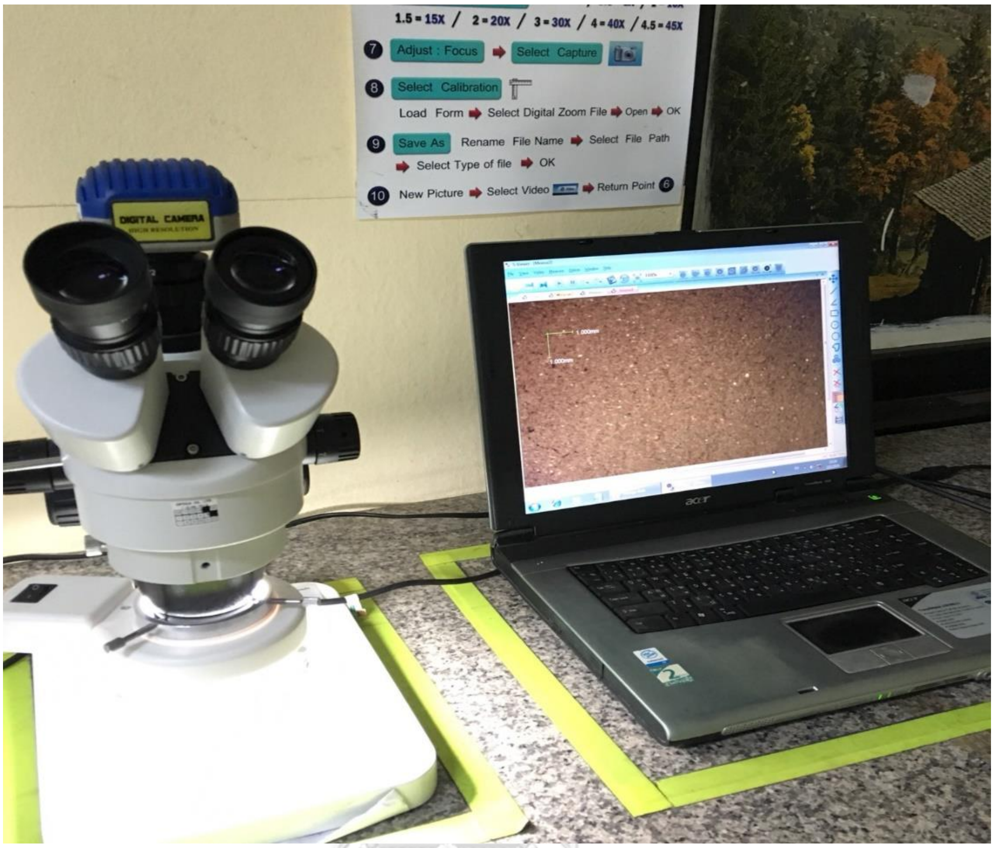


Figure 3.13 A Binocular Microscope and laptop

❖ **Procedure**

Following to the digital microscope manual, in the first step, the laptop and digital microscope are turned on. Then the USB of digital microscope is connected to laptop. After the light is turned on, the sample is placed on plate. Then is opening S-Viewer program.

The second stage is adjusting the auto white balance. In this step, the process is conducted on S-Viewer program by following: Option/ Video Capture Filter/ AWB Once/ Ok. Then continue to adjust: Focus/Select capture.

The third step is the select calibration: Load form/ select Digital Zoom File/ Open/ Ok.

Finally, we need to save as it: Rename File Name/ Select File Path/ Select Type of file/ Ok.

To continue the new process: New picture/ select video/ return point.

3.2.3. Determination of specific gravity

Specific gravity is calculated by the ratio of the density of a substance to the density of water at a specified temperature. The following formula is used to calculate specific gravity.

$$SG = \rho_{substance} / \rho_{H2O}$$

Where

SG = Specific Gravity of the mineral

$\rho_{substance}$ = Density of the mineral (kg/m^3)

ρ_{H2O} = Density of water - normally at temperature 4^{o}C (kg/m^3), 0.99904 (kg/m^3)

It is proven that the weight of two minerals can be different even the same size. The SG of a mineral also shows how heavy it is by its relative weight to water. Water specific gravity is 1.0.

The result of the specific gravity experiment provides the data for the calculation process of the hydrometer experiment.

- **Method**

Determination of specific gravity by water replacement.

The density of supplementary cementitious materials (SCM), such as fly ash, and slag, would be calculated better by utilizes a liquid displacement method to measure the volume instead of by mass (Helsel *et al.*, 2015).

❖ **Equipment and materials**

Figure 3.14 Graduated cylinder of 50 ml

Figure 3.15 A balance

Graduated cylinders used in this experiment have capacity of 50 ml, as shown in Figure 3.14.

Figure 3.15 shows the balance used to weigh the materials, which is manufactured by Ohaus Company. It has the maximum capacity of 200 g, and an accuracy of 0.0001g.

All water used in this experiment is distilled water. The oven-dried samples is taken with approximate 20 g each.

❖ **Procedure (Numprasanthai, 2017)**

Firstly, the graduated cylinder is cleaned and dried. Then the empty graduated cylinder is weighed (W_1). Taking the mineral sample approximate 20 g each (W_0).

In next step, 25 ml of distilled water is putted in the graduated cylinder, and then put the sample in the graduated cylinder as Figure 3.16 shown.

Figure 3.16 Put the sample in the graduate cylinder

Observing the water volume changed (V_0).

Finally, record and calculate the specific gravity (S_0): $S_0 = \frac{W_0}{V_0}$ (g/cm^3).

3.2.4. Determination of water (moisture) content of soil

The water content by mass of a material is the ratio of the mass of water contained in the pore spaces of material, expressed as a percentage.

The result of the moisture experiment provides the data for the calculation process of the hydrometer experiment.

❖ Equipment and materials

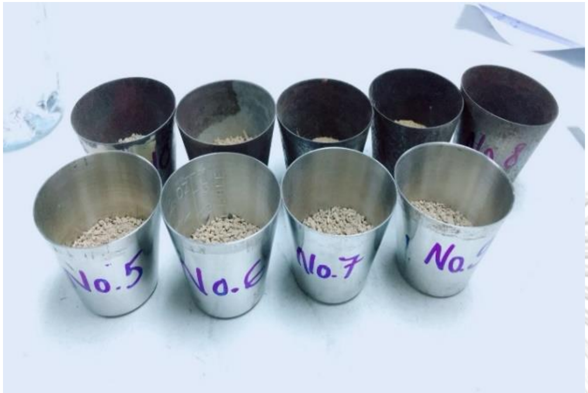


Figure 3.17 Containers

Figure 3.18 A balance

The steel containers used to contain samples as shown in Figure 3.17.

Figure 3.18 shows the balance used to weigh the materials, which is manufactured by Ohaus Company. It has the maximum capacity of 200 g, and an accuracy of 0.0001g.

A drying oven as shown in Figure 3.7, which can maintain a uniform temperature of 110 ± 5°C is used in this experiment.

All samples used in this experiment is the air-dried samples.

❖ Procedure

In the first step, the mass of the clean and dry container (M_c) is determined and recorded.

Then put the moist sample in the container. The mass of the container and moist sample (M_{cms}) is determined and recorded by using a balance.

In next step, put the container with the moist sample in the drying oven at 110±5°C. The sample is dried to a constant mass. In most cases, drying a test sample takes about 12h to 16h.

Then the mass of the container and oven-dried sample is measured Record this value (M_{cds}).

The water content of the material is calculated as follows:

$$W = [(M_{cms} - M_{cds})/ (M_{cds} - M_c)] \times 100 = (M_w/M_s) \times 100$$

Where:

W = water content, %

M_{cms} = mass of container and moist specimen, g

M_{cds} = mass of container and oven dry specimen, g

M_c = mass of container, g

M_w = mass of water ($Mw= M_{cms} - M_{cds}$), g

M_s = mass of oven dry specimen ($M_s = M_{cds} - M_c$), g

3.2.5. Soil pH, ECse experiment

❖ **Equipment**

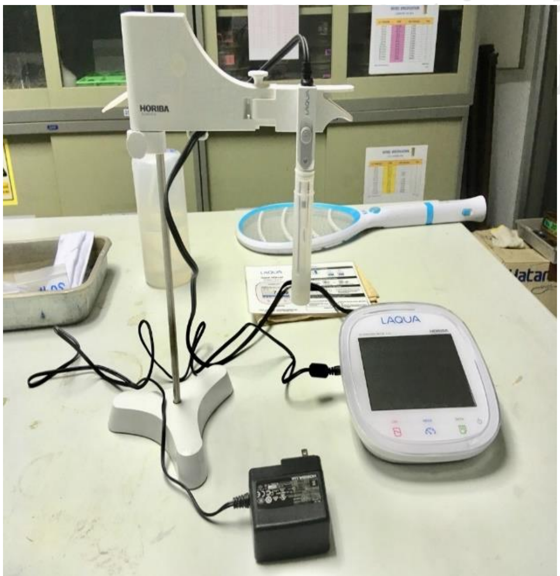


Figure 3.19 A pH/ION/COND METER

Figure 3.20 A balance

The parameters of soil like pH, EC $_{(1:5)}$ is measured by a pH/ION/COND METER with model LAQUA F-74G, which is manufactured by Horiba.Ltd, Japan as shown in Figure 3.19.

Figure 3.20 shows the balance used to weigh the materials, which is manufactured by Ohaus Company. It has the maximum capacity of 200 g, and an accuracy of 0.0001g.

All water used in this experiment is distilled water. The mass of the air-dried samples is approximate 16 g each.

❖ **Procedure (Rayment and Higginson, 1992, Webb, 2011)**

The material has been sieved through a No. 10 sieve (2 mm holes) to remove the coarser soil fraction. Measure the weight of material 16 g and then put this into the container.

In the next step, adding approximately 80 ml of distilled water to prepare a 1:5 soil: water suspension. Figure 3.21 presents a pH/ION/COND METER and materials to conduct this experiment.

Figure 3.21 pH/ION/COND METER LAQUA F-74 and samples

Then shake the container for about 2-3 minutes then allow the soil to settle for 2 minutes, and read pH, EC $_{(1:5)}$ on pH/ION/COND METER.

3.2.6. Bulk density experiment

❖ **Equipment**

Figure 3.22 A cylinder for core sample

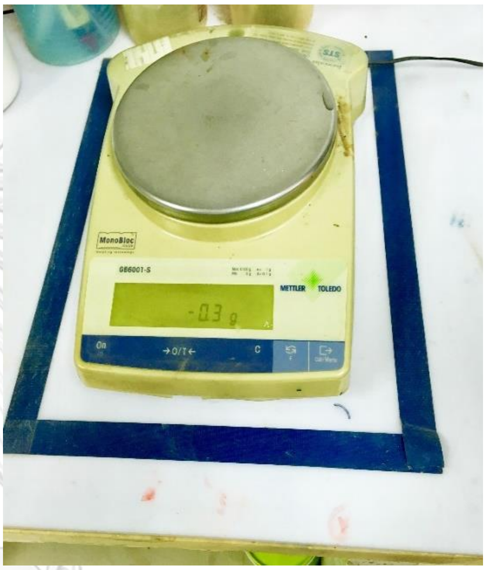


Figure 3.23 A balance

A cylinder has a volume of about 100 cm^3 as shown in Figure 3.22 used to do this experiment.

A GB6001-S balance from Mettler Toledo Company as shown in Figure 3.23, which is used to weigh the samples in this experiment. This balance has a maximum capacity of 6,100g, a minimum weight of 5 g, and an accuracy of 0.1g.

A drying oven which can maintain a uniform temperature of 110 ± 5°C, as shown in Figure 3.7 used in this experiment.

❖ **Procedure (Tan, 2005)**

Measuring bulk density of disturbed samples

This method is useful for sampling clods is not feasible. Similarly, soils in nurseries and greenhouses are loose and very friable.

In the first step, the cylinder is weighed and recorded its weight.

In next step, the cylinder is filled with a little bit of soil that has passed a 2mm sieve. The first addition of soil is compacted by tapping the bottom of the cylinder 10 times with palm of hand. Soil is continually added in the cylinder and tapped until a tapped soil volume of cylinder is obtained. The weight of cylinder containing the soil is measured and recorded.

Measuring bulk density of undisturbed samples or clod method

For the clod method, we need to push a cylinder into the soil to collect an undisturbed sample as shown in Figure 3.24. The cylinder containing undisturbed soil is carefully excavated.

Figure 3.24 Bulk density ring with intact soil core inside

Then any excess soil from the outside the ring is removed, and any plants or roots off at the soil surface are also cut with scissors. The sample is placed into the plastic bag and seal the bag with the taken date and location.

Finally, carefully remove the all soil from the bag into the container. Dry the soil for 12h in a conventional oven at 105ºC.

❖ **Calculate**

Calculate the oven dry weight of the soil in a cylinder above.

Total soil volume = $\pi.R^2.H$

Where:

H: the height of the ring

R: the diameter of the ring

Dry soil weight:

i. Weigh a container in grams (W_1).

ii. Carefully remove the all soil from the bag into the container. Dry the soil for 12 hours in a conventional oven at 105ºC.

iii. When the soil is dry, weigh the sample on the scales (W_2).

iv. Dry soil weight (g) = $W_2 - W_1$

Bulk density (g/cm^3) = (oven dry weight of soil in cylinder)/ (Volume of cylinder)

Soil porosity (%) = 1- (bulk density/ sample's particle density)

3.3. Plant Growth

Growing plant is the second part of this research. Coal ash is mixed with soil and fertilizer ranging from 0 to 30% wt. The mixtures are filled in the pots to grow plants. Two plants, including Bird Peppers and Holy Basil, are selected. The original soil without coal ash is performed as well to compare the result for this study.

The effects of coal ash as a soil amendment on plant growth is investigated in this study. Two parameters plant height and leaf size of plant are recorded. The height and leaf size of each plant are recorded properly at each three days interval until 5th month and after that, it is observed every two weeks. The study is continued for seven months.

3.3.1. Plant height measurement

Plant height is measured from its base to its highest point. Smaller plants can be measured with a ruler, while taller plants may require a measuring meter stick. Make sure that the ruler begins at zero on the bottom as shown in Figure 3.25.

Record this in a chart with both the date and the height.

Figure 3.25 Measuring plant height

3.3.2. Leaf size measurement

Choose a sampling of four or five leaves that are biggest ones. Hold the ruler from the bottom to the tip of the leaf as shown in Figure 3.26. The average leaf length is the measurements divided by the number of measurements taken. Measure the leaves at their widest part to find the width of the leaves as shown in Figure 3.27. The average leaf width is the measurements divided by the number of measurements taken.

Figure 3.26 Measuring leaf length

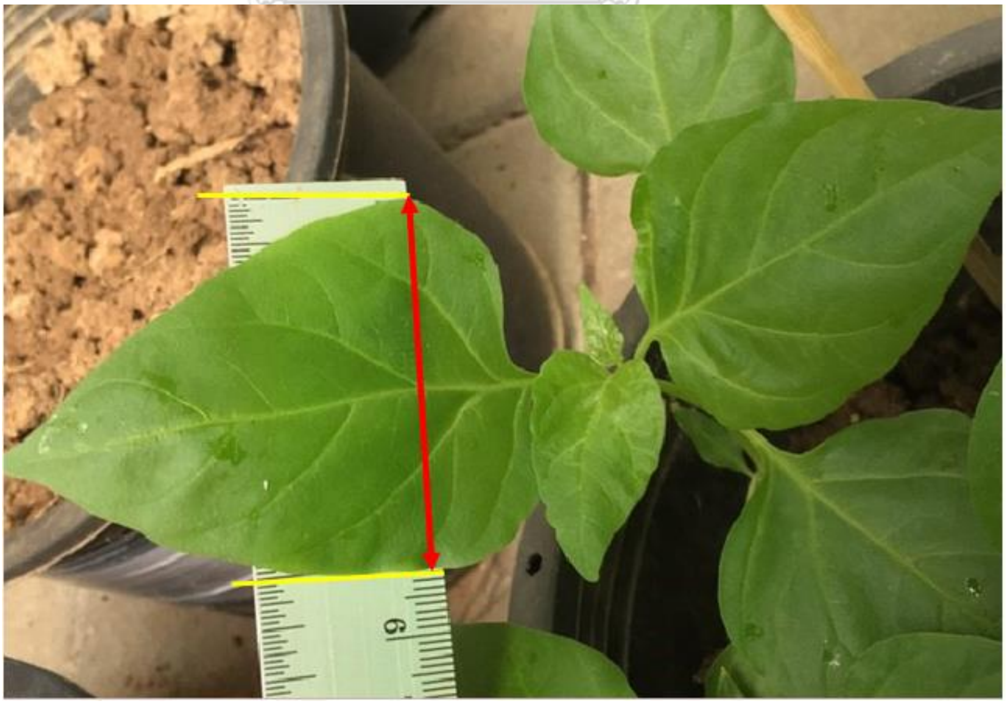


Figure 3.27 Measuring width of the leaves

CHAPTER 4
RESULTS AND DISCUSSION

This presents the results of this study and discusses the effect of coal ash on soil properties and plant growth.

4.1. Effect of Coal Ash on Soil Properties

4.1.1. Operating conditions for coal ash amend soil

The operating parameters are percent of coal ash mixed with soil and fertilizer ranging from 0 to 30% wt. as presented in Table 4.1 below.

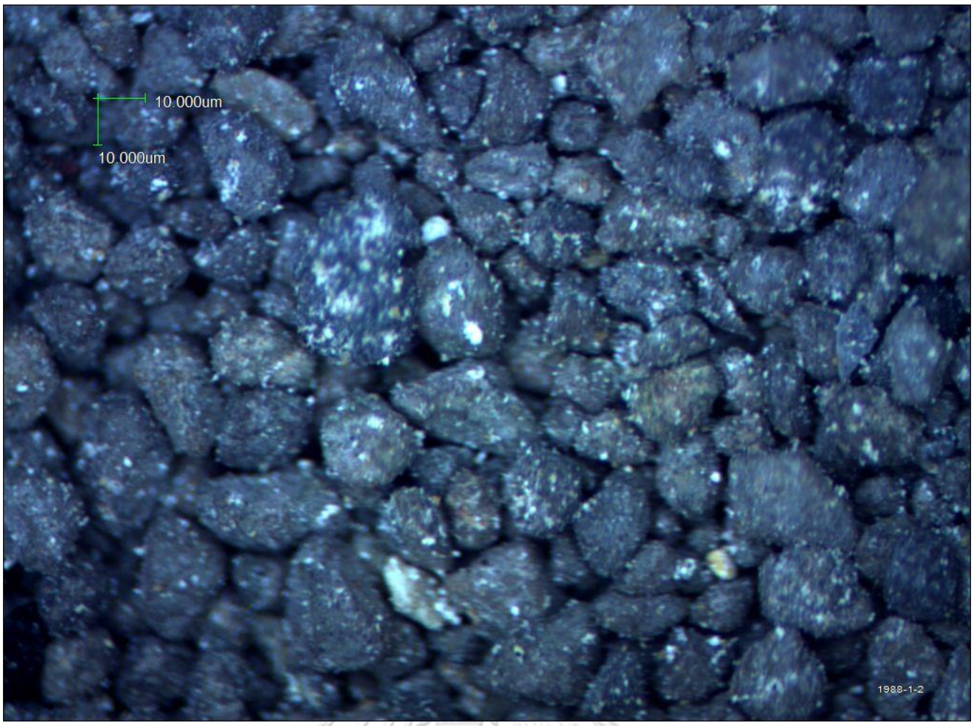
Table 4.1 The percent of coal ash mixed with soil and fertilizer

No.	Mixtures	Ratio (%)	Plants
1	Normal soil	100	Bird Pepper & Holy Basil
2	Soil + Bottom ash	(95:5)	Bird Pepper & Holy Basil
3	Soil + Bottom ash	(90:10)	Bird Pepper & Holy Basil
4	Soil + Bottom ash	(85:15)	Bird Pepper
5	Soil + Bottom ash	(80:20)	Bird Pepper & Holy Basil
6	Soil + Bottom ash	(75:25)	Bird Pepper
7	Soil + Bottom ash	(70:30)	Bird Pepper & Holy Basil
8	Soil + Fly ash	(90:10)	Bird Pepper & Holy Basil
9	Soil + Fly ash	(80:20)	Bird Pepper & Holy Basil
10	Soil + Fly ash	(70:30)	Bird Pepper & Holy Basil
11	Soil + Fertilizer	(90:10)	Bird Pepper & Holy Basil
12	Soil + Fertilizer	(80:20)	Bird Pepper & Holy Basil
13	Soil + Fertilizer	(70:30)	Bird Pepper & Holy Basil
14	Soil+fertilizer+ FA	(90:5:5)	Bird Pepper & Holy Basil
15	Soil+fertilizer+ BA	(90:5:5)	Bird Pepper & Holy Basil

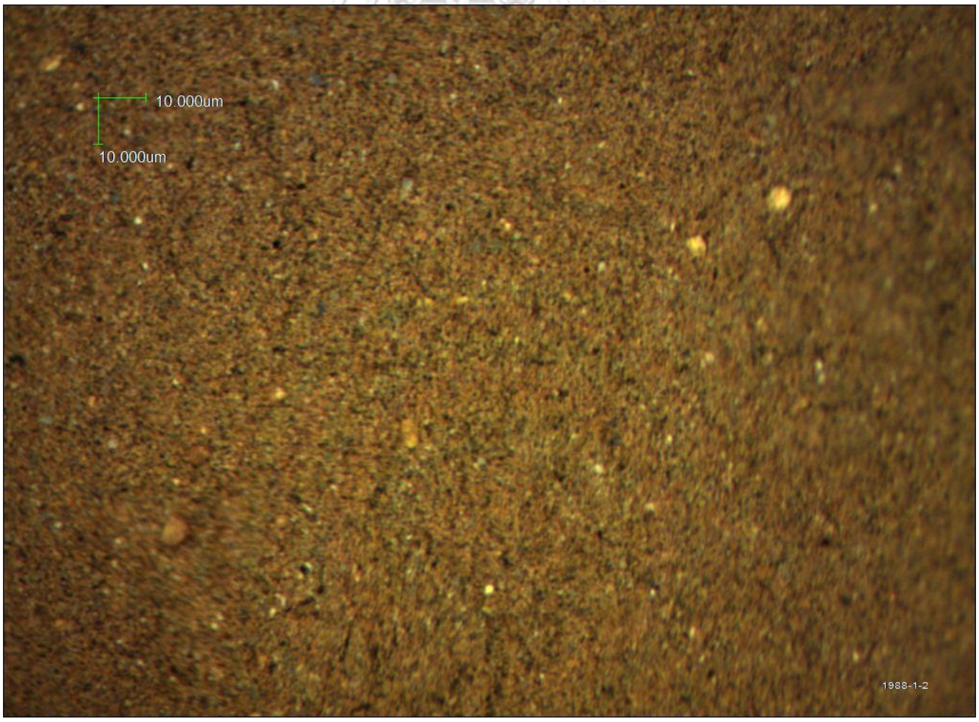
4.1.2. Effect of coal ash on particle size distribution, soil texture

Figure 4.1 shows the photomicrograph of normal soil, bottom ash and fly ash using a Microscope with optical zooms is 20x. In this case, soil is gray, fly ash particles are brown and the little of white particles that mixed. Meanwhile, the color of bottom ash is dark grey and the white adhering to the surface of the particle. According to Figures. 4.1a) and c), normal soil, and fly ash have the proportion of fine particle in high content. Figure 4.1b) illustrates a photomicrograph of bottom ash revealing a mixture of spherical and angular particles that are either separate or loosely bonded together. In addition, many of the particles are porous or hollow providing the lightweight and absorbent nature of bottom ash.

a) Photomicrograph of normal soil



b) Photomicrograph of bottom ash



c) Photomicrograph of fly ash

Figure 4.1 Photomicrograph of normal soil, bottom ash, and fly ash

Figure 4.2 shows the particle size distribution curve of normal soil, bottom ash and fly ash. It is clear that the percentage of the fine particle of normal soil is also high, which has more than 50% of soil particles are fall in fine particles. Meanwhile, fly ash has high percentage of fine particle with more than 90% particle in silt and clay particles group. By contrast, bottom ash low proportion of fine particle size with less than 1% in silt and clay particles group.

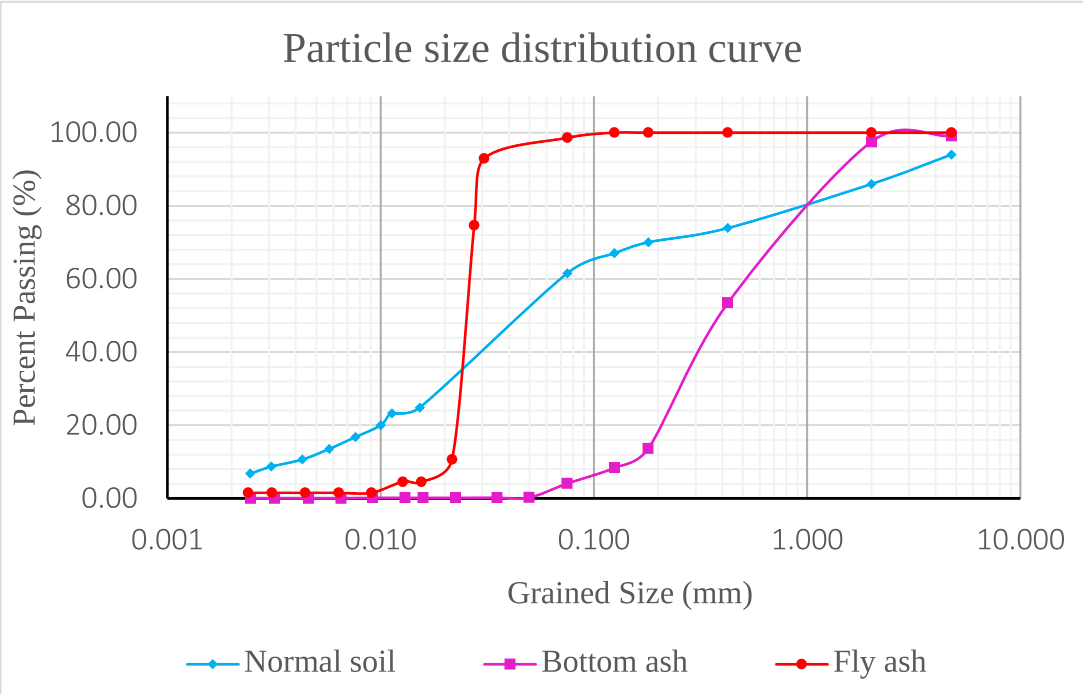


Figure 4.2 The particle size distribution curve of normal soil, bottom ash and fly ash

As a result, the application of bottom ash to soil significantly increases the proportion of coarse particles, which has particle size more than 0.05 mm. Figure 4.3 compares the particle size distribution curve between normal soil and amended soils by bottom ash. Since the percentage of fine particle of normal soil is quite high which is more than 50% wt., the application of bottom ash decreases the percentage of fine particle help the soil texture with higher porosity. It is noticeable from the line graph that the decrease in the proportion of clay and silt particles group is directly proportional to the concentration of bottom ash applied. Furthermore, the percentage of fine particles in normal soil is the highest proportion compared to the mixtures of bottom ash used.

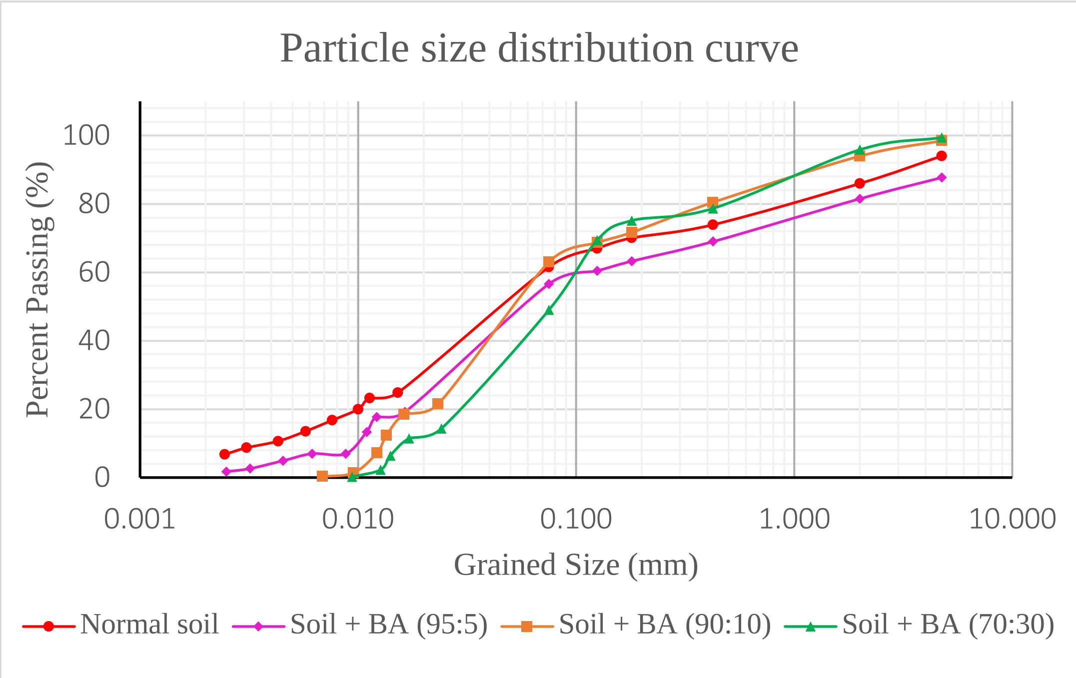


Figure 4.3 The particle size distribution curve of mixture with bottom ash

In contrast to bottom ash, the adding of fly ash to soil leads to increase the rate of fine particle size, which is larger 0.05 mm, in the mixtures as shown in Figure 4.4. The graph in Figure 4.4 indicates that the rate of fine particles in the mixture with 30% wt. of fly ash is the highest, whereas the figure for normal soil is lowest.

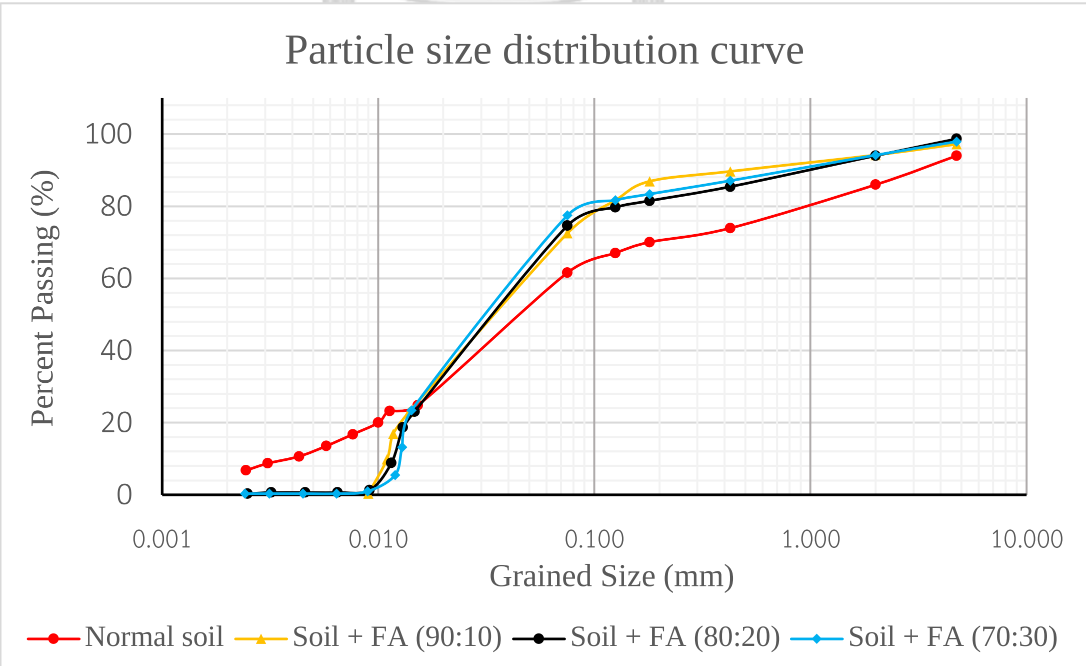


Figure 4.4 The particle size distribution curve of mixtures with fly ash

The soil texture of the initial soil samples and post-harvest is shown in Table 4.2 below. The initial texture of normal soil is silt loam, which has a moderate amount of fine sand and only a small amount of clay. Silty loam describes soils that contain from 0-50% sand and up to 27% clay particles (CAERT, 2018). When silty loam soil is dry, it is clods difficult to break. It is suitable for growing the crops that particularly like loose, fertile soil do especially well such as grasses, bamboo, wetland and aquatic plants, vegetables, fruit trees, berry bushes, and ferns.Meanwhile, the texture of bottom ash and fly ash are sand and silt, respectively. It is proven that plants grow in silty loam need more water than those in clay soil, but much less than those in a sandy soil (Barth, 2018).

From the result as shown in Table 4.2, the application of bottom ash ranging at 25% and 30% wt. makes to change texture of normal soil from silt loam to sandy loam, whereas the texture of soil does not change when applies fly ash. In addition, soil texture of most the post-harvest samples is not changed when compared to initial samples.

Table 4.2 Soil texture classification

No	Name	Initial samples	After harvest Bird Pepper samples	After harvest Holy Basil samples
1	Normal soil	Silt loam	Silt loam	Silt loam
2	BA (100%)	Sand	-	-
3	Fly ash (100%)	Silt	-	-
4	Soil + BA (95:5)	Silt loam	Silt loam	Silt loam
5	Soil + BA (90:10)	Silt loam	Sandy loam	Silt loam
6	Soil + BA (85:15)	Silt loam	Sandy loam	-
7	Soil + BA (80:20)	Silt loam	Sandy loam	Sandy loam
8	Soil + BA (75:25)	Sandy loam	Sandy loam	-
9	Soil + BA (70:30)	Sandy loam	Sandy loam	Sandy loam
10	Soil + FA (90:10)	Silt loam	Silt loam	Silt loam
11	Soil + FA (80:20)	Silt loam	Silt loam	Silt loam
12	Soil + FA (70:30)	Silt loam	Silt loam	Silt loam

Figure 4.5 illustrates the change in the texture of normal soil when applying bottom ash ranging from 25% to 30% wt.. In Figure 4.5, the initial texture of normal soil is silt loam, while the texture of bottom ash is sand. The application of bottom ash ranging

from 25% to 30% wt. makes the texture of normal soil changes to sandy loam, which has proportion of sand higher than loam. Sandy loam describes soils that contain from 43–85% sand and up to 20% clay particles. When sandy loams soils are compressed, they hold their shape but break apart easily. For growing plant, sandy loam soils are able to quickly drain excess water but it requires more frequent irrigation and fertilization than soil has a higher concentration of clay. The combination of sandy loam soil and organic matter is considered as the best way to improve a sandy loam soil (Thompson, 2018). According to a previous research, sandy loam soil is good for the growth of Bird Pepper (Ashilenje, 2014).

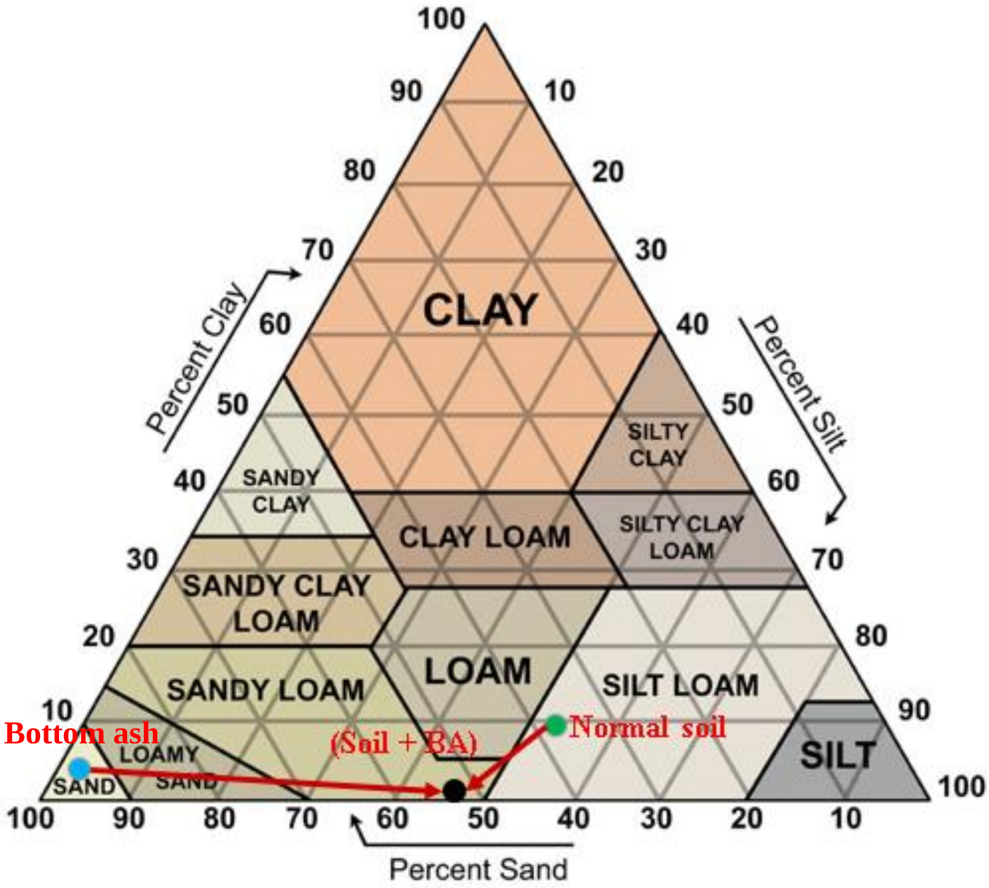


Figure 4.5 The change in texture of normal soil when apllies bottom ash

According to the previous research, soil texture directly affects the available water content that is an important parameter for plant growth. The available water content is measured by the difference between the maximum amount of water available (field capacity) and the amount of water that cannot be extracted by the plant (permanent wilting point). Figure 4.6 illustrates the relationship between available water and texture of the soil. From Figure 4.6, the available water content of silt loam is quite high, whereas the figure for sandy loam is slightly lower. As the application of bottom ash from 25% to 30% wt. makes the texture of normal soil change from silt loam to sandy loam that means using bottom ash more than 25% wt. leads to decreasing the available water content in the normal soil.

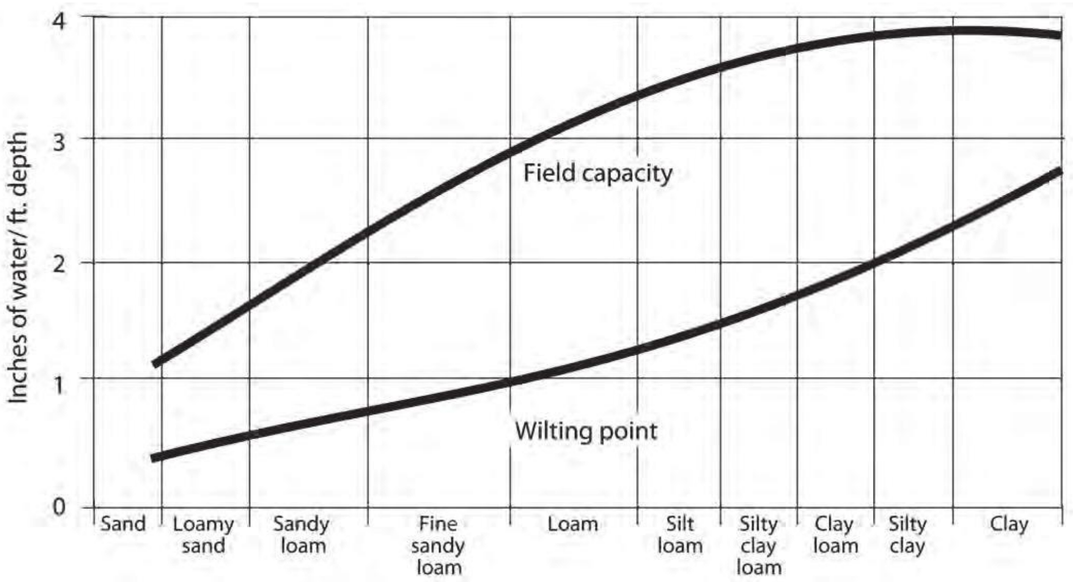


Figure 4.6 Relationship between available water and texture (Barker et al., 2005)

4.1.3. Effect of coal ash on pH, ECse

Figure 4.7 presents the pH of the initial samples before plant growing. The normal soil is nearly neutral that is suitable for growing almost plants. In contrast to normal soil, coal ash is strongly alkaline. There are a number of reasons why coal ash strongly alkaline. The first reason is the presence of Ca, K, Mg that has an alkaline effect. Another reason is the main composition of coal ash is CaO that forms $Ca(OH)_2$ with water and attributes to alkalinity. Therefore, the application of coal ash steeply increases pH of soil as shown in Figure 4.7. It causes pH of soil to alkaline. The pH range of mixture after applying coal ash is from 8.58 to 11.61. Hence, in the future, the application of this coal ash should be applied to more acidic soils in order to achieve higher efficiency.

In addition, pH of fertilizer is alkaline so applying fertilizer to soil result in increase in pH of soil. The pH after applying fertilizer is quite suitable for plants growth ranging from 7.32 to 7.44. Meanwhile, the mixture of soil, fertilizer, and bottom ash or fly ash at concentrate 90%, 5%, 5% wt., respectively has relatively high pH. The pH of the mixture of soil, fertilizer, and fly ash is 9.67, whereas the figure for the mixture of soil, fertilizer, and bottom ash is slightly lower, which has a value about 8.42.

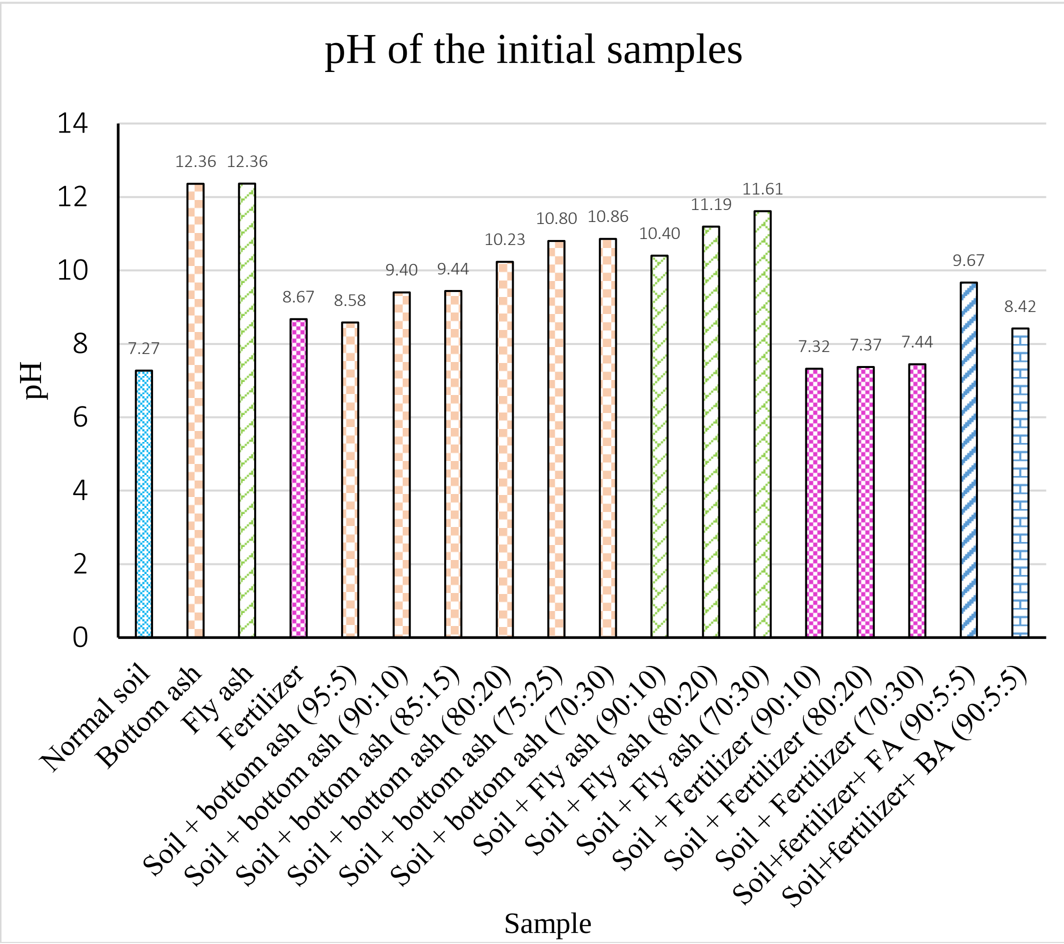


Figure 4.7 pH of initial samples

Figure 4.8 shows pH of the samples after harvest plants compared to initial samples. From the result shown in Figure 4.8, pH of the samples after harvest steadily decreases when compared to the initial samples but still keeping at high pH.

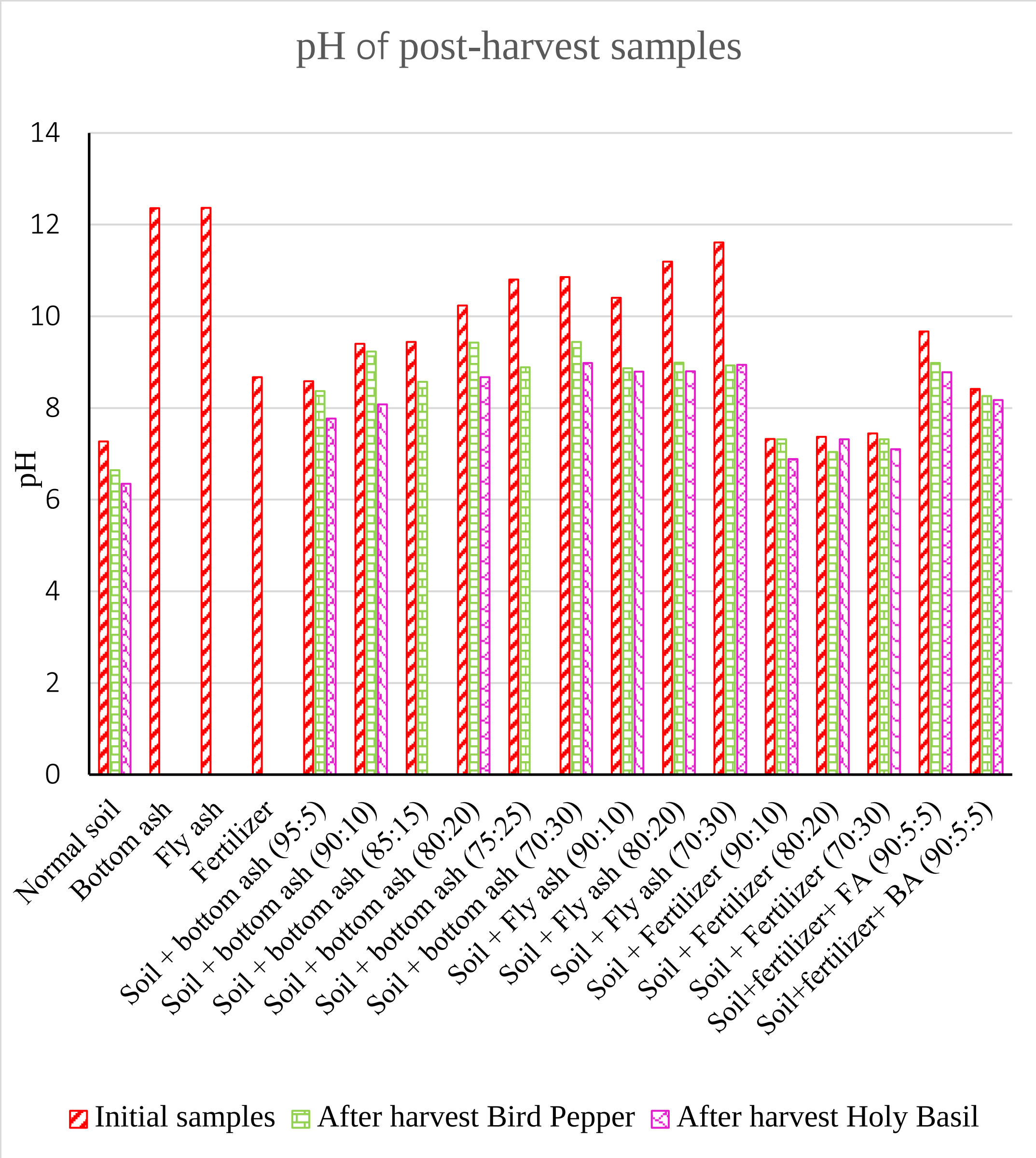


Figure 4.8 pH of the samples after harvest Bird Pepper and Holy Basil

Salinity is one of the major factors threats to agriculture worldwide. Soil salinity depends on the electrical conductivity of the extract of a soil-saturated paste (ECse, in dS/m). The higher ECse, the higher salinity. The ECse of the initial samples are shown in Figure 4.9 below. From Figure 4.9, ECse of normal soil is 1.35 dS/m, which is considered as a non-saline soil when compared to the soil salinity classification in Table 4.3. ECse of coal ash is very high, at above 200 dS/m, which is a strongly saline material. According to Figure 4.9, the application of coal ash to soil leads to an increasing ECse of soil that means increasing soil salinity. The increase in salinity is directly proportional to concentration of coal ash used. Particularly, ECse of the mixture applied 5% wt. of bottom ash is below 2 dS/m, which is a non-saline material, whereas the applying bottom ash ranging from 10% to 30% wt. makes soil to saline that will restrict the yields of many crops.

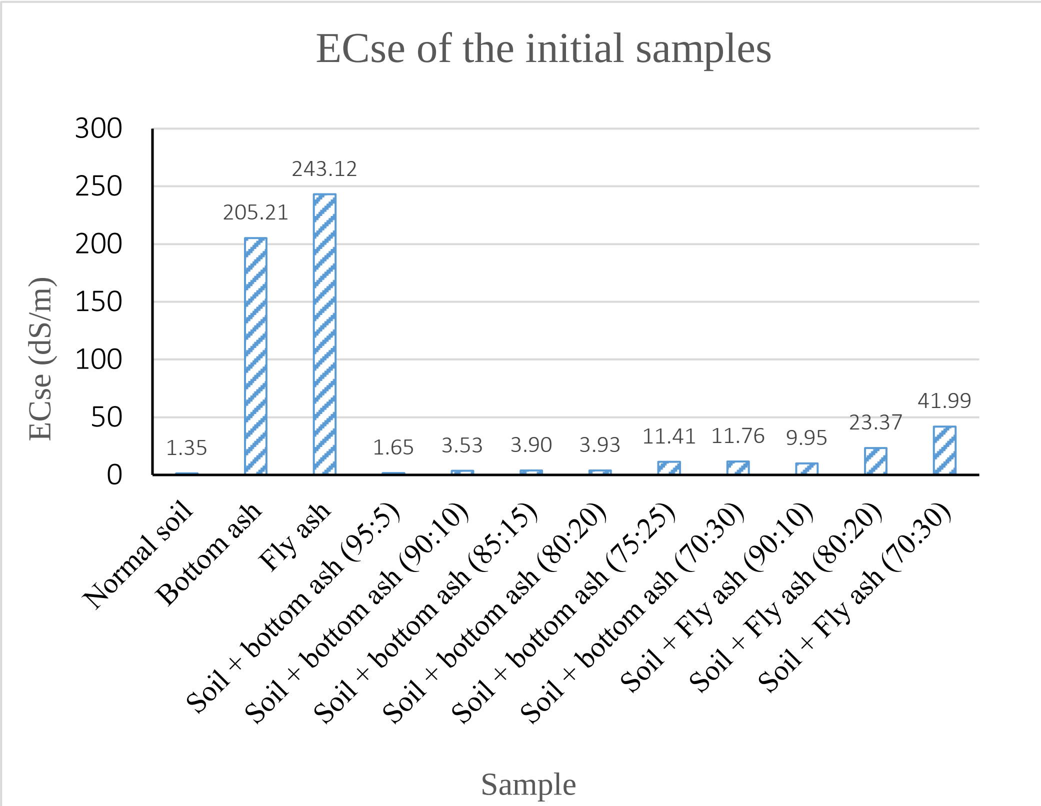


Figure 4.9 ECse of initial samples

Figure 4.10 shows the division for classifying crop tolerance to salinity. Bird Pepper is moderately sensitive crop that can grow well as ECse less than 4 dS/m as shown in Figure 4.10.

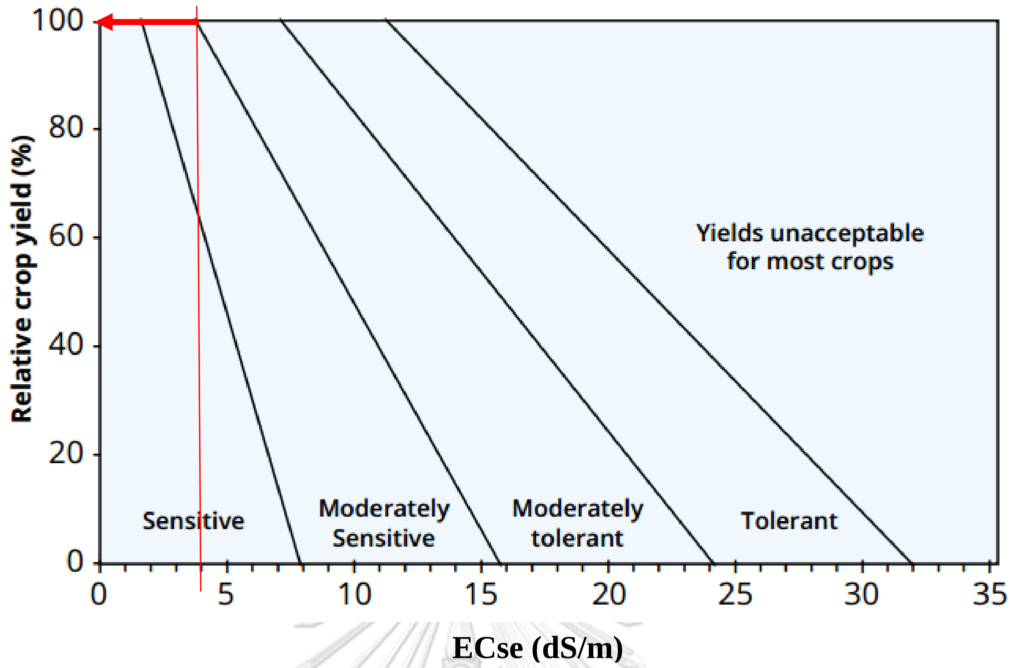


Figure 4.10 Division for classifying crop tolerance to salinity (FAO, 2018)

The application of bottom ash ranging from 25% to 30% wt. and the application of fly ash ranging from 10% to 30% wt. makes a significantly increase in ECse in samples. ECse of all samples is larger than 9.95 dS/m.

Figure 4.10 used to predict the effect of ECse on Bird Pepper's growth. From Figure 4.10, the application of 10% wt. of fly ash could decrease in yield of Bird Pepper by 50%, while the using fly ash ranging from 20% to 30% wt. could lead to death of Bird Pepper. Meanwhile, Bird Pepper grown in the mixtures of bottom ash ranging from 25% to 30% wt. could decrease in the yield of Bird Pepper by approximately 70%.

ECse of the samples after harvesting is shown in Figure 4.11 below. The ECse of samples significantly decreases after growing plants. At the time after harvest, the mixture has the concentration of bottom ash from 10% to 30% tend to decrease salinity to slightly saline, excepting the mixture of 25% wt. of bottom ash used to grow Bird Peppers. The salinity of that mixture still remains at moderately saline.

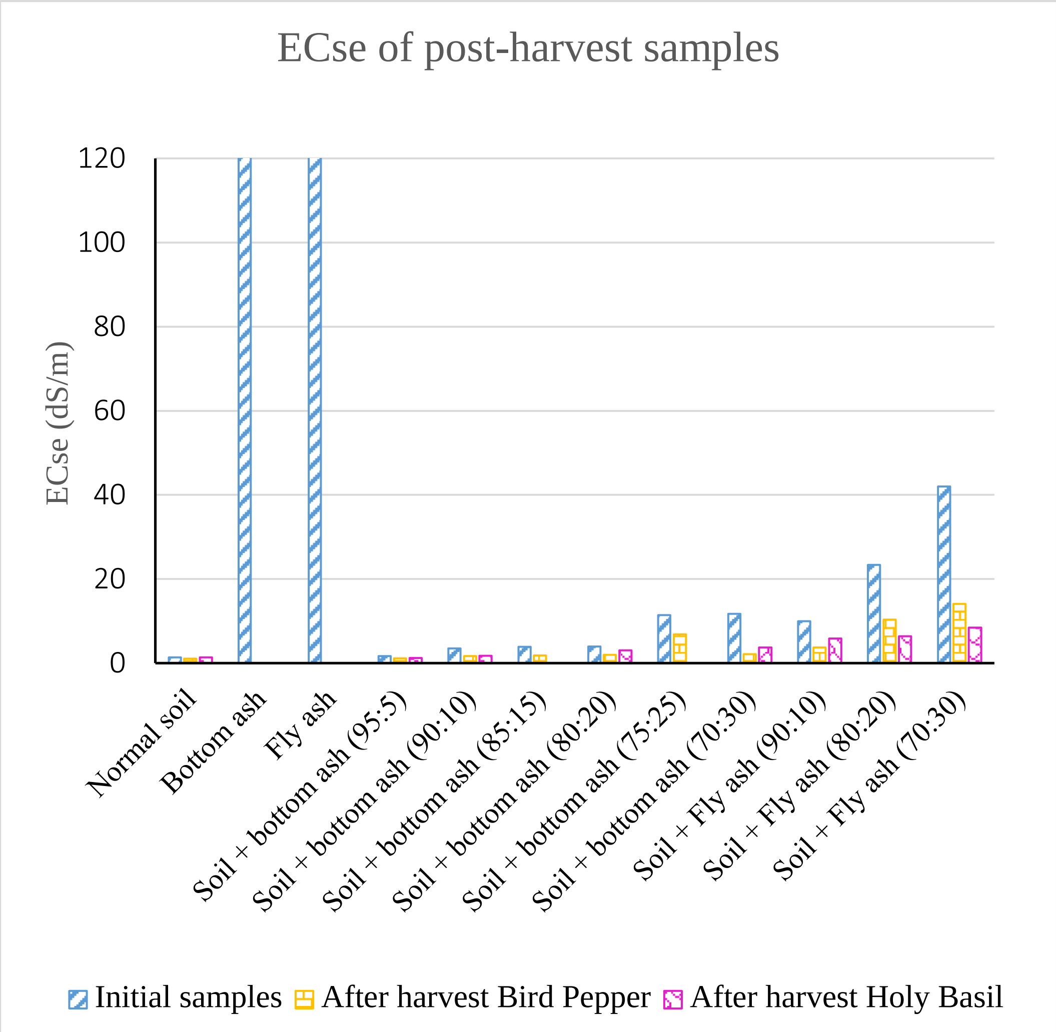


Figure 4.11 ECse of the samples after harvest Bird Pepper and Holy Basil

Table 4.3 shows soil salinity classification that is often used as a general guideline in relation to crop growth.

Table 4.3 Soil salinity classes and crop growth (Abrol et al., 1988)

Soil salinity class	ECse (dS/m)	Effect on crop plants
Non-saline	0-2	Salinity effects negligible
Slightly saline	2-4	Yields of sensitive crops may be restricted
Moderately saline	4-8	Yields of many crops are restricted
Strongly saline	8-16	Only tolerant crops yield satisfactorily
Very strongly saline	>16	Very strongly saline. Only a few very tolerant crops yield satisfactorily

4.1.4. Effect of coal ash on bulk density

Bulk density of initial samples is shown as in Figure 4.12 below. It indicates that the mixtures of soil and coal ash have bulk density lower than normal soil. From Table 4.2, the mixtures between soil and coal ash are sandy loam or silt loam, which have suitable bulk densities for plant growth less than 1.4 (g/cm^3) as shown in Table 2.10. This means using coal ash to amend soil help to improve bulk density of soil to suitable condition for plant growth. Since fertilizer has organic matter very high, amount of fertilizer apply to soil makes the bulk density of soil lower to adequately support, which ranges from 0.61 to 0.91 (g/cm^3).

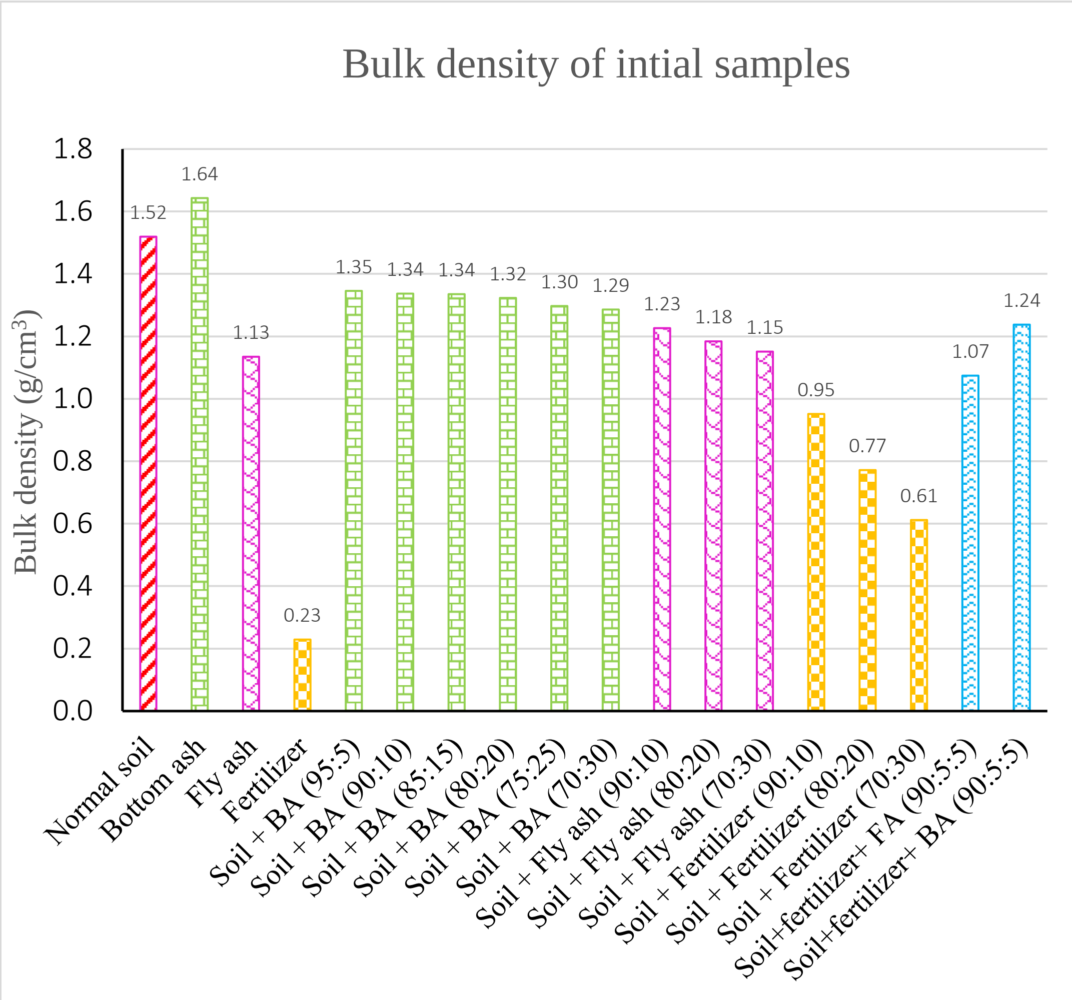


Figure 4.12 Bulk density of initial samples

Figure 4.13 compares bulk density of samples after harvest plants to initial samples. From the bar chart, the bulk density of samples tends to increases after harvesting. The reason can be explained that during the study period, the soil samples are subjected to a weight bearing from the plant growing on. It makes soil became more compact over the time.

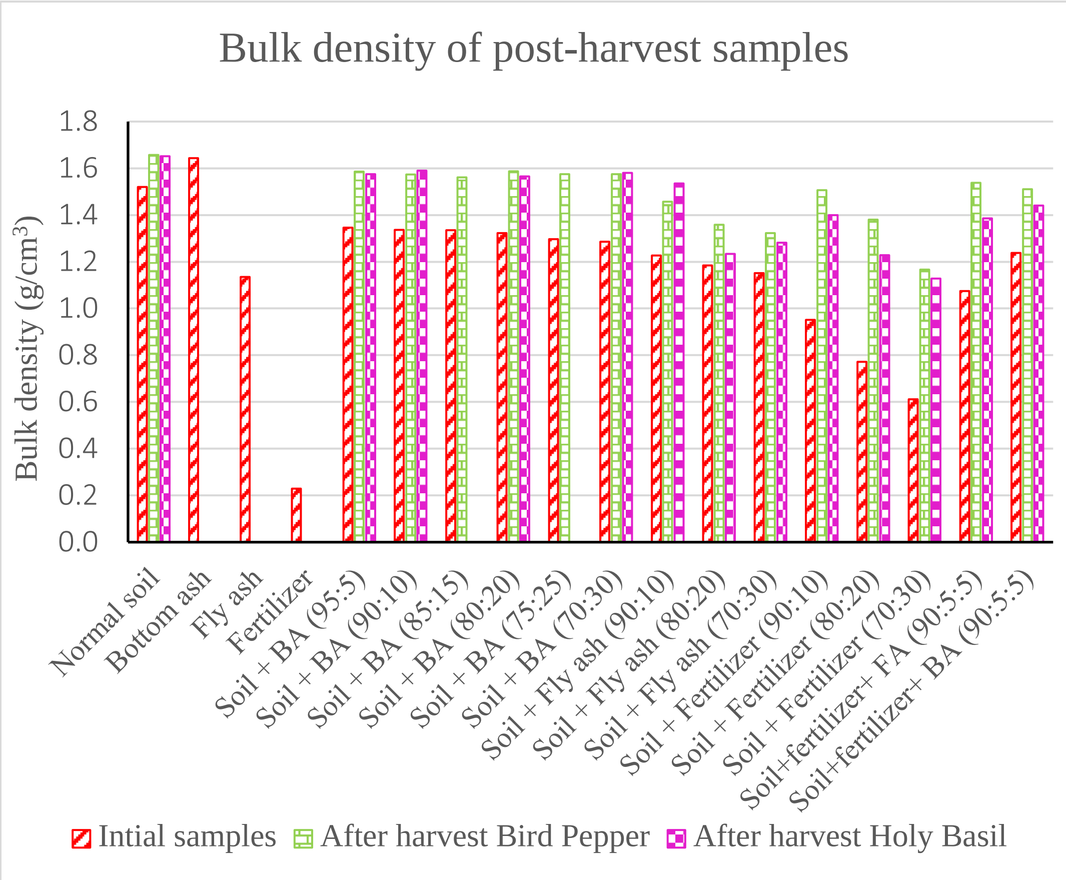


Figure 4.13 Bulk density of the samples after harvest Bird Pepper and Holy Basil

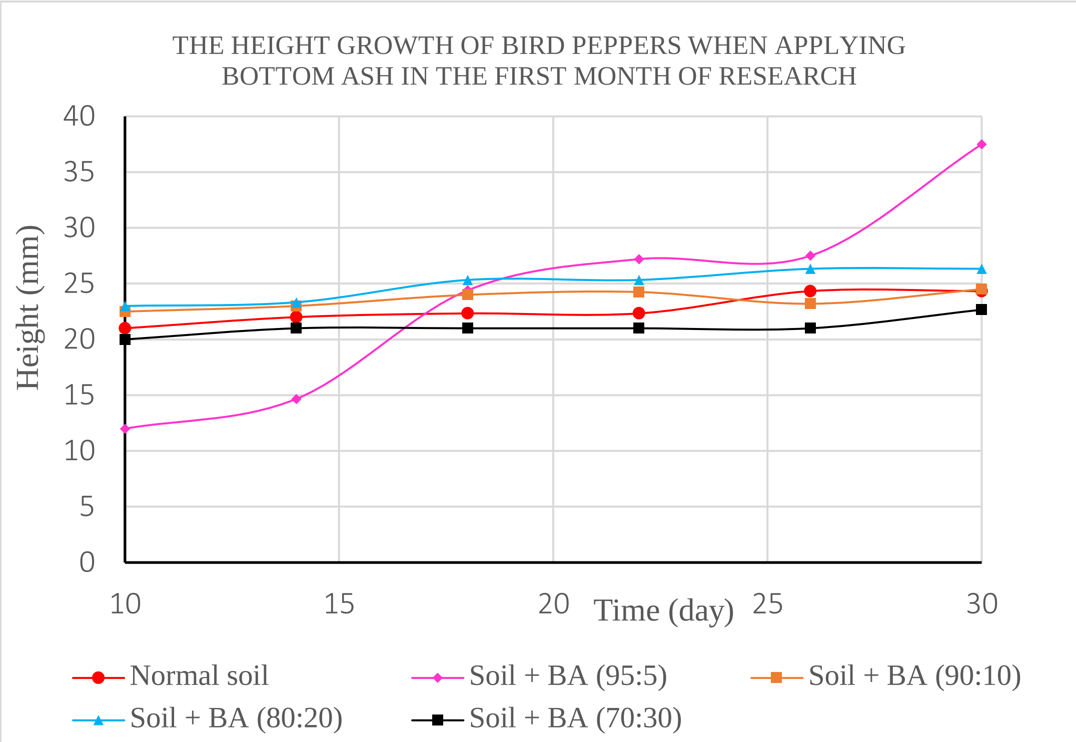
4.2. Effect of Coal Ash on Plant Growth

4.2.1. Growth of plants when using bottom ash as a soil amendment

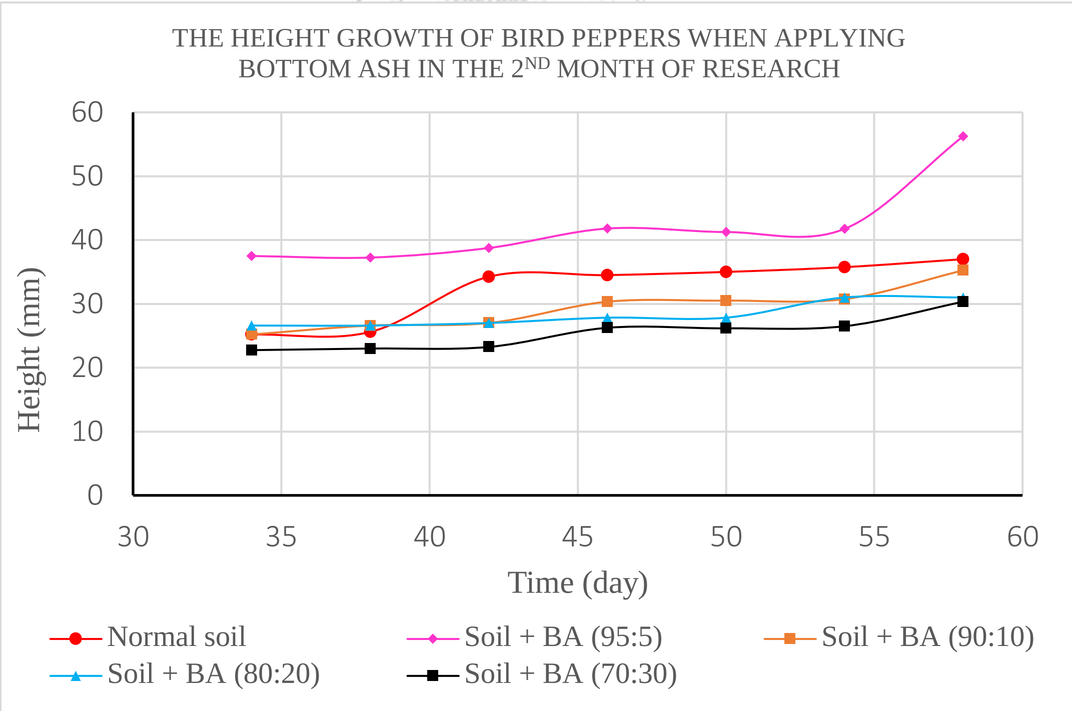
4.2.1.1. Bird Peppers

Figure 4.14 illustrates the growth height of Bird Peppers when apply bottom ash as a soil amendment during the first three months of research.

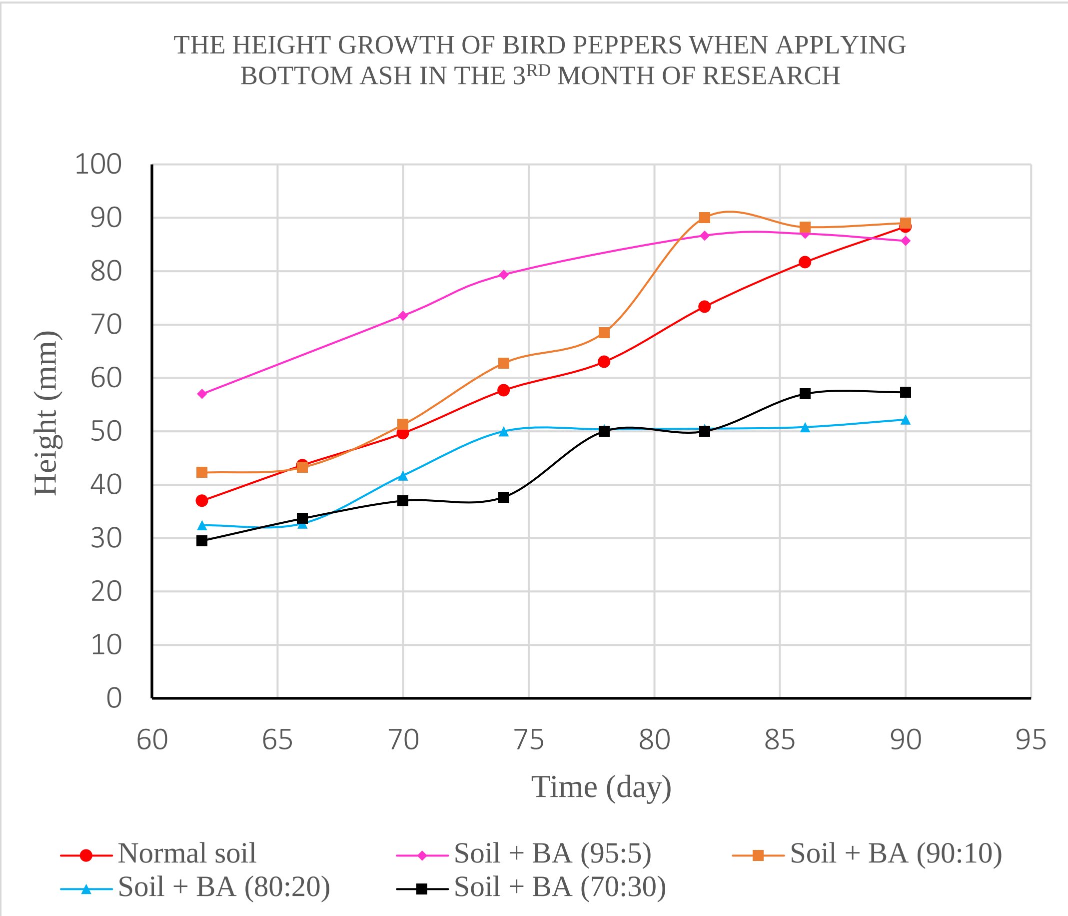
It is clear from Figures 4.14a), b), and c) that the application of bottom ash at 5% wt. help to increase significantly the growth of Bird Peppers when compared to the normal soil during the first three months of the study time. Moreover, the height of Bird Peppers grown with a concentration of 5% wt. of bottom ash is by far highest during this period time. By contrast, the figure for the mixture of 30% wt. of bottom ash is lowest during the first three months. In addition, using bottom ash at a concentration of 10% wt. also helps Bird Peppers slightly increased.



a) The height growth of Bird Peppers in the first month



b) The height growth of Bird Peppers in the 2nd month



c) The height growth of Bird Peppers in the 3rd month

Figure 4.14 The height growth of Bird Peppers when apply bottom ash as a soil amendment during the first three months of research.

In the first month, the height Bird Peppers that is grown with the mixture of bottom ash from 5% to 20% wt. is higher than normal soil as shown in Figure 4.14a). Particularly, the applications of bottom ash at concentration 10%wt. and 20%wt. help to increase plant height up to 9% and 14%, respectively.

For one month later, the height for normal soil is higher than that of the mixtures of 10% and 20% wt. of bottom ash. However, the plant growth using 5% wt. of bottom ash is still highest in Figure 4.14b).

All the figures of mixtures increased during the third month as illustrated in Figure 4.14c). Application of 5% wt. of bottom ash help to Bird Peppers grows well. Particularly, Bird Peppers grown in the mixture of 5% wt. of bottom ash increases height plant approximately 60% on the 70th day. Meanwhile, the height for plants which grown in the mixture of 10% wt. of bottom ash experienced the dramatic change and became higher than that of the normal soil.

The height growth of Bird Peppers for the rest months of research is shown in Figure 4.15 below. In these months, the height of Bird Peppers grown with normal soil is by far highest, whereas the height for the mixture of 10% wt. of bottom ash is slightly lower. Furthermore, after the 3rd month, the height of Bird Peppers grown with the mixture of 5% wt. of bottom ash has an insignificant increase, and became dramatically lower as compared to the height of normal soil.

Bird Peppers grown with the mixture of 5% wt. of bottom ash is attacked by Broad mite *(Polyphagotarsonemus latus)* from the 3rd month. There are symptoms that appears on Bird Peppers as shown in Figure 4.16. Firstly, distorted and curled leaves, then treetops get attacked most of leaves and become stunted. Finally, plant growth become greatly slow.

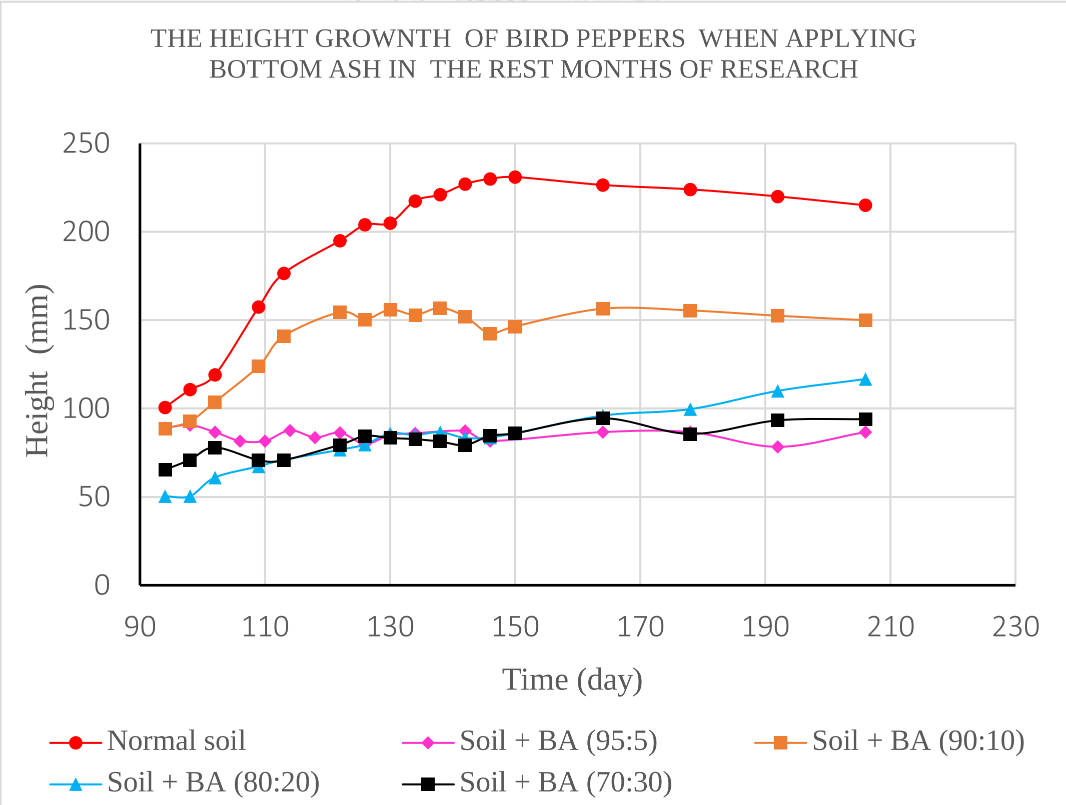


Figure 4.15 The height growth of Bird Peppers in the rest months of research when apply bottom ash as a soil amendment.

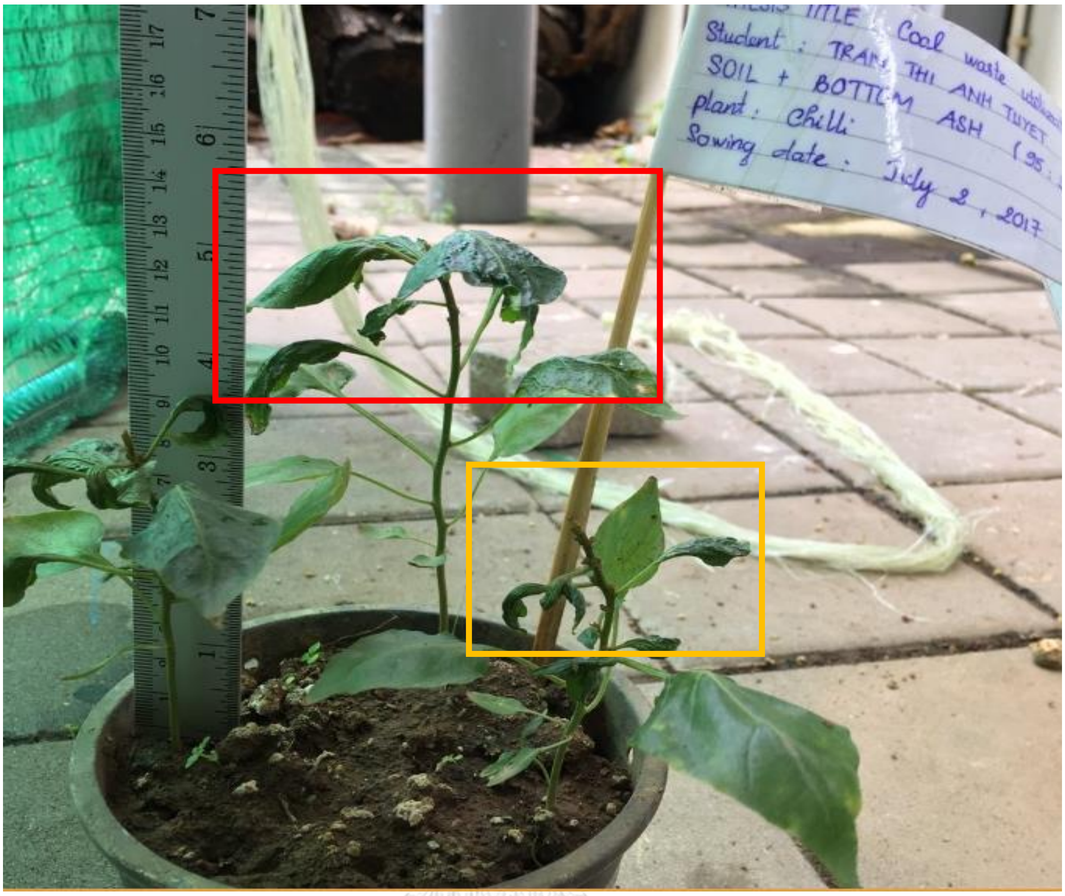
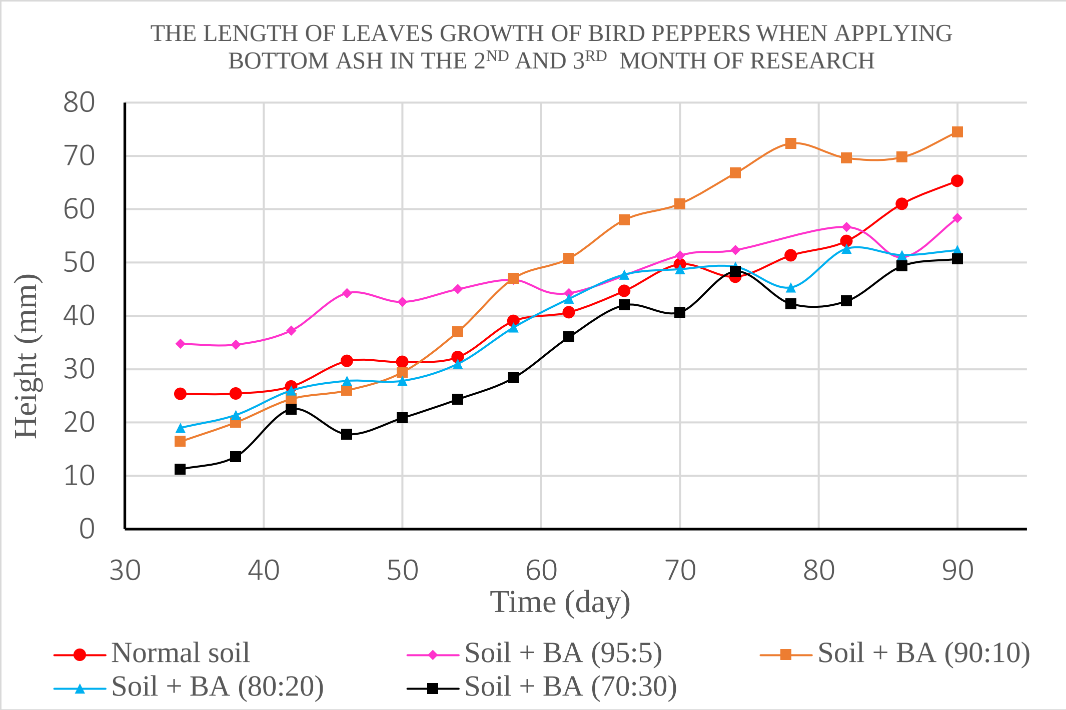


Figure 4.16 Bird Pepper grown in the mixture of 5% wt. of bottom ash. Picture was took on 9 October 2017 (98th day)

The application of bottom ash to soil also affects significantly the leaf growth. The leaf growth of Bird peppers when applying bottom ash in the 2nd and 3rd month of research is shown as in Figure 4.17. In the first time recorded, leaf size of plant grown in the mixture of 5% wt. of bottom ash is the largest, whereas the figure for normal soil is significantly smaller. Meanwhile, the figure of 10% wt. of bottom ash is slightly smaller when compared to normal soil. At the same time, the leaf size of plant grown in the mixture of 30% wt. of bottom ash is smallest.

The leaves size of Bird Peppers that is grown in the mixture of 5% wt. bottom ash is larger the figure for normal soil until 70th day, but becomes smaller the figure for normal soil from 74th day. It is clear from the graph that the leaf size of Bird Peppers grown in the mixture of 10% wt. of bottom ash increases gradually, and take over normal soil from 54th day, and became the biggest figure compared to other cases.



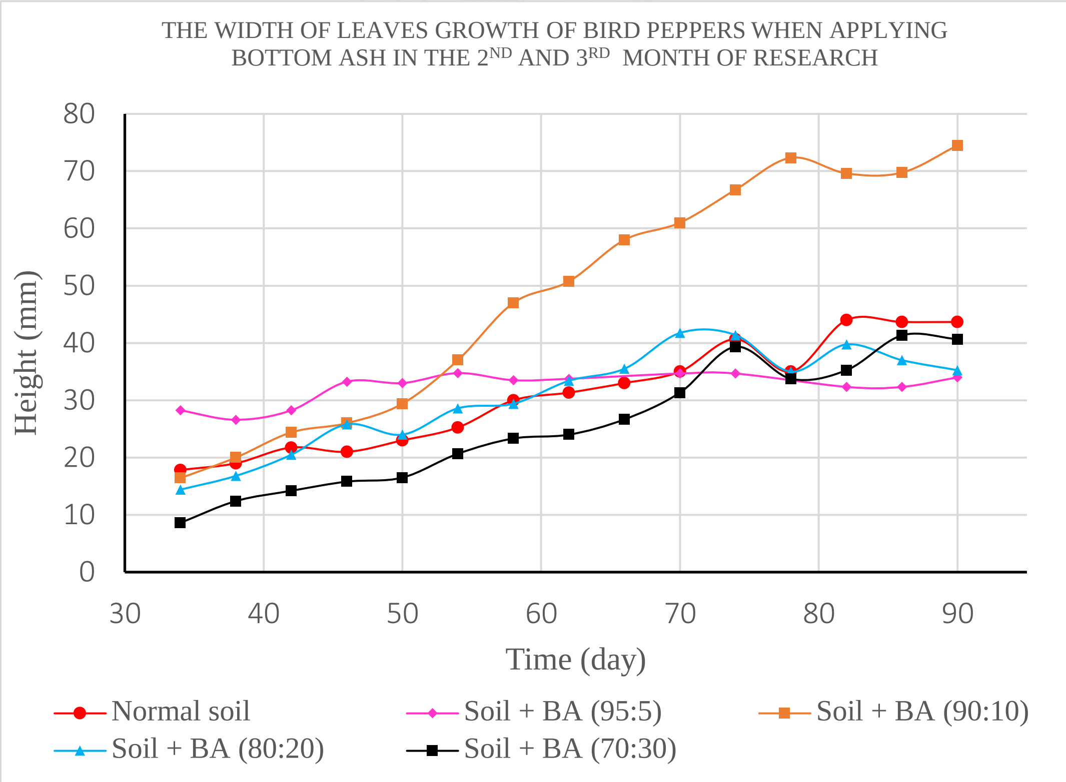
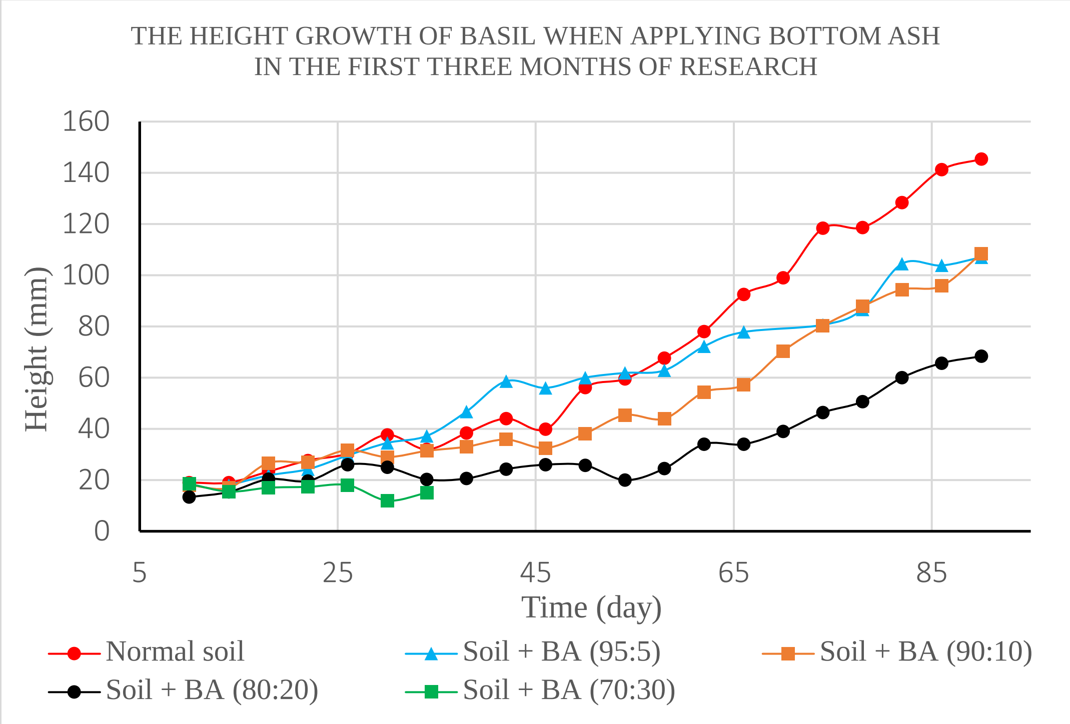
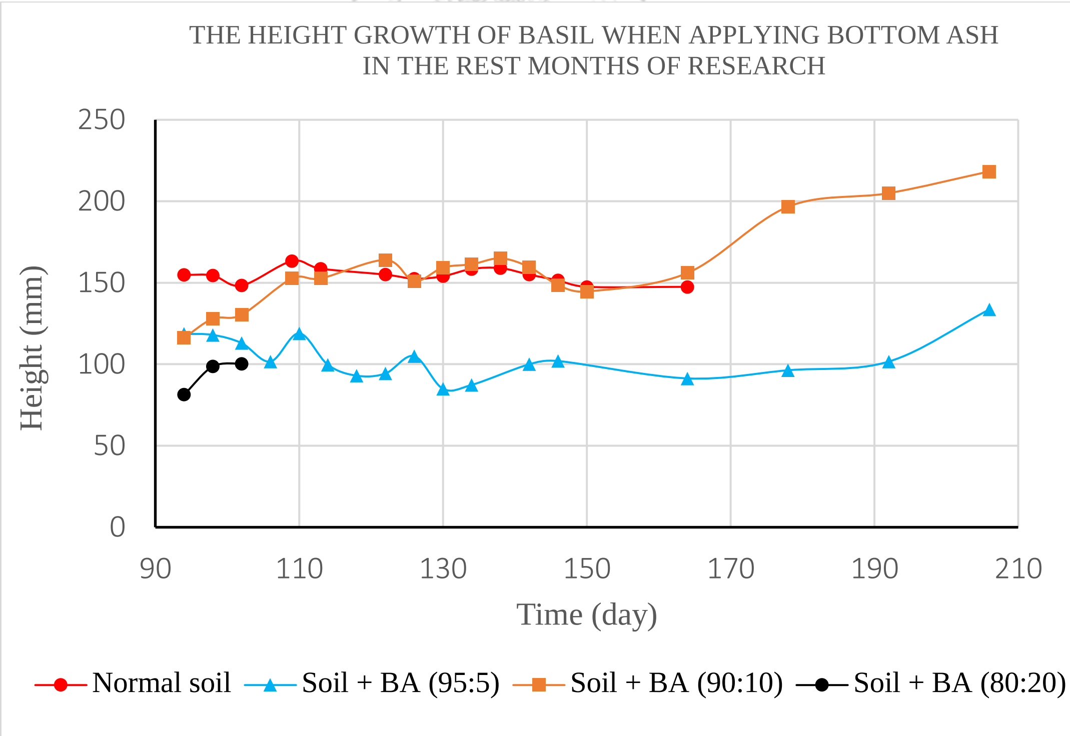


Figure 4.17 The leaf growth of Bird peppers when applying bottom ash in the 2nd and 3rd month of research

4.2.1.2. Holy Basil



a) The height growth of Holy Basil in the first three months of research



b) The height growth of Holy Basil in the rest months of research

Figure 4.18 The height growth of Holy Basil when applying bottom ash

It is clear from Figure 4.18a) that although the growing plant is best with normal soil, the application of bottom ash ranging from 5% to 10% wt. also help Basil grow well. According to Figure 4.18b), the height growth of Holy Basil grown in the mixture of 10% wt. of bottom ash is slightly higher when compared to normal soil since 4th month. Furthermore, Holy Basil grown in the mixtures of 5% and 10% wt. of bottom ash has the lifetime more than normal soil.

4.2.2. Growth of plants when using fly ash as a soil amendment

Figures 4.19 and 4.20 show the height growth of Bird Peppers and Holy Basil when using fly ash to amendment soil. From Figure 4.19, the application of fly ash at all concentrations in this study shows a significant reduction in plant growth of Bird Peppers, including plant height and leaf size. Particularly, the mixtures of 20% and 30% wt. of fly ash lead to Bird Peppers's death, which is logical with the prediction about the effect of ECse on Bird Pepper's growth as shown in Figure 4.10. The reduction of plant growth is directly proportional to the increase in fly ash concentration. For instance, Bird Peppers grown with 20% and 30% wt. of fly ash is died at 70th and 38th day, respectively. This means that applying a higher concentration of fly ash, the plant is dead earlier.

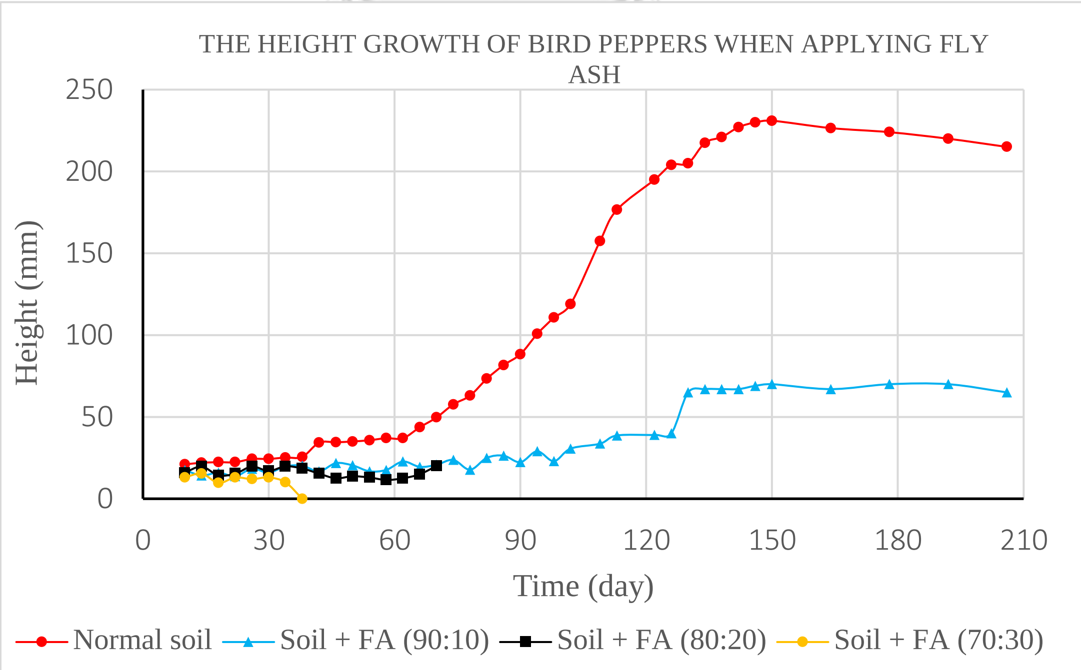


Figure 4.19 The height growth of Bird Peppers when applying fly ash

As shown in Figure 4.20, the Basil has died when growing with amended soils by fly ash in this study. That means that Holy Basil is not a suitable crop for growing in amended soils with fly ash. Furthermore, it maybe is a sensitive crop to salinity because it died when ECse of soil is larger than 9.95 dS/m.

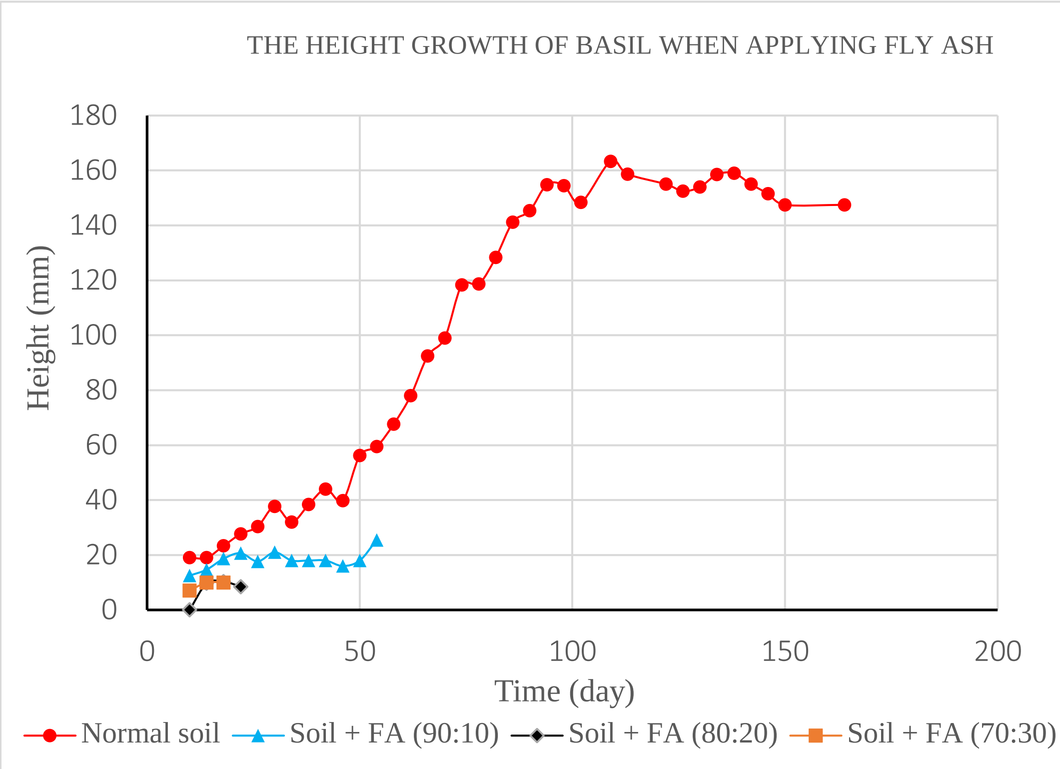


Figure 4.20 The height growth of Holy Basil when applying fly ash

4.2.3. Growth of plants when using fertilizer as a soil amendment

The height growth of Bird Pepper grown in the mixtures of fertilizer is shown in Figure 4.21 below. This study is found that the mixture of soil, fertilizer and bottom ash by 90, 5, 5% wt., respectively helps to significantly increase the growth of Bird Peppers compared to the normal soil. The application of this mixture increases height plant about 66% at the 66th day. Additionally, the figure for the mixture of soil, fertilizer and bottom ash by 90, 5, 5% wt., respectively is higher than that of the mixtures of fertilizer at 10%wt, 20% wt. in most of the study period. In contrast to using bottom ash, the application of the mixture of soil, fertilizer and fly ash by 90, 5, 5% wt., respectively shows a significant reduction in the growth of Bird Pepper.

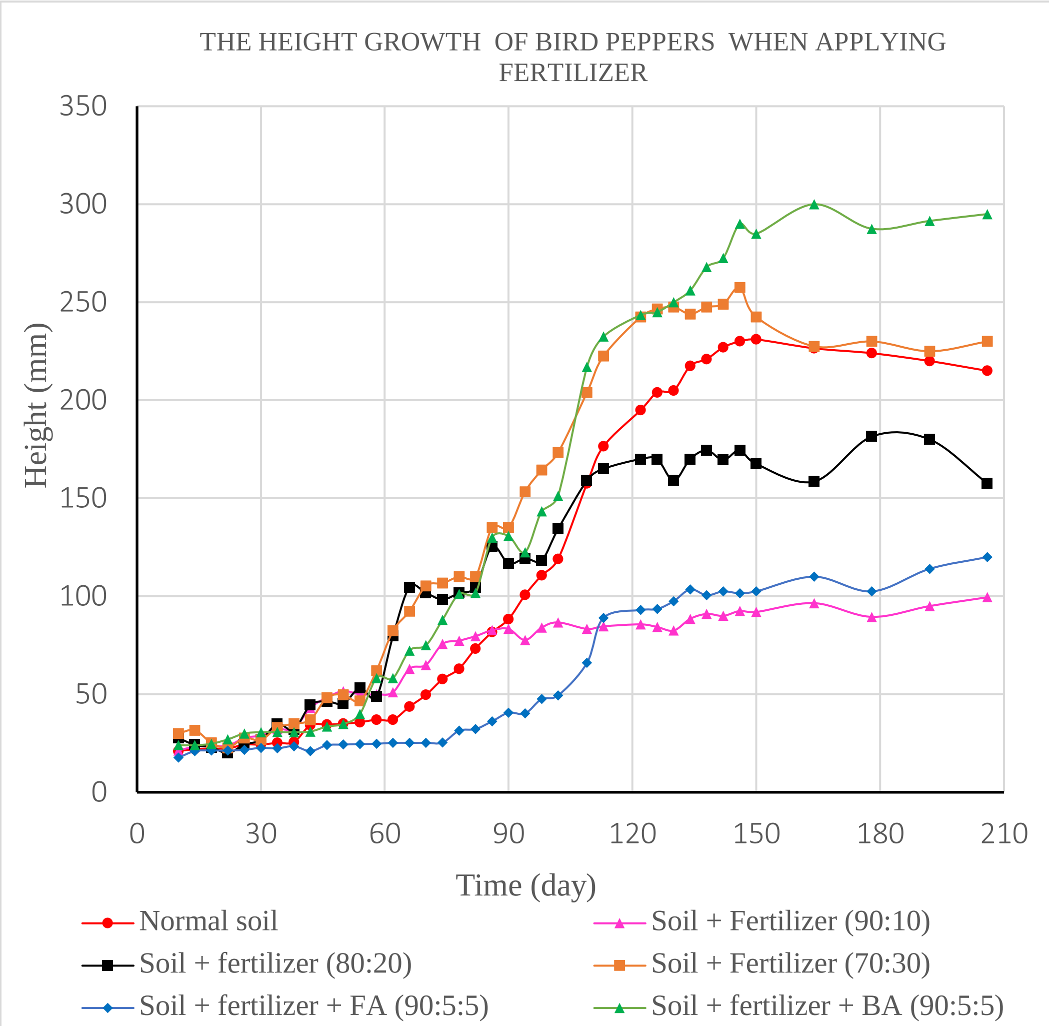


Figure 4.21 The height growth of Bird Peppers when applying fertilizer

Figure 4.22 shows the height growth of Holy Basil when applying the mixtures of fertilizer. From the chart, the height growth of Holy Basil grown in the mixtures of 20% and 30% wt. of fertilizer are best. The height of Holy Basil grown with the mixture of soil, fertilizer and bottom ash by 90, 5, 5% wt., respectively became better than normal soil from 109th day to the rest of research. In contrast to applying bottom ash, Holy Basil is grown with the mixture of soil, fertilizer and fly ash by 90, 5, 5% wt., respectively dies after more than one month grown.

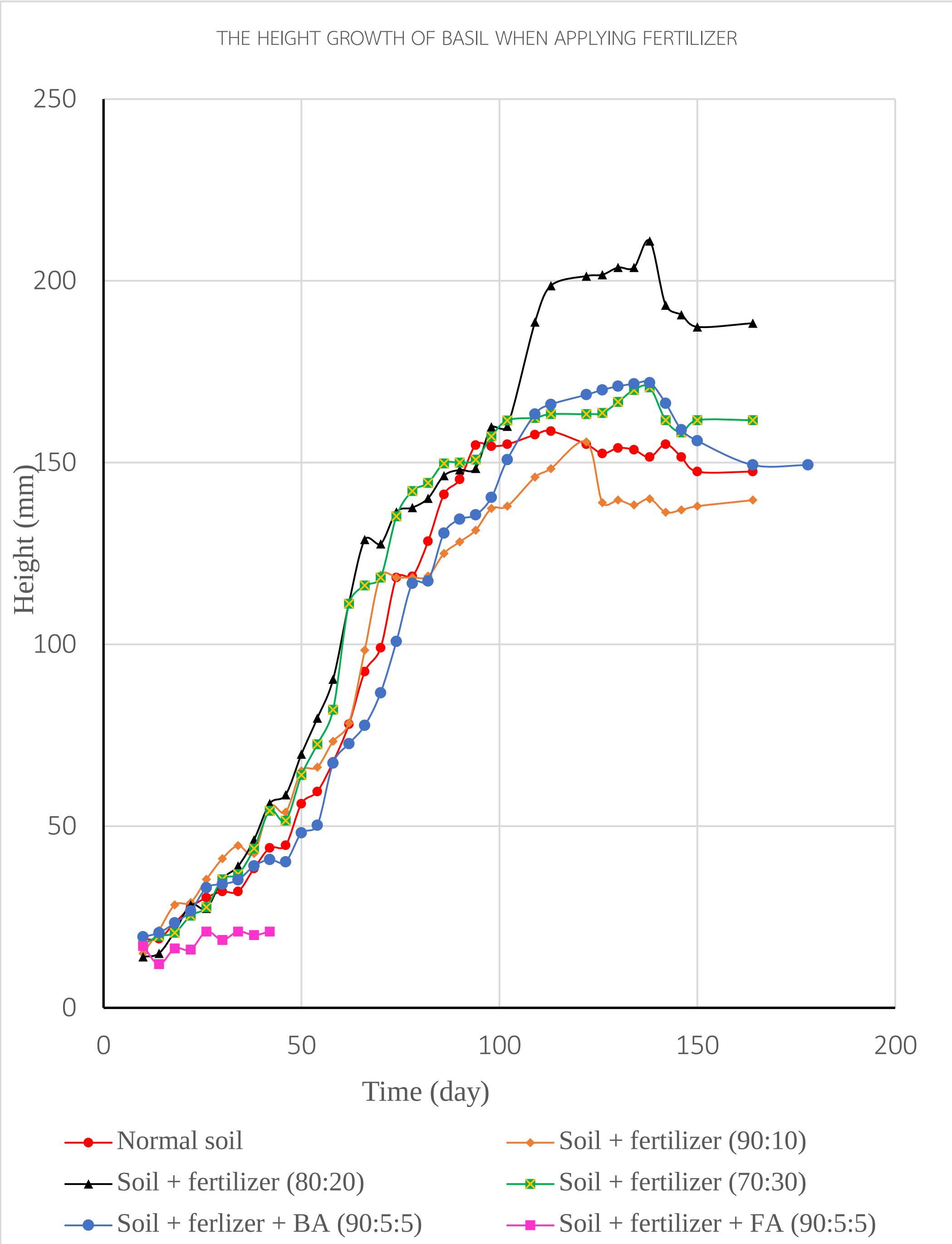


Figure 4.22 The height growth of Holy Basil when applying fertilizer

CHAPTER 5
CONCLUSIONS AND RECOMMENDATION

In this chapter, conclusions and recommendations from experiment and plant growing in this research are presented.

5.1. Conclusions

Based on the statistics and forecast, coal is and continues to be one of the most important primary energy sources for countries all across the world. It is not surprising that coal ash production, including bottom ash and fly ash, is generated from coal-combustion process has been increased gradually over the years. Nowadays, landfilling still is the most common method for coal ash disposal, which lead to environmental problems such as air pollution, the leak of landfill water to groundwater, and high cost for construct landfilling. The study is conducted to gives a better way to manage the waste as well as to reduce the environmental impacts and increase the profit for the manufacturer. From the results of the research, the following conclusion can be drawn:

1. The texture of soil has changed when applies coal ash to amend soil. The application of bottom ash ranging from 25% to 30% makes the texture of soil changes from silt loam to sandy loam.

2. The coal ash used is alkaline. The application of bottom ash ranging from 5% to 30% wt. makes soil pH significantly increase from 18% to 49%, respectively. Same as above, soil pH also has a sharp rise when using fly ash as a soil amendment. It would be more beneficial to this ashes improve pH of acidic soil.

3. The texture of the mixtures between soil and coal ash are sandy loam or silt loam, which would be good for plant growth when the bulk density is less than 1.4 g/cm^3. The amended soil with coal ash has a range of bulk density from 1.15 to 1.35 g/cm^3, which means that the application of coal ash ranging from 5% to 30% wt. helps to improve bulk density of soil to suitable conditions for plant growth.

4. ECse of bottom ash is larger than 16 dS/m that is considered as a saline material when compared to the soil salinity classification as shown in Table 4.3. In this study, the normal soil used has ECse lower than 2 dS/m, meaning it is a non-saline soil. ECse of the mixture between soil and 5% wt. of bottom ash is below 2 dS/m, which is a non-saline material. ECse of the the mixtures of bottom ash with concentration from 10% to 30% wt. is from 3.53 to 11.76 dS/m, respectively. These numbers indicate that the applications of bottom ash from 10% to 30% wt. increase ECse of soil. As a result, it makes none-saline soil become saline soil. Thus, the concentration applied should be less 5% wt. to keep the soil do not become saline.

5. The research is found that the application of bottom ash at 5% wt. help to increase significantly the growth of Bird Peppers when compared to the normal soil during the first three months of the study time.

6. The application of the mixture of soil, fertilizer and bottom ash by 90, 5, 5% wt., respectively has the plant growth of Bird Peppers higher than that of the mixtures of fertilizer at 10%wt, 20% wt. in most of the study period.

7. From the result, fly ash does not help plants growing of both Bird Peppers and Holly Basil. Furthermore, the author recommends that Holly Basil is not suitable to be grown in an amendment soil with fly ash.

5.2. Recommendation

The coal ash used in this study should be applied to acidic soils in order to gain higher efficiency.

Two parameters water holding capacity and amount of heavy metal absorbed in plants are expected to do in future research.

Following the soil salinity classification, the ashes have the ECse values lager than 16 dS/m, so these are saline materials. The application of the ashes tends to increase ECse of soil that makes soil become more saline. Therefore, it would be more beneficial to choose crops, which could tolerate moderately to salinity such as corn.

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APPENDIX

A.1. Converting from EC (1:5) to ECse

Table A.1 ECse Conversion Factors vary with clay content (Catchment Management Authority, 2018)

Calculating the saturated extract electrical conductivity (EC_{se})* from the 1:5 water extract electrical conductivity ($EC_{1:5}$) value								
Plant Tolerance Group	Saturated Extract *Electrical Conductivity ECse (dS/m)*	Soil Salinity Rating	*Soil Water Extract Electrical Conductivity - EC1:5 (ds/m)*					
			%Clay					
			<10%	*10-15%*	*25%*	*35-40%*	*40-45%*	*>45%*
			Sands, loamy sand, clayey sand	Sandy loam, Fine Sandy loam	Loam, silty loam, light sandy clay loam	Clay loam, clay loam sandy, silty clay loam, sandy clay, silty clay, light clay	Light medium clay, medium to heavy silty and sandy clays	Medium to heavy clays, heavy silty and sandy clays
Multiplication Factor			22.7	13.8	9.5	8.6	7.5	5.8
Sensitive crops turnip, strawberry beans, carrot	<0.95	Very low	<0.04	<0.07	<0.10	<0.11	<0.13	<0.16
Moderately sensitive crops clovers, potato, grapes, corn	0.95 - 1.9	Low	0.04-0.08	0.07-0.14	0.10-0.20	0.11-0.22	0.13-0.25	0.16-0.33
Moderately tolerant crops lucerne, kikuyu, phalaris grain sorghum, rice	1.9 - 4.5	Medium	0.08-0.20	0.14-0.33	0.20-0.47	0.22-0.52	0.25-0.60	0.33-0.78
Tolerant crops buffel grass, oats, wheat, perennial ryegrass	4.5 - 7.7	High	0.20-0.34	0.33-0.56	0.47-0.81	0.52-0.89	0.60-1.03	0.78-1.33
Very tolerant crops Barley, cotton	717 - 12.2	Very High	0.34-0.54	0.56-0.88	0.81-1.28	0.89-1.42	1.03-1.63	1.33-2.10
Generally too saline for crops	>12.2	Extreme	>0.54	>0.88	>1.28	>1.42	>1.87	>2.10

A.2. Calculations of Hydrometer Experiment

A.2.1. Particle diameter in suspension

For each hydrometer reading, calculate and record the particle diameter of the soil using the following equation:

$$D_m = \left(\sqrt{\frac{18\mu}{\rho_w(G_s-1)}\frac{L_m}{t_m}}\right) x\ 10$$

Where:

D_m = particle diameter, two significant digits, mm

μ = viscosity of water at reading temperature,

ρ_w = mass density of water at reading temperature, g/cm^3

g = acceleration dues to gravity, 980.7 cm/s^2

G_s = specific gravity of soil, three significant digits (dimensionless),

t_m = elapsed (fall) time, two significant digits, s

L_m = particle fall distance, two significant digits, cm

m = subscript indicating the reading number during the sedimentation test.

Table A.2 Viscosity of Water (μ) Versus Temperature (T) (Vietnam Ministry of Construction, 2014)

Temperature (^{0}C)	μ	Temperature (^{0}C)	μ
10	0,01308	26	0,00874
11	0,01272	27	0,00854
12	0,01236	28	0,00836
13	0,01208	29	0,00818
14	0,01171	30	0,00801
15	0,01140	31	0,00784
16	0,01111	32	0,00768
17	0,01086	33	0,00752
18	0,01056	34	0,00737
19	0,01050	35	0,00722
20	0,01005	36	0,00718
21	0,00981	37	0,00695
22	0,00958	38	0,00681
23	0,00936	39	0,00668
24	0,00914	40	0,00656
25	0,00894		

Table A.3 Density of Water (ρw) Versus Temperature (T) (International, 2017)

T (°C)	ρ_w (g/ML)	*T (°C)*	ρ_w (g/ML)	*T (°C)*	ρ_w (g/ML)	*T (°C)*	ρ_w (g/ML)
15.0	0.99910	16.0	0.99895	17.0	0.99878	18.0	0.99860
.1	0.99909	.1	0.99893	.1	0.99876	.1	0.99858
.2	0.99907	.2	0.99891	.2	0.99874	.2	0.99856
.3	0.99906	.3	0.99890	.3	0.99872	.3	0.99854
.4	0.99904	.4	0.99888	.4	0.99871	.4	0.99852
.5	0.99902	.5	0.99886	.5	0.99869	.5	0.99850
.6	0.99901	.6	0.99885	.6	0.99867	.6	0.99848
.7	0.99899	.7	0.99883	.7	0.99865	.7	0.99847
.8	0.99898	.8	0.99881	.8	0.99863	.8	0.99845
.9	0.99896	.9	0.99879	.9	0.99862	.9	0.99843
19.0	0.99841	20.0	0.99821	21.0	0.99799	22.0	0.99777
.1	0.99839	.1	0.99819	.1	0.99797	.1	0.99775
.2	0.99837	.2	0.99816	.2	0.99795	.2	0.99773
.3	0.99835	.3	0.99814	.3	0.99793	.3	0.99770
.4	0.99833	.4	0.99812	.4	0.99791	.4	0.99768
.5	0.99831	.5	0.99810	.5	0.99789	.5	0.99766
.6	0.99829	.6	0.99808	.6	0.99786	.6	0.99764
.7	0.99827	.7	0.99806	.7	0.99784	.7	0.99761
.8	0.99825	.8	0.99804	.8	0.99782	.8	0.99759
.9	0.99823	.9	0.99802	.9	0.99780	.9	0.99756
23.0	0.99754	24.0	0.99730	25.0	0.99705	26.0	0.99679
.1	0.99752	.1	0.99727	.1	0.99702	.1	0.99676
.2	0.99749	.2	0.99725	.2	0.99700	.2	0.99673
.3	0.99747	.3	0.99723	.3	0.99697	.3	0.99671
.4	0.99745	.4	0.99720	.4	0.99694	.4	0.99668
.5	0.99742	.5	0.99717	.5	0.99692	.5	0.99665
.6	0.99740	.6	0.99715	.6	0.99689	.6	0.99663
.7	0.99737	.7	0.99712	.7	0.99687	.7	0.99660
.8	0.99735	.8	0.99710	.8	0.99684	.8	0.99657
.9	0.99732	.9	0.99707	.9	0.99681	.9	0.99654
27.0	0.99652	28.0	0.99624	29.0	0.99595	30.0	0.99565
.1	0.99649	.1	0.99621	.1	0.99592	.1	0.99562
.2	0.99646	.2	0.99618	.2	0.99589	.2	0.99559
.3	0.99643	.3	0.99615	.3	0.99586	.3	0.99556
.4	0.99641	.4	0.99612	.4	0.99583	.4	0.99553
.5	0.99638	.5	0.99609	.5	0.99580	.5	0.99550

T (°C)	ρ_w (g/ML)	*T (°C)*	ρ_w (g/ML)	*T (°C)*	ρ_w (g/ML)	*T (°C)*	ρ_w (g/ML)
.6	0.99635	.6	0.99607	.6	0.99577	.6	0.99547
.7	0.99632	.7	0.99604	.7	0.99574	.7	0.99544
.8	0.99629	.8	0.99601	.8	0.99571	.8	0.99541
.9	0.99627	.9	0.99598	.9	0.99568	.9	0.99538

Table A.4 Values of Effective Depth Based on Hydrometer and Sedimentation Cylinder of Specified Sizes (Standard, 2007)

Hydrometer 151H			
Actual Hydrometer Reading	Effective Depth, L, cm	Actual Hydrometer Reading	Effective Depth, L, cm
1.000	16.3	1.020	11.0
1.001	16.0	1.021	10.7
1.002	15.8	1.022	10.5
1.003	15.5	1.023	10.2
1.004	15.2	1.024	10.0
1.005	15.0	1.025	9.7
1.006	14.7	1.026	9.4
1.007	14.4	1.027	9.2
1.008	14.2	1.028	8.9
1.009	13.9	1.029	8.6
1.010	13.7	1.030	8.4
1.011	13.4	1.031	8.1
1.012	13.1	1.032	7.8
1.013	12.9	1.033	7.6
1.014	12.6	1.034	7.3
1.015	12.3	1.035	7.0
1.016	12.1	1.036	6.8
1.017	11.8	1.037	6.5
1.018	11.5	1.038	6.2
1.019	11.3		

A.2.2. Cumulative percent passing

Cumulative percent passing when using hydrometer

$$\%F = \frac{G_s}{G_s-1} x \frac{R_c}{W_s} x100$$

Where:

G_s = Spacific density of sample

R_c = Hydrometer reading after calibration

W_s = Dry soil weigh used to do hydrometer experiment, g

Cumulative % passing for all process (hydrometer and sieves)

$$\% F' = \%F \text{ x } F_{200}$$

Where:

%F = Cumulative Percent passing when using hydrometer, %

$\%F_{200}$ = Percent Passing the No. 200 (75-µm), %

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