CHAPTER 4

DISCUSSION

Acidity is commonly measured by pH values. Theoretically, pH of natural rainwater is 5.6. pH of rainwater depends on several factors including the presence of acidic substances in the atmosphere. Increasing conductivity of rainwater is associated with decreasing pH. Babich *et al.*, (1980) considered rainwater having pH values below 5.6 to be acid rain.

Natural rainwater collected in Chiang Mai during the study period (May to August of 2002) was neutral, having a pH ranging from 6.9 to 7.1 ($pH < 5.6$), and EC ranging from 17.6 to 66.4 μS/cm.

Simulated acid rainwater prepared in this study had pH's of 2, 2.5, 3, 4 and 5 and EC between 77.93 and 5015 μS/cm.

Among the various chemical elements present in precipitation, cations and anions deserve special attention. Since SO_4^{2-} is the acid-forming species, most widely mixed in simulated rainwater by adding sulfuric acid, it is of principal relevance to acid rain (pH less than 5.6). The acidity in rainwater can lead to increase leaching from soil of calcium and other nutrient elements which could damage vegetation. However, in this study showed that calcium actually increased in the soil with increasing acidity. The impacts on soil and plants of this simulated rainwater, with different pHs varied depending on the ionic species such as Cl^-, NO_3^- SO_4^{2-}, Na^+ , K^+, Mg^{2+}, Ca^{2+} and PO_4^{2-}, and their concentrations in the rainwater. In this study concentrations of cations and anions in the natural rainwater, Na^+, NH_4^+, K^+, Mg^{2+},

Ca^{2+} and Cl^-, NO_3^- and SO_4^{2-} are very low and were not dangerous to the environment, compared with WHO's drinking water standards as shown in Table 4.1.

Only the simulated acid rainwater at pH 2.0 exceeds than the WHO's drinking water standards for SO_4^{2-}.

Table 4.1 Comparison of rainwater to WHO's drinking water standard

Parameters	**Concentration of Anions in this study (ppm)**	
	Cl^-	SO_4^{2-}
Natural rainwater	0.65-1.11	0.90-2.05
Simulated rainwater Control	1.23	3.08
pH 5.0	1.07	13.47
pH 4.0	26.81	202.73
pH 3.0	50.27	210.3
pH 2.0	71.95	2,182.96
WHO's drinking water standard	250	250

The agricultural suitability of water is determined by the concentration of three constituents; sodium, chloride and boron. Table 4.2 shows the classification of water by toxic constituents. For irrigation water, both sodium and chloride should be less than 4 and 3.5 meq/l, or equivalent to 92 ppm and 124.25 ppm, respectively. Therefore, in this study rainwater was ranked as excellent, because the Na^+ and Cl^- concentrations in natural rainwater ranged between 0.02-0.04 and 0.02-0.03 meq/l, while concentrations in simulated rainwater ranged between 0.02-0.24 and 0.03- 2.03 meq/l, respectively.

Table 4.2 Classification of water by toxic constituents

Classification	Concentration of constituents	
	Na (meq/l)	**Cl (meq/l)**
Excellent	less than 4	less than 3.5
Good to very good	4-6	3.5-4.5
Fair to good	6-7	4.5-5.5
Poor to fair	7-9	5.5-7.5
Very poor to possibly injurious	9-12	7.5-10
Very poor to possibly injurious	12-16	10-14
Injurious to unsuitable if used over a prolong period of time	Over 16	Over 14

The first physiological impact of acidity on the plants occurred at the germination stage and continued with the growing stage, flowering stage and yield stage. The percent germination of seeds was highest in treatments with natural rainwater, pH 5.0, pH 4.0 pH 3.0 and pH 2.5 while pH 2.0 had the lowest (Table 3.1). The degree of impact was depend on the levels of acidity. Low germination rate of seed plants was found in acidic conditions with the lowest percent of germination rate in plants treated with simulated rainwater at pH of 2.0. However, the effect on the germination rate was different among plant species and sensitivity of plant to acid. The lowest germination rate was found in tobacco while the highest rate was observed in pole bean. This result was supported by the study of Lee and Weber (1979) of eleven plant species subjected to simulated acidic rainwater having pH values from 3.0 to 5.6 which showed significant stimulation of germination for five species at pH of 3.0.

After germination different plant growth rates were observed. All plants treated with low pH at pH 2.0 grew taller than with other treatments except pole bean, which grew less tall in treatment groups. This means acidic substance in simulated rainwater influenced plant height because it may be supplied sulfur which essential for plant food to the soil and helps to plant growth.

In this study, there were no differences in plant weight among plants subjected to natural rainwater and strongly acidic rainwater, except pole bean and tomato plants, which had more weight compared with the control and pH 2.0, respectively. This result can indicates that acidic rainwater increased acidity in the soil but did not reduce nutrients. In the case of tomato, which had higher weights with treatment at pH 2.0, this was because only one tomato plant survived at pH 2.0 in each pot, while with the other treatments many plants survived. In the treatment with pH 2.0, tomato survived in only two pots and the other three died. Therefore, the tomato plant survived could absorb more nutrients from the soil, due to reduced competition.

In addition, plants treated with strongly acidic rainwater were also affected with visible symptoms and impact on yields. In this study, plants responded to acidic rainwater in two ways; 1) there were physiological damages to the plant tissues such as leaves, stem and yield decline and 2) there were a chemical processes in soil and soil water, which accumulated high acidity and plants roots absorb to stem and leaves (Figures 3.1, 3.2 and 3.3). Therefore, acidic rain can affect plant growth in two ways; 1) can cause physiological damage to the cell tissues of the plants and 2) can interfere with the ability of plant to take up nutrients in the soil. The effect depends upon how acidic the precipitation is and the sensitivity of the plants. Young plants are more susceptible, but each type of plant responds differently. Some plants adapted to be more tolerant to changes in environments, including variability in pH. This results suggested that all plants species were relatively tolerant to exposure to acidic rainwater at pH 3.0 or higher. Excess acidity in the soil can release trace metals which harmful to plant growth and reduce absorption of necessary nutrients. Beside pole bean, the growth of all plants in term of height were decreases with decreasing of pH (Table 3.2). The direct adverse effects on plants were also observed by Ponnamperuma *et al.,* (1973) from rainwater having strong acidity of pH 3.5 to 4.0. Because plant were wither and their leave fall into the ground when they exposed to strong acid rain.

Table 3.3, plants in particular tobacco demonstrated higher growth as pH was increased. All plant species, except tomato, had higher fresh weight in treatments higher than pH 2.0. The weight of plants exposed to simulated rainwater with pH 2.0 decreased significantly, due to defoliation of scale leaves associated with the development of necrosis. This suggested that soil acidification stress, due to acidic precipitation, was not sufficient to induce plant growth reduction.

Different effects were found with different plant species and plant tissues. Young roots and leave shoots were typically very sensitive to low pH conditions because they could not resist strong acid rainwater. Young plants treated with normal rainwater and rainwater with pH 5.0, pH 4.0 and pH 3.0 did not show as greater impact as with pH 2.0 (Figures 2.3 and 3.1). However, the other aspects of the plant can be harmed as well. Most of the tomato plants in the study that were treated with simulated rainwater at pH 2.0 died in the second week after germination, leaving only one plant in each pot. This mortality was caused by high concentrations of sulfuric acid in simulated rainwater. The acid entered into leaves, stem and elsewhere by absorption from soil and direct exposure to watering and also had high concentration of SO_4^{2-} in soil. Moreover, the impacts on surviving tomato plants were occurred on growth rate, visible impact on stem and leaves, including shape of yield. Injury of soybeans when watered with simulated acidic rainwater was significantly higher than for other plants that received an acidic treatment of pH of 3.0(Banwart *et al.*, 1990). Raynal *et al.,* (1982) indicated that, at least for some species, seed germination is less sensitive to acidic precipitation than subsequent seedling establishment. However, seed germination in all plants species were unaffected by the acidic treatment.

At the seedling stage and mature stage, some spots were found on the plants, especially plants watered by simulated rainwater of pH lower than pH 3.0. White, black and brown spots were found on the stems, leaves, flowers and yields. When leaves lose their coating, the plant was open to any possible diseases. By damaging the leaves, the plant cannot produce enough food energy for it to remain healthy. This impact was also reported by Kuja *et al.,* (1986) in the study to determine the effects of simulated acidic rainwater on seed germination, seedling establishment, and early stages of plant growth. Visible foliar injury was observed only at pHs of between 3.0 and 2.6. Simulated acid rainwater at pH of 2.0 had visible foliar injuries, but at pH of 3.0 or higher there were no visible symptoms (Kohno *et al.*, 1995). Moreover, observations in this study found that all plants under those treatments produced some yield, however some of a small size and abnormal shape were found in plants watered by simulated rainwater with low pH than high pH.

In this study, plants were found to be sensitive to rainwater of pH below 3.0 as shown in the result on visible impact on plant (Figures 3.2, 3,3 and 3.4). The typical symptoms were necrotic spots, or necrosis, marginal and tip necrosis, and defoliation.

Exposure to extremely low pH of simulated rainwater at pH 2.0 or pH 2.5 induced necrotic lesion or spots. Exposure to simulated rainwater at pH 2.0 or 2.5 caused severe acute leaf necrosis. Plants defoliated and regenerated new leaves. However, further continuous exposure to simulated rainwater induced another necrosis and leaves did not have enough time to recover from injuries. Thus, leaves became shorter or smaller in size than the normal. This suggested that if short term exposure would be terminated, plants could recover from injuries due to extremely low pH and they could re-grow normally. Therefore, it is important to clarify when plants have been exposed to acidic precipitation, how frequently for, how many hours or the amount of precipitation have been exposed to plants. In this study, all plants species did not show any visible symptoms at pH 3.0 or higher than pH 3.0 for 3-4 months exposure to simulated rainwater. This results suggested that all plants species were relatively tolerant to exposure to acidic rainwater at pH 3.0 or higher. These wide differential responses in seed germination, plants growth and plant impact may be due to different sensitivity to soil stress, soil chemical conditions or nitrogen uptake efficiency by input of acidic precipitation. These results suggest that natural rainwater with the current acidity, could not cause growth reduction in any of the species tested. Rice was quite tolerant to acid input while tomato was the sensitive species because tomato was relatively more sensitive than other plants because they had smallest number to survival.

Most plants grow by absorbing nutrients from the soil. Their ability depends on the nature of the soil such as soil texture, soil acidity and nutrients available to plants. In this study found fewer amounts of plant nutrients supply in soil and caused to visible symptoms of foliar damage.

Acidic rainwater is able to mobilize cations from the soil in two ways; 1) H^+ ion in acidic water displaces other positive ions from their binding sites and increases this concentration in soil water. When soil particles are no longer able to bind anymore H^+ ions, the concentration of H^+ in soil water also increases and 2) sulfate and nitrate ions (negatively charged) in acid rain act as "counter-ions" which allow positive ions to be leached from the soil. The mean SO_4^{2-} concentration in simulated rainwater treated at pH 2.0, pH 3.0, pH 4.0 and pH 5.0 were high at 2,182.96, 210.35, 202.73 and 13.47 ppm, respectively (Table 3.9).

Soil pH is one of the most important soil properties in soil that effects the availability of nutrients. After application of simulated acidic rainwater for a period of about four months, the soil treated with rainwater at pH 2.0 became more acidic which was not suitable for most plants. The pH of soil is critical to the health of vegetation and soil microorganisms since it determine the availability of nutrients to plants. In Table 3.10 shows that soil treated with rainwater pH 2.0 had mean lowest pH at about 5.07, and pH ranging from 4.79 to 5.24, whereas soils with other treatments had pH ranging from 6.24 to 6.60. This suggests that soil pH with pH 2.0 was classified to very strongly acid, because Sparks (1995) showed soil pH ranged between 4.5-5.0 was very strongly acid, and strongly acid had pH ranged between 5.1-5.5 (Table 4.3). Major nutrient tend to be less available in soils with low pH and minor nutrient will less available in soil with high pH (Sparks,1995).

Table 4.3 Classification of soil acidity

Terms/Description	pH range
Extremely acid	< 4.5
Very strongly acid	4.5-5.0
Strongly acid	5.1-5.5
Moderately acid	5.6-6.0
Slightly acid to neutral	6.1-7.3
Slightly alkaline	7.4-7.8

Source: Sparks, 1995

Large inputs of acid deposition will cause soil acidification. Soil analysis data can indicate the chemical composition of the watering used. Soil samples treated with natural rainwater and simulated rainwater were analysed for nutrients such as Na^+, K^+, Mg^{2+}, Ca^{2+}, PO_4^{2-} and SO_4^{2-}. Low levels of all nutrients were found, except SO_4^{2-} which was quite high. Tables 3.11-3.14 shows Na^+, K^+, Mg^{2+} and Ca^{2+} in soil treated with different pH's of rainwater. There were no differences among treatments for Na^+, K^+ and Mg^{2+}, except for Ca^{2+} which significantly increased at pH 5.0 compared with the control treatment. In general, soil provides a neutralizing capacity, however after prolonged exposure to acid rain, soil will loose this buffering capacity. The ability of soil to buffer acid rain is dependent upon several factors, including soil type, the pH of acid precipitation and the duration and frequency of these acid events. Soils that contain alkaline material such as limestone or calcite, have a better ability to neutralize acid rain, while soils containing materials such as granite rocks provide a poor buffer to the acid rain (Sekiguichi,1987).

Results from chemical analysis of soil showed lower concentrations of Na^+, K^+, Mg^{2+} and Ca^{2+}, compared with general nutrients in soil recommended by the Department of Agriculture and the Cooperative Promotion, Thailand (Table 4.4). The probability of soil acidity contributing directly to plant growth problems on some acidic sulfate soils was reported by Brinkman and Pons (1973) as well.

In addition, the study found SO_4^{2-} in soil planted with pole bean and tomato treated with pH 2.0 were high at 23.37 and 14.66 ppm, while both plants treated with natural rainwater had SO_4^{2-} at 0.34 and 0.32 ppm and there were significant differences at p value less than 0.05 level. Acidic in soil was increase by simulated rainwater at pH 2.0 between 44-67 times of former concentration. This is suggested to be dangerous to the environmental, especially plant (Table 3.16).

Soil acidity causes phosphorus in the soil to become less available to plants, deficiency of calcium, magnesium and the ability of plants to use nutrient will be limited. Moreover, uptake by crop plants of SO_4^{2-} may increase because in the analysis of plants tissues found very high SO_4^{2-} concentration (Table 3.23).

In contrast, soil pH treated with normal rainwater, pH 5.0, pH 4.0 and pH 3.0 were classified to slightly acid to neutral because pH ranged between 6.24-6.60 (Table 4.2). Plants grown in the nutrient solution at pH ranged of 2-3 showed some growth reduction different other. This suggested that these plants species have a great adaptability to low pH condition. Although tomato and pole bean were only cases study, they suggest that a possible wide significant difference in sensitivity and potential adaptability to soil acidity and its related chemical properties, prior to releasing lot of inorganic at low pH ranged. Adverse effects were found in plant, treated with low pH after the plants received simulated rainwater at pH 2.0 for growing to seedling, pole bean, tomato, cucumber even though rice showed severe impacts on growth reduction and plant performance (Figures 3.2, 3.3 and 3.4).

There are mineral nutrients that come from the soil, are dissolved in water and absorbed through a plant's roots. The mineral nutrients are divided into two groups: major nutrients and minor nutrients. Nitrogen, phosphorus and potassium are the primary major nutrients and they are usually lacking from the soil because plants use large amounts for their growth and survival. Calcium, magnesium and sulfur are the secondary nutrients. There are usually enough of these nutrients in the soil. Boron, copper, iron, chloride, manganese, molybdenum and zinc are minor elements essential for plant growth which are needed in only very small quantities (Kooten *et. al,* 2002).

The results of nutrients in the soil are presented in Tables 3.12-3.18. Data show that Ca^{2+}, Mg^{2+} and K^{+} in soil were deficient, PO_4^{2-} was moderately high and SO_4^{2-} quite highest.

Department of Agriculture and the Cooperative Promotion, Thailand determined the soil quality classifications that present nutrients concentrations in soil as shown in Table 4.4. This study found nutrient concentration in all soil samples considered to medium to low because treatment mean of phosphorus and potassium were ranged 14.70-16.12 and 0.33-0.38 ppm (Tables 3.13 and 3.16).

Table 4.4 Nutrients concentrations in soil

Type of nutrients	Soil quality classification		
	low	medium	High
Organic matter (%)	< 1.8	1.8-3.0	> 3.0
Phosphorus (ppm.)	<10	10-30	>30
Potassium (ppm.)	<40	40-100	>100

Source: Department of Agriculture and the Cooperative Promotion, 1998.

Soil quality has been divided into seven classes by observing on nutrient concentrations (Table 4.5). The comparison of the soil result from the study to Table 4.5 found that soil considered to moderately high phosphorus and it rate was sufficient to plant growing and production. But it was considering to low and moderately sodium and it should be improve by fertilizer. Calcium and magnesium were considered to low and have to improve. Potassium was the lowest and lack of this nutrient was not suitable for plant growth (Tables 4.6- 4.8). Soil with pH 6.0-7.0 will enrich available phosphate benefited to plant (Department of Agriculture and the Cooperative Promotion, 1987). Therefore, the quality of soil in this study was insufficient for good plant growth.

Thus, the soil should be improved by using lime. The application of fertilizers to the soil would add nutrients available for plant and a large amounts of calcium and magnesium are added when lime is applied to acidic soils. Acid rain could unlock acidity, nutrients and toxic metals that were bound in the soil. This study found high concentrations of SO_4^{2-} in the soil (Tables 3.17 and 3.24). Toxic metals, leached from soils, are very important to the welfare of green plants. Through a series of chemical reactions, important ions such as K^{+}, $Ca^{2+,}$ Mg^{2+} and Na^{+} are leached out and become unavailable to plants as nutrients. Since the experiment found high concentration nutrients, including high SO_4^{2-}, in plants tissue, it suggests that plants absorbed nutrients with acidic SO_4^{2-} ions.

Table 4.5 Classification of soil concentration

Chemical Characteristic of soil	**lowest**	**low**	**moderately low**	**moderate**	**moderately high**	**high**	**highest**
Base Saturated (%)		<35		35-75		>75	
Exchangeable base cation: ECECmol/kg)	<3	3-5	5-10	10-15	15-20	20-30	>30
Exchangeable Anions (Cmol/kg)							
-Calcium	<2	2-5		5-10		10-20	>20
-Magnesium	<0.3	0.3-0.6		1-3		3-8	>8
-Sodium	<0.1	0.1-0.3		0.3-0.7		0.7-2	>2
-Potassium	<0.2	0.2-0.3		0.3-0.7		0.6-1.2	>1.2
-Organic matter (%)	<0.5	0.5-1.0	1.0-1.5	1.5-2.5	2.5-3.5	3.5-4.5	>4.5

Source: Aerb, 1983.

Table 4.6 Comparison of soil concentrations in this study with soil classification

Type of nutrients	Soil concentration in this study		Soil quality classification
	ppm (mg/kg)	Cmol/kg	
Phosphorus	14.70-16.12	-	moderately high
Sodium	0.10-0.94	0.05-0.44	low to moderate
Calcium	4.61-6.84	2.49-3.69	low
Magnesium	0.42-0.55	0.37-0.49	low
Potassium	0.33-0.38	0.09-0.10	lowest

Table 4.7 Available phosphorous in soil to plant

Phosphorous (ppm)	Classification	Recommendations
< 3	lowest	extremely improve
3-6	low	improve
6-10	moderately low	consider to improve
10-15	moderately	suitable for some plant
15-25	moderately high	sufficient for general plant
25-45	high	sufficient for some plant
>45	highest	sufficient

Source : Mongkol and Somrit, 1996

Table 4.8 Available potassium in soil to plant

Potassium (ppm)	Classification	Recommendations
< 30	lowest	lacking
30-60	low	Sufficient for some plant
60-90	moderately low	Sufficient for general plant
90-120	moderately	sufficient

Source : Mongkol and Somrit, 1996

The most important result of this study was sulfate in soils. It was present at very high concentrations, especially in soils watered with simulated rainwater at low pH. The simulated rainwater having pH of 2 had the highest sulfate concentrations. Table 3.17 shows concentration of sulfate in soils treated with pH 2.0 was very high compare with other treatment and it ranged between 6.14-23.37 ppm, while in control treatment it ranged between 0.31-0.60 ppm. There is not the limit of sulfate value in soil yet, but the Land Development Department suggested that more than 100 ppm of sulfate in soil is high level. High sulfate caused by sulfuric acid added into the simulated rainwater to vary the pH levels and it might be that damaged soil properties and nutrients in the soil. The sulfuric acid lowers pH made several soil nutrients less available to plants. This suggested that SO_4^{2-} concentration fluctuated with the soil pH, carrying plant to absorb SO_4^{2-} into their tissue as shown in table 3.24. Pole bean and tomato had high concentration of SO_4^{2-} with treated by simulated pH 2.0 at p value less than 0.05 level. Acid dissolves from the soil and become available to plants in toxic quantities. These conditions reduce plant growth, and only acid-tolerant plants can survive and few plants can grow where acidity is as low as pH 2.5

(Bashkin and Park, 1998). The hydrogen ions in the sulfuric acid trade places with the metal ions. The hydrogen ions are retained and neutralized by the soil. Calcium, potassium, and magnesium ions are leached from the soil profile or washed out of into lower subsoil and leaving behind more concentration of sulfate. Then, these ions are not available, as nutrients needed for plant growth because it was very high at 23.37 ppm.

The data in Table 3.18 show that total soil nitrogen in all treatment averaged between 0.18-0.23 percent. Nitrogen in soil and plant were not different significant between treatments at p value more than 0.05 level. Table 4.9 shows the classification level of total that suitable for plant. The suitable level was ranged between 0.125-0.225 percent. This means that total soil nitrogen in this study was at a high level and enough for plant to use it as nutrient. Total nitrogen in plant tissues ranged between 0.66-0.94 percent (Table 3.25). This means there was a sufficient amount than plant requires and it will effect to stem. It will be bigger stem and high weight.

Table 4.9 Classification level of total nitrogen in soil

Total nitrogen in soil (%)	Classification	Recommendations
< 0.025	Lowest	extremely Lacking
0.025 – 0.050	Low	lacking
0.050 – 0.075	moderately low	need to add nutrients
0.075 – 0.125	Moderately	enough for some plant
0.125 – 0.175	moderately high	enough
0.175 – 0.225	high	enough
> 0.225	highest	enough

Source: Mongkol and Somrit, 1996

The calculation of nutrient ratio in plant (nutrient in plant/nutrient in soil) did not differ greatly among Na^+, K^+, Mg^{2+}, Ca^+, PO_4^{2-} and nitrogen in plant treated with control, pH 5.0, pH 3.0 and pH 2.0, except SO_4^{2-} that showed greatly different between treatments.

Na^+ ratio in pole bean subjected with pH 3.0 was higher than pH 2.0, pH 5.0 and control treatments, respectively. While tomato subjected pH 3.0 was higher ratio of Na^+ than control, pH 2.0 and pH 5.0 treatments (Table 4.10). However, Na^+ is not most useful for plant because it is not a macro nutrient or micro nutrient.

Mg^{2+} ratio in pole bean was higher with control treatment than pH 3.0, pH 2.0 and pH 5.0, while in tomato plants showed higher ratio in treatment with pH 2.0 than pH 3.0, control and pH 5.0 (Table 4.10).

Ratio of K^+ in pole bean plant showed higher in pH 3.0 than pH 5.0, pH 2.0 and control treatments, while in tomato plant had higher ratio at pH 3.0 than pH 5.0, pH 2.0 and control treatments (Table 4.10).

Ca^{2+} ratio in pole bean was higher in control than pH 3.0, pH 5.0 and pH 2.0, while in tomato plant showed higher ratio in control than pH 3.0, pH 2.0 and pH 5.0 (Table 4.10).

Ratio of PO_4^{2-} in pole bean was lower in control than pH 5.0, pH 3.0 and pH 2.0, while in tomato plant showed lower ratio in pH 2.0 treatment than control, pH 3.0 and pH 5.0 treatments (Table 4.10).

Sulfur is an essential nutrient for plans food for production of protein. Sulfate is the second most abundant element (after nitrogen) taken up from the soil and metabolized. Sulfur showed clear decreasing ratio of nutrient in pole bean and tomato, particularly in the treatment with pH 2.0. Sulfur concentration was ranged between

68.2-165.17 ppm and pH 2.0 had highest concentration (Table 3.24). Pole bean and tomato treated with pH 2.0 had sulfur at 145.25 and 195.06 ppm, respectively. While, in the control treatment treated with normal rainwater were 63.56 and 72.85 ppm. SO_4^{2-} ratio in pole bean was higher with control treatments than pH 5.0, pH 3.0 and pH 2.0, respectively while in tomato showed higher ratio in control than pH 5.0, pH 2.0 and pH 3.0 treatments (Table 4.10). In this study, pole bean and tomato had higher sulfur in plant tissue than others benefit nutrients. The ratio of sulfur in pole bean and tomato treated with pH 2.0 exhibited higher sulfate levels, because in the soil, higher sulfate levels were found in treatment with pH 2.0 and plant absorbed sulfur instead of nutrients. High concentrations of sulfur in plants are toxic and can damage or sicken, as well as kill the plants. Evidence of the impact were observed for both pole bean and tomato grown in acidic soil watered by low pH simulated rainwater and sulfate was found at high levels in soil and plant tissues. Low pH levels also accelerated the release of anions such as sulfate. Moreover, sulfate accumulated in the soil was absorbed by plants and accumulated in plant tissues, especially in the leaves. The uptake of sulfate into roots and subsequent transport system to leaves are mediated by sulfate transporter. In the case of sulfate soils, Department of Agriculture and the Cooperative Promotion recommend using lime for change sulfuric acid soil to be neutral soil.

However, the data of nutrients ratio presented that pole bean and tomato plant were absorb enlarge amount of sulfur from soil. The ratio of sulfur in pole bean and tomato treated with pH 2.0 was 6.21 and 13.31, respectively while plants treated with control treatments had ration at 186.94 and 227.66 respectively. Therefore, acidic could blocked other nutrients and presented damaging symptoms in plants.

Total nitrogen ratio in pole bean plant was higher in pH 3.0 than pH 5.0, control and pH 2.0, respectively while in tomato showed higher ratio in pH 5.0 than in pH 2.0, control and pH 3.0, respectively (Table 4.10).

Table 4.10 Nutrients ratios in pole bean and tomato plants

Nutrients	**Control**		**pH 5.0**		**pH 3.0**		**pH 2.0**	
	Pole bean	Tomato	Pole bean	Tomato	Pole bean	Tomato	Pole bean	Tomato
Na^+	2.13	7.33	2.15	4.40	5.13	11.71	3.09	6.60
K^+	15.74	10.33	19.16	11.42	21.54	12.71	18.37	10.46
Mg^{2+}	196.89	33.98	105.76	33.17	180.89	36.16	171.30	55.13
Ca^{2+}	4.68	3.28	3.13	2.20	3.68	2.67	2.54	2.31
PO_4^{2-}	0.01	0.03	0.02	0.02	0.02	0.03	0.02	0.01
SO_4^{2-}	186.94	227.66	42.13	161.36	8.76	13.25	6.21	13.31
Total-N	3.57	3.00	4.55	4.19	4.58	2.43	3.21	3.70

In this study, sulfate was found in both normal rainwater and simulated acid rainwater but at different concentrations. Na^+, K^+, Mg^{2+} and Ca^{2+} were lacking from the soil, and should be improved by fertilizer. The results of this study found that soil acidification was induced by acidic rainwater within three to four months. Plant cloud access high sulfate concentration in soil water, and the uptake of sulfate by the root was partially inhibited. Sulfur saturation also effects to plant growth, therefore pole bean and tomato in this study absorbed more of sulfur and saturated with sulfate. The sulfate uptake in these plants might be related to a high sulfate content in combination with an accumulation in the soil and transport to plant by plant roots.

The threshold of pole bean and tomato plants to acidic rainwater was found at rainwater pH higher than 3.0, and soil with pH higher than pH 6.0. The lower pH in rainwater at pH 2.5 and 2.0, including lower of soil at pH 5were effected to plant growth and yield.

Plants derive their primary nutrition from element ions such as calcium, magnesium and potassium that have dissolved from soil. Acidic rainwater adds hydrogen ions, which displace these important nutrients in a process of leaching. Leaching means that the ions are washed deeper into the subsoil or washed out of the top soil. If ions are leached from the soil, they are no longer available to the roots of the plants (Kooten *et. al,* 2002).

In addition, potassium also absorbed by plants in larger amounts than any other mineral element except nitrogen and, in some cases of calcium. Sulfur can reduce growth and their production including the chance of survival of the plants. Because in this study found the reduction of plant growth and reduction of plant's production, especially in plant treated with lower pH than 3.0. Because concentration of sulfur in plant including sulfate in soil which grown the plants were very high. The majority of plants do best in a pH of about 6.5 and in this study also found soil pH was ranged 6.4-6.5 except soil treated with low pH at 2.0 that contain soil pH at 4.8-5.2. Concentration of Na^+, K^+ Mg^{2+} and Ca^{2+} in plants tissue of pole bean and tomato cultivated at normal rainwater and simulated rainwater with pH 2.0, pH 3.0 and pH 5.0 showed no significant differences at all.