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THE CHEMISTRY AND FERTILITY OF SOILS UNDER TROPICAL WEEDS

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The Chemistry and Fertility of Soils

Under Tropical Weeds

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Abdul Kadir Salam and Nanik Sriyani – 2019

Dedicated to my son and daughter
Fiqi and Rahma
~ with a sincere love

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PREFACE

Weeds are distinct due to some of their characteristics in the soil environment. In addition to the fact that they are destructive to crops, and therefore they are undesirable in cultivated land, weeds are more importantly very competitive. Their competitiveness is not only physically and biologically but also chemically.

A great deal of researches reveals that the presence of weeds modifies the chemistry and fertility of soil environment. The chemistry and fertility of soils affected by weeds may include soil reaction and other soil properties affected by the changes in soil pH like the soil cation exchange capacity, the soil enzymatic activities such as those of phosphatases, ureases, arylsulfatases, and β-glucosidases, the soil exchangeable potassium, the soil organic carbon, phosphorus, nitrogen, and sulfur contents, and the heavy metal solubility. This book deals with these kinds of soil chemical and fertility properties under various tropical weeds mostly investigated in the Province of Lampung Indonesia.

Gratitude is extended to the institutions supporting each of the research: the University of Lampung and the Japanese Society for the Promotion of Science, all students participating in each research, and also my colleagues in the Department of Soil Science the University of Lampung for their invaluable participation, suggestion, and criticism. We hope this concise book may contribute something to the fast growing science particularly in tropical agriculture.

Bandar Lampung, 6 June 2019

AKS/NS

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Chapter 1

Introduction

1.1 The General Chemistry of Soils
1.2 Weed Effects on the Chemistry and Fertility of Soils
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Key Questions

It is well known that weeds are very distinct due to some of their characteristics in the soil environment. In addition to the fact that they are destructive to crops, and therefore they are undesirable in cultivated land, weeds are more importantly very competitive. Their competitiveness does not only physically and biologically but also chemically affect the soil environment. There are a great deal of researches reporting the effects of weeds on soil chemical and fertility properties such as soil pH (Salam et al., 1997a; 1997b; 1997e; 2018; Ontia, 2018), soil cation exchange capacity (Sembodo et al., 2012; 2017), soil organic C or organic matter contents (Sembodo et al., 2012; 2017), soil total N (Sembodo et al., 2012; 2017), soil P (Sembodo et al., 2012; 2017), and soil S, soil exchangeable K (Salam et al., 2019), soil heavy metals (Fe, Mn, Zn, Cu, and Pb) (Salam, 1999), and soil enzymatic activities (Salam, 1996; Salam et al., 1997a; 1997b; 1999b).

Some of these soil chemical properties are directly and some are indirectly affected by weeds. Soil pH is directly affected by the root excretion of H^+ and organic acids (Song and Huang, 1988; Walker et al., 2003; Calvaruso et al., 2010). The degree of excretions is dependent on weed species. For example, soil planted with *Arachis pintoi* is reported to show lower ambient soil pH than is that planted with *Pennisetum purpureum* (Lestari, 2018; Ontia, 2018; Salam et al., 2019).

Soil exchangeable K is indirectly affected by the presence of weeds, particularly related to the decrease in the ambient soil pH that may ease the detachment of some weakly held structural K attacked by H^+ ions (Salam et al., 2019). The excretion of soil enzymes by weed roots (Duxbury and Tate III, 1981; Bolton et al., 1985; Reddy et al., 1987; Rejsek, 1991; Sakai and Tadano, 1993; Joner et al., 1995; Salam, 2014; 2017) may also ease the detachment of part of the organically bound K into the soil solution.

1.1 The General Chemistry of Soils

Soil is a complex and dynamic chemical system comprising a matrix containing solid (mineral and organic matters), liquid (solution), and gas (air) component with ions (cation and anions) and molecules dissolved in soil liquid dynamically interacting with those attached to or structurally bound in soil solid and those contained in soil air. Parts of ions and molecules in the soil system may chemically converts into any of the soil components in a system. The soil chemical system is basically affected and governed by two major variables i.e. soil pH (soil reaction) and soil E (redox potential).

The effect of pH is apparent in all soils both in dryland and in wetland. Like those in dry land soils which are always oxidative, the role of soil E in wetland soils, which are always reductive, is not significant. The roles of soil E is, however, very obvious in soils subjected to flooding and draining like in paddy soils. Soil is oxidative with high redox potential upon draining and is reductive with low redox potential upon flooding. Draining may cause, for example, the existence of more SO_4^{2-} and less S^{2-} and FeS due to oxidation reaction. Conversely, flooding may cause more S^{2-}, FeS, and low SO_4^{2-}. The effects of draining and flooding on the chemistry of paddy soils are shown in **Table 1.1**. Draining may cause higher Fe^{3+} at low pH and $Fe(OH)_3$ at high pH, and conversely flooding may cause higher Fe^{2+} at low pH and $Fe(OH)_2$ at high pH (Salam, 2017) as shown in **Fig. 1.1**. This shows that the existence of Fe species depends on and is governed by the two major soil variables i.e. soil pH and soil E. Alkalization/acidification and draining/flooding are the important techniques to manage the Fe species and many other heavy metal elements subjected to precipitation/dissolution reactions by OH^- ions and oxidation/reduction reactions.

Table 1.1. Effects of flooding and draining on the chemistry of paddy soils[1].

Condition	Chemical Changes	Effects
Drying	• Redox Potential (E) increases • Oxidative • $[Fe^{2+}]$ decreases • $[Mn^{2+}]$ decreases	• Al-P precipitates • Fe-P precipitates • Mn-P precipitates • Fe, Mn, P insoluble
Flooding	• Redox Potential (E) decreases • Reductive • $[Fe^{2+}]$ Increases • $[Mn^{2+}]$ Increases • $SO_4^{2-} \rightarrow S$	• Al-P dissolves • Fe-P dissolves • Mn-P dissolves • P more soluble • FeS precipitates

[1] Adapted from Bohn et al. (1985)

The magnitude of soil pH and soil E is therefore determine the reactivity and mobility of a particular species of element. Taking Fe as an example, Fe may exist in various species in the soil system depending on the magnitude of soil pH and soil E. Iron may exist as Fe^{2+}, Fe^{3+}, $Fe(OH)_2$, and $Fe(OH)_3$ (**Fig. 1.1**). It may also exist as Fe_2O_3, Fe_3O_4, FeS, FeS_2, etc. (Lindsay, 1979; Salam, 2017).

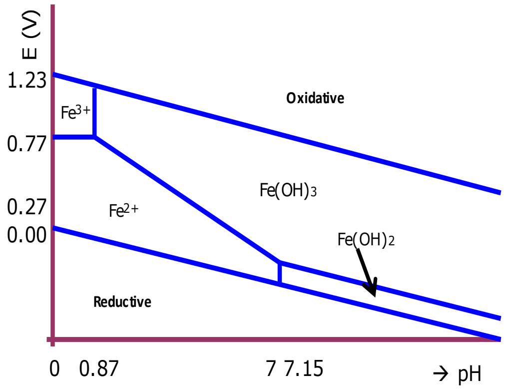

Fig. 1.1. The role of pH and E in governing Fe species in soil water (Salam, 2017).

In dryland soils with low pH, Fe mostly exists as Fe^{3+} and therefore it is very reactive and may probably be toxic to the living things like plants and soil microorganisms. This form may also interact with the soil solid through cation exchange (adsorption/desorption reaction) governed by a cation exchange equilibrium constant. Higher concentration of Fe^{3+} may drive the increase in exchangeable Fe through adsorption reaction and conversely low concentration of Fe^{3+} may drive desorption of exchangeable Fe. The trivalent Fe also show high mobility and therefore it may move in the soil body through mass flow and/or diffusion and leaching by water. These processes may cause plant absorption and translocation of Fe^{3+} in soils. This form of Fe may also be chelated by dissolved organic molecules that may increase its mobility in soils. The fate of Fe^{3+} is described in **Fig.1.2**.

The concentration of Fe^{3+} in soil solution may decrease with the increase in soil pH as shown in **Fig. 1.1** and **Fig. 1.3**. The presence of more OH^- ions with the increase in soil pH by liming (Salam, 2017; Salam, 2019) may cause Fe^{3+} to be precipitated through precipitation reaction forming precipitate of $Fe(OH)_3(s)$. The formation of this Fe species significantly decreases the reactivity and mobility of Fe^{3+} ion. In this form, Fe may not engage in a cation exchange reaction and be relatively toxic. In this form, Fe may also not move through mass flow, diffusion, as well as leaching by water. Lowering the soil pH through acidification may reverse the Fe to Fe^{2+} with its characteristics mentioned previously.

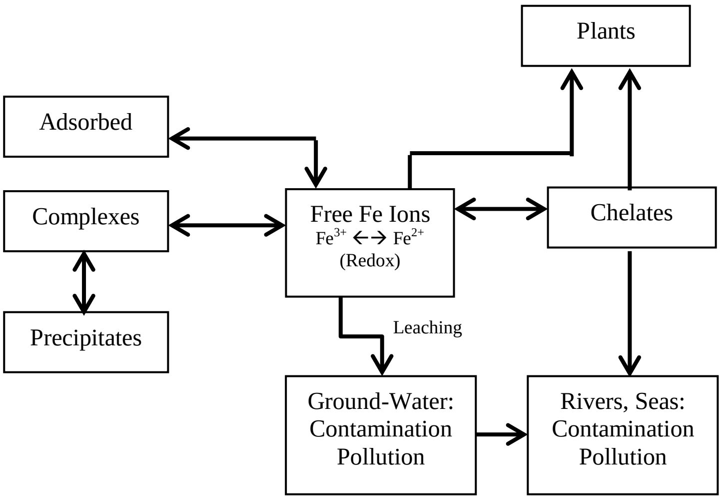

Fig. 1.2. The fates of Fe^{2+} or Fe^{3+} in the soil system (Adapted from Salam, 2017).

In wetland soils where the soil condition is reductive with low redox potential, Fe may exist as Fe^{2+}. This Fe species in some respect is similar to Fe^{3+}. This form shows high reactivity and mobility in soils. Therefore, the fate of this Fe species is similar to that of Fe^{3+} as depicted in **Fig. 1.2**. The Fe^{2+} ion may participate in adsorption/desorption reaction through cation exchange processes (**Fig. 1.2**), may precipitate as $Fe(OH)_2$ as the soil pH increases (**Fig. 1.1**, **Fig. 1.2**, **Fig. 1.3**), may move in the soil body through mass flow, diffusion, or water leaching (**Fig. 1.2**), and be chelated and absorbed by plants (**Fig. 1.2**).

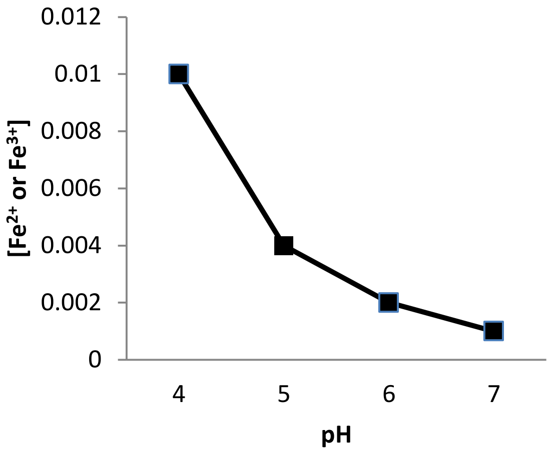

Fig. 1.3. The relationship between Fe^{2+} or Fe^{3+} concentration and soil pH (Adapted from Salam, 2019).

In wetland soils subjected to flooding and drying like paddy soils, Fe and other multivalent cations like Mn, Cu, Hg, and Pb are subjected to oxidation/reduction or redox reaction. As described previously, Fe may exist as Fe^{2+} during flooding at low pH and as $Fe(OH)_2$ at high pH. Conversely, it exists as Fe^{3+} during drying at low pH and as $Fe(OH)_3$ at high pH. Shifting wetland to dryland by draining the water may cause the oxidation of Fe^{2+} into Fe^{3+} and $Fe(OH)_3$. In this case, the chemical reactions involve not only H^+ but also electron as shown by the changes in soil pH and soil E (**Fig. 1.1**). While the chemical reaction of some divalent heavy metals like Fe, Mn, Pb, Hg, and Cu involves both H^+ and e^-, the chemical reactions of major cations (Ca, Mg, K, and Na) in soil water are known to involve only H^+.

Soil pH is proven very influential to other soil chemical properties, clearly shown by liming or acidification, which can be conducted by lime and sulfur treatment, respectively. The presence of more OH^- ion caused by lime treatment may cause the dissociation of bonded H on soil mineral and organic matter functional groups forming water and negative charges on the surface of soil solid. Therefore, increasing soil pH may cause the increase in soil CEC as shown in **Fig. 1.4**. The reverse reaction is usually conducted by application of S. Acidifying the soil using S may increase H^+ ion concentration that may fill the soil negative charges. This process may eventually decrease the soil CEC (**Fig. 1.4**).

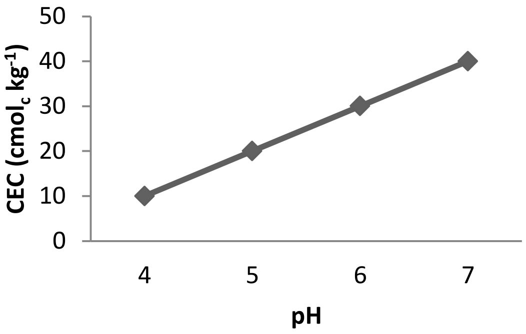

Fig. 1.4. The effect of pH on soil CEC (Salam, 2019).

The increase in the number of soil negative charges or CEC due to the increase in soil pH may increase the amount of exchangeable base cations including exchangeable Ca, Mg, K, and Na and conversely decrease the amount of exchangeable H and Al. By this consideration, the increase in soil pH may definitely increase the soil base saturation due to 3 reasons. The first reason is the increase in the amount of exchangeable base cations. The second is displacement of exchangeable acid cation (H and Al) by base cations. The third is the neutralization of soluble H^+ and Al^{3+}. Hydrogen ions react with OH- ions producing water molecules while Al^{3+} and OH^- precipitate forming $Al(OH)_{3(s)}$.

The changes in soil pH may affect also the concentration of soluble P and S. The presence of more OH^- ion with the increase in soil pH may decrease the concentration of $H_2PO_4^-$ and increase the concentration of HPO_4^{2-} and at high pH the concentration of PO_4^{3-} may dominate (**Fig. 1.5**). However, at high pH P may not be soluble and may precipitate as Ca-P which is not available unless this form of P is released by soil acidification. Acidification is not always beneficial to avail P because the high solubility of Al , Fe, and Mn at low pH may also precipitate P as Al-P, Fe-P, and Mn-P. Metalloids like Mo may show chemical behaviors like those of P (Salam, 2014).

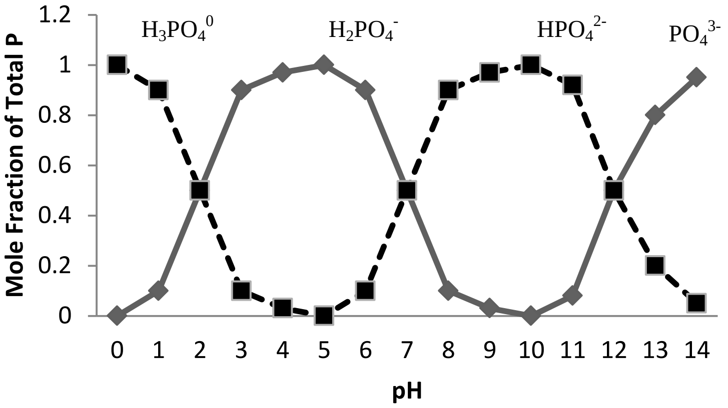

Fig. 1.5. The dependence of P species concentration on soil pH (After Lindsay, 1979).

The soil pH also greatly influences the precipitation/dissolution reaction as shown by the precipitation/dissolution of Fe species where Fe precipitation intensifies with the increase in soil pH due to the increase in OH^- ion concentrations. The precipitation of heavy metal cations may follow **Eq. 1.1**. (Salam, 2017).

Log (M^{2+}) = X – 2 pH ……. Eq. 1.1

where X = log K_{sp} – 2 log (10^{-14}) which is specific for a particular heavy metal cations. This equation show that pH is determining in precipitation/dissolution processes. Scientific reports (Lindsay, 1979; Workman and Lindsay, 1990; Ma and Lindsay, 1990; El-Falaky et al., 1991) show this relationship for several heavy metal cations as shown in **Table 1.2**. The precipitation occurs at low pH when the concentration of heavy metal is high and conversely it occurs at high pH when the concentration of heavy metal is low (**Fig. 1.6**).

The dependence of precipitation/dissolution reaction on pH is shown by the weathering of some soil minerals such as the dissolution of K-feldspars as shown by **Eq. 1.2**. It is clear that the release of K from K-feldspars is dependent on soil pH. The amount releases may be greater at low pH. Salam (1989) reports the pH dependence of soil mineral dissolution from an Ultisol from West Java Indonesia and a Mollisol from Wisconsin USA. The released Ca, Mg, K, and Zn increased with the decrease in soil pH from 7 to 4 buffered by a resin method (**Table 1.3**).

$$\mathbf{KAlSi_3O_8 + 4\ H_2O + 4\ H^+ \leftrightarrow K^+ + Al^{3+} + 3\ Si(OH)_4} \quad \ldots\ldots. \quad \textbf{Eq. 1.2}$$

Table 1.2. The experimental relationships between Cd, Cu, and Zn solubilities with soil pH[1)].

No	Heavy Metal	Equation
1	Cd	$\log (Cd^{2+}) = 6.50 - 2\ pH$
2	Cu	$\log (Cu^{2+}) = 2.80 - 2\ pH$
3	Zn	$\log (Zn^{2+}) = 5.80 - 2\ pH$

[1)] Taken from Lindsay (1979), Workman and Lindsay (1990), Ma and Lindsay (1990), El-Falaky et al. (1991)

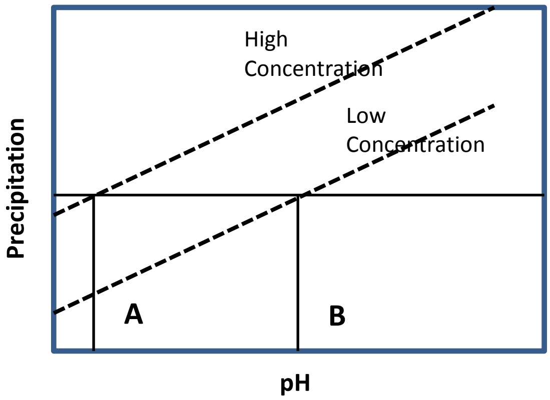

Fig. 1.6. The precipitation of heavy metal cation as a function of pH.

Table 1.3. The dependence of soil mineral dissolution (weathering) on soil pH.

pH	Mollisols*				Oxisols**			
	Ca	Mg	K	Zn	Ca	Mg	K	Zn
	.... mg kg^{-1}							
4	594	271	96	11	26	27	85	6.5
5	540	250	60	10	19	9	50	6.0
6	315	105	48	8.5	12	0	45	5.5
7	204	49	47	7.4	3.0	0	30	4.0

Adapted from Salam (1989); *from Wisconsin USA, ** from West Java Indonesia

Unlike the precipitation/dissolution process, the adsorption/desorption processes are independent of soil pH as described by **Eq. 1.3** (Salam, 2017)

$$\log [M^{2+}] = k + \log [Ca^{2+}] \quad \ldots\ldots \quad \textbf{Eq. 1.3}$$

where k is a constant. This equation shows that the adsorption/desorption process is governed by the controlling cation. The dependence of low metal concentration on soil pH as reported by Salam and Helmke (1998) is an indirect effect of soil pH which increase the soil CEC with increasing soil pH (Salam, 2017).

In addition to the above chemical reactions, there are also enzymatic reactions involving soil enzymes occurring in the soil environment. Soil enzymes are biologically produced by plant roots, microorganisms, and meso-organisms (earthworms) (Hayano, 1973; Alexander, 1977; Ross and Cairns, 1982; Frankenberger, Jr. and Dick, 1983; Baruah and Mishra, 1984; Satchell et al., 1984; Satchell and Martin, 1984; Nasution, 1986; Tate III, 1987; Park et al., 1992; Sakai and Tadano, 1993; Joner et al., 1995; Joner and Jakobsen, 1995; Dharmakeerti and Thenabadu, 1996; Vinotha et al., 2000; Supriatin et al., 2007; Salam, 2014). These biochemical compounds act as bio-catalysts that accelerate the transformation of organically bound elements into inorganic elements. One example are phosphatases that accelerate the transformation of organic P, that is not readily absorbed by plant roots, into orthophosphates ($H_2PO_4^-$ and HPO_4^{2-}) that are readily available to plants as shown in **Eq. 1.4** (Salam, 2014).

$RO—PO_3^{2-} + H_2O \rightarrow R—OH + HO\text{-}PO_3^{2-}$ .... Eq. 1.4

As shown by **Eq. 1.4**, this reaction depends on the availability of organic P and water. Phosphatase accelerates this reaction but does not react with any of the substances in the reaction.

The presence of soil enzymes is of utmost importance related to the cycles of nutrient elements absorbed from soils and accumulated in organic matter. The presence of soil enzymes may accelerate the cycling of nutrient elements such as P, S, and N, which are very important for plant growth. Some of the nutrient cycles are shown in **Fig. 1.7**, **Fig. 1.8**, and **Fig. 1.9** for P, S, and N, respectively.

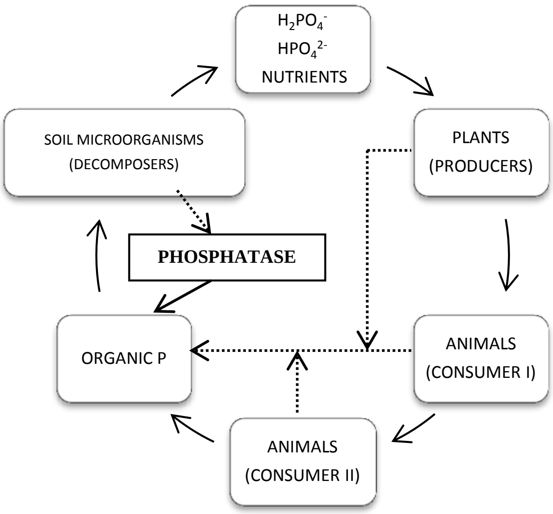

Fig. 1.7. The cycle of P in the soil – plant system (Salam, 2014).

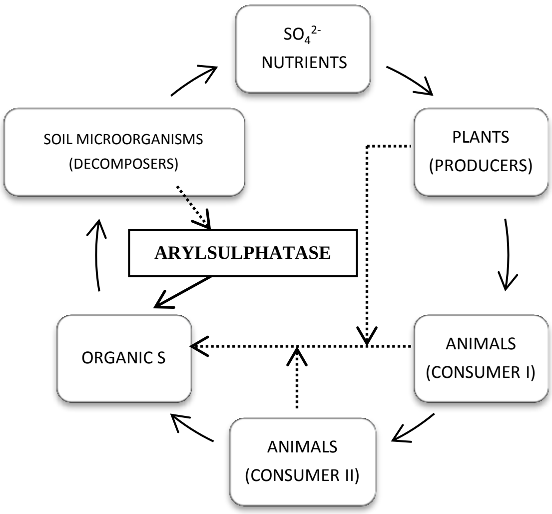

Fig. 1.8. The cycle of S in the soil – plant system (Salam, 2014).

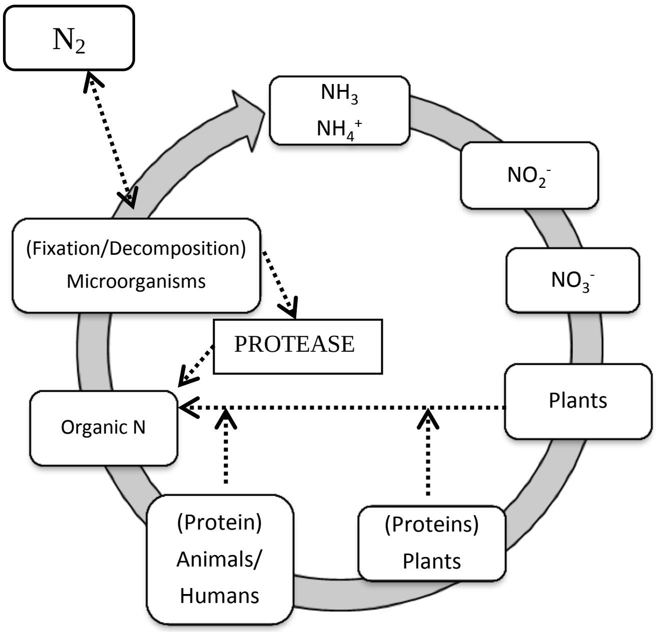

Fig. 1.9. The N Cycle (Adapted from Salam, 2014).

The decomposition of organic matters may release not only the inorganic N, P, and S, but also all other nutrient elements structurally bonded in organic matters. Therefore, the decomposition or organic matter may also increase the soluble and adsorbed species of all nutrient elements in soils. The nutrient elements released by the decomposition of organic matters therefore may complement the nutrient elements released by the weathering processes. These elements may affect and participate in some or all soil chemical properties and processes (**Table 1.4**)

Table 1.4. The main chemical properties and reaction of soils.

No.	Properties	Reactions
1	Soil Reaction (pH)	Precipitation/Dissolution
2	Soil Redox Potential (E)	Chemical Weathering
3	Cation Exchange Capacity (CEC)	Adsorption/Desorption
4	Organic C or Organic Matter Contents	Ion Exchange
5	Total N	Chelation
6	Exchangeable Cations: Base Cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) Acid Cations (Al^{3+}, H^+)	Oxidation/Reduction (Redox)
7	P and S	Decomposition
8	Heavy Metal Cations: Nutrients ((Fe^{2+}, Mn^{2+}, Cu^{2+}, Zn^{2+}) Non-Nutrients (Pb^{2+}, Cd^{2+}, Hg^{2+})	
9	Enzymatic Activities (Phosphatase, Urease, Protease, Arylsulfatases)	

1.2 Weed Effects on the Chemistry and Fertility of Soils

Like plants and vegetation in general, weeds produce H^+ ions and organic acids released into the soil solution. As mentioned previously, these substances may acidify the ambient soil solution. Plants and vegetation also produce CO_2 that also acidify the soil solution. However, weeds are significantly different because they grow more extensively and competitively. They produce more biomass and probably more H^+ ions, organic acids, and CO_2 that acidify the soil environment. Their acidifying effect may be greater in soils planted with weeds with high root-to-shoot ratios. High root-to-shoot ratios and production of acidifying substances may cause high capability of weeds to dissolve soil minerals containing nutrient elements such as K, Ca, Mg, and micronutrients.

Arachis pintoi showed higher root-to-shoot ratio than did *Asystacia gangetica*, *Widelia sp*., *Paspalum conjugatum*, and *Pennisetum purpureum* (Ontia, 2018; Salam et al., 2019). *A. pintoi* showed the highest effectiveness in stimulating the release of K from infertile soil of Ultisol Tanjung Bintang from South Lampung and from fertile soil of Mollisol Jabung from East Lampung. Their effectiveness follows the sequence of *A. pintoi* > *A. gangetica* > *Widelia sp*. > *P. conjugatum* > *P. purpureum*. The released K was reported to be well-correlated with the dry-weight of root and shoot.

The conceptual mechanisms of weed roots in affecting the soil properties are described in **Fig. 1.10**. As pointed out previously, the weed roots may release the H^+ ions in exchange of the absorption of cations including K^+, Ca^{2+}, Mg^{2+}, Cu^{2+}, Zn^{2+}, etc. The root respiration may also release CO_2 that upon reaction with water molecules produces H^+ ion as shown by **Eq. 1.5**.

$$\mathbf{CO_2 + H_2O \leftrightarrow H^+ + HCO_3^- \quad ……. \quad Eq.\ 1.5}$$

These processes may increase the concentration of H^+ ions, which may then attack the nutrient element position in the structure of soil minerals. As reported, the released K^+ and other nutrient elements are intensified by the presence of more H^+ ions (Johnston and Olsen, 1972; Manley and Evals, 1986; Salam, 1989; Najafi-Ghiri and Jabari, 2013). The excreted organic acids by weed roots may also lower the ambient soil pH and intensify the effectiveness of weed roots in stimulating the release of nutrient elements from soil minerals matters.

The production of various enzymes by weed roots and microorganisms stimulated by the presence of weed roots, such as phosphatases, arylsulfatase, proteases, etc., may accelerate the decomposition of soil organic matters releasing various nutrient elements from the organic matter structures. This process of decomposition along with the weathering of soil mineral matters may accumulate the soluble K^+ and other nutrient elements in the soil solution.

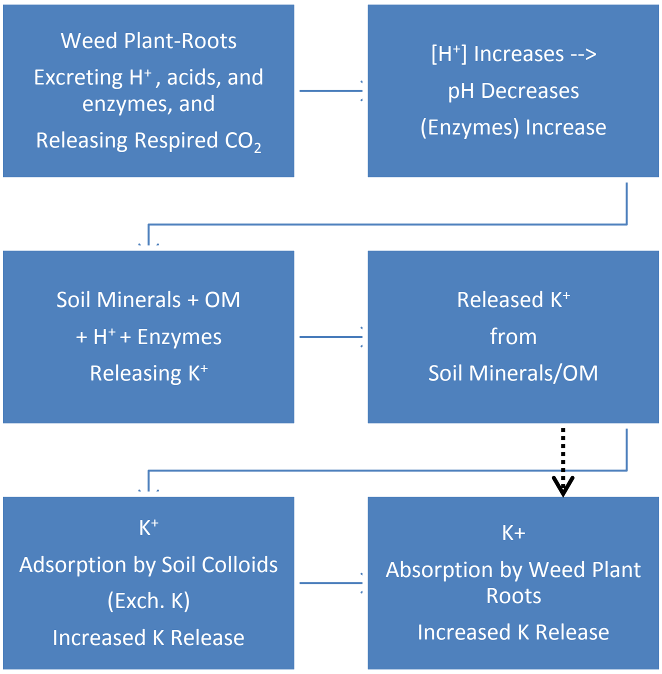

Fig. 1.10. Conceptual relationship between excreted H^+ and organic acids and respired CO_2 by plant roots, released K^+ from soil minerals and organic matters, and improvement of plant growth (Salam et al, 2019).

The soluble nutrient elements released from soil mineral and organic matters may encounter different fates like those happening for free Fe (**Fig. 1.2**). Part of the released K and other nutrient elements may be absorbed by weed and plant roots. Some other parts may be adsorbed by soil colloids increasing the soil exchangeable nutrient elements like exchangeable K, exchangeable Ca, etc. or leached through the soil body by water percolation. Some parts may also precipitate forming secondary minerals or absorbed by microorganisms.

The effects of weeds are not limited to those mentioned above. In addition to intensifying the weathering of soil mineral matters and the decomposition of soil organic matters, weeds may also increase the total organic C and total N through the excretion of organic acids and their dead parts (Sembodo et al., 2017). The relationship between the existence of weeds on soil properties is described conceptually in **Fig. 1.11**. In general, weeds may affect the soil pH and soil enzymatic activities, which may then affect the processes of soil mineral weathering and organic matter decomposition. This processes may affect the status of soil base cations (Ca, Mg, K, Na) and acid cations (Al, H) as well as soil solution anions (P, S, N) and also heavy metal nutrient elements (Fe, Mn, Cu, Zn, Mo) and heavy metal non-nutrient elements (Pb, Cd, Hg). The soil negative charges, soil CEC, and base saturation may also change due to the changes in soil pH. The decrease in soil pH may of course lower the amount of soil negative charges, CEC, and base saturation.

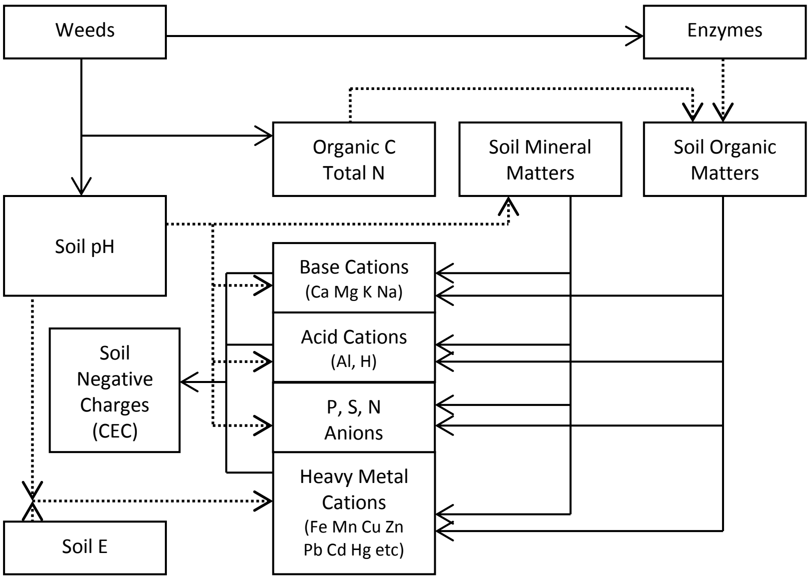

Fig. 1.11. The direct and indirect effects of weeds on the chemistry of soils.

1.3 Scope of *The Chemistry and Fertility of Soils under Tropical Weeds*

This book is organized into nine chapters. Chapters 1 (Introduction) briefly focuses on the interrelationship between the chemistry of soils and the existence of plants and weeds in the soil environment. Chapters 2 (The Soil – Weed Interrelationships) describes more specifically the interrelationship between the chemistry of soils and the growth of weeds while Chapter 3 (The Important Facts about Tropical Weeds) briefly describes the important weeds of the tropics: their concepts, their effects, invasion and dominance, and their control and management. Chapters 4 - 9 deal with the effects of weed presence on the chemistry of soils that include soil pH and soil enzymatic activities (Chapter 4: Effects of Forest Conversion, Chapter 5: Effects of Tropical Weeds on Soil pH and Enzymatic Activities), soil contents of carbon, nitrogen, phosphorus, and sulfur (Chapter 6: Effects of Tropical Weeds on Soil Carbon, Nitrogen, Phosphorus, and Sulfur), soil exchangeable potassium (Chapter 7: Effects of Tropical Weeds on Soil Potassium), and heavy metals (Chapter 8: Effects of Tropical Weeds on Heavy Metals). Chapter 9 (Closing Remarks) highlights some important conclusions related to the effect of weed existence on the chemistry and fertility of soils.

This discussion is completed with tables and diagram of researches reported in several scientific journal conducted by the authors by employing tropical soils of Lampung Indonesia. Some data from other parts of the world were also used in the discussion.

Key Questions

1. How do weeds affect the soil chemical properties? What soil chemical properties are affected the most?
2. Explain how weeds change the soil reaction (pH) and indirectly affect the soil negative charges and cation exchange capacity!
3. What are the difference between soil pH and soil E?
4. Explain the chemical properties of soils? Why are the soil pH and soil E considered the master variables!
5. How do the soil pH and the soil E control the dominance of Fe species in the soil – water system?

6. How do multivalent cations behave with the changes in soil pH in dryland soils?
7. How do multivalent cations behave with the changes in soil pH in wetland soils?
8. How do the chemical properties of paddy soils behave in response to the changes in soil pH and E?
9. How do the chemical properties of paddy soils behave in response to flooding and drying?
10. Explain the effect of the changes in soil pH on the magnitude of soil CEC and base saturation!
11. Explain the effect of the changes in the soil pH and soil E on the reactivity and mobility of multivalent metal cations!
12. Explain the fates of free ions in soi-water system!
13. What is the importance of adsorption/desorption reactions and ion exchange in the soil environment? Explain!
14. What is the importance of precipitation/dissolution reactions and soil mineral weathering in the soil environment? Explain the soil pH at which these processes occur when the concentration of metals is low or high!
15. What is the importance of adsorption/desorption reaction and ion exchange in the soil environment?
16. What is the importance of enzymatic reaction and organic matter decomposition in the soil environment?
17. Explain the P cycle related to the role of phosphatase! What does this enzyme exactly do in the cycle?
18. Explain the S cycle related to the role of arylsulfatase! What does this enzymes exactly do in the cycle?
19. Explain the N cycle related to the role of protease! What does this enzyme exactly do in the cycle?
20. Where do the soil enzymes come from?
21. What is the importance of oxidation/reduction (redox) reactions in the soil environment?
22. Explain the role of pH in controlling the above reactions that occur in the soil environment!
23. What is enzyme? What is its role in the soil environment?
24. How do base cations behave in the soil environment?
25. How do acid cations behave in the soil environment?
26. How do the nutrient element anions behave in the soil environment? What happen to P anions in response to the changes in soil pH?
27. How do weeds change the soil pH and stimulate the dissolution of soil mineral matters and the decomposition of soil organic matters?
28. How do the secreted organic acids and enzymes participate in the processes of soil mineral dissolution and organic matter decomposition?
29. How do the soil CEC, exchangeable base cations, and exchangeable acid cations response to the changes in soil pH stimulated by weeds? Explain!

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30. What is the importance of weed roots in affecting the soil chemical properties? Does the root-to-shoot ratios of weeds play any important role in affecting the soil chemical properties?

Chapter 2

The Soil – Weed Interrelationships

Just like plants, crops, and all vegetation, weeds directly and indirectly interact with the soil system. All absorb nutrient elements from soil water and excrete H^+ ions in exchange of cation absorption or OH^- ions in exchange of anion absorption. In addition, all also excrete organic acids into the soil solution where they absorb nutrient elements from, which in turn acidify the soil ambience. The net excretion of H^+ ion, and also the evolution of CO_2 produced by weed roots and its associated microbial respiration, may cause the soil acidification even more intensively and significantly affect other properties of soil environment. As pointed out previously, weeds are significantly different from other vegetation; they are progressive, expansive, and competitive. Therefore, weeds may produce more H^+, organic acids, and CO_2, particularly those that have high root-to-shoot ratios (Salam, 2019).

These characteristics of weeds may enable weeds to stimulate changes in several soil chemical properties since weed roots are related to other soil components like soil mineral matters and soil organic matters. As discussed previously, these changes may affect the soil pH, which is very closely related to the soil mineral matter weathering through dissolution processes. The dissolution processes are more vigorous at low pH (Salam, 1989). The changes in soil pH not only affect the soil mineral weathering, but as pointed out previously, also affect several other soil chemical properties such as soil CEC and BS (Salam, 2017; Salam, 2019).

Like soil mineral matters, soil organic matters are most likely affected by the presence of weeds since weeds may also produce soil enzymes like phosphatases, aryl-sulfatases, proteases, etc. In the presence of soil enzymes, the decomposition of soil organic matter is speeded. The mineral matter weathering and the organic matter decomposition may produce nutrient elements and substances that may change the chemical properties of the soil system. These two processes that release nutrient elements and other substances into the soil water may complete the relationship between soil – nutrient element – water – weeds as a system.

2.1 The Soil – Water – Nutrient – Weed Relationships

The relationship between soil, water (soil water), nutrient elements, and weeds is depicted in **Fig. 2.1**. Weed roots are directly connected to the soil water where they absorb most of the nutrient elements needed for their growth and development. As they are competitive and progressive, weeds may significantly absorb the soluble nutrient elements from soil water. Of course, absorption by weeds is not the only mechanism for nutrient element losses in the soil environment. The soluble nutrient elements in soil water are also absorbed by plants and parts of it may be adsorbed by the soil adsorption sites, precipitated, or leached. However, the presence of weeds may lower the nutrient element losses through all these mechanisms and increase that lost by weeds. Therefore, this stimulates farmers to eradicate weeds employing several mechanisms.

The above explanation shows that weeds may cause a significant effect on the nutrient element balance in the soil environment. The imbalance of nutrient element in soil water is chemically buffered by some mechanisms mentioned previously. The first mechanism is the detachment of adsorbed nutrient elements as described in **Eq. 2.1** called desorption.

$$\mathbf{X-NE \rightarrow X- \;+\; NE \quad \ldots\ldots\quad Eq.\ 2.1}$$

where X – is the soil adsorption sites and NE is nutrient element cations like Ca^{2+}, K^{+}, Cu^{2+}, etc. This mechanism may supply the soluble nutrient elements relatively fast controlled by the related equilibrium constant. The process is intensified by the lower concentration of nutrient elements caused by element absorption by weed roots.

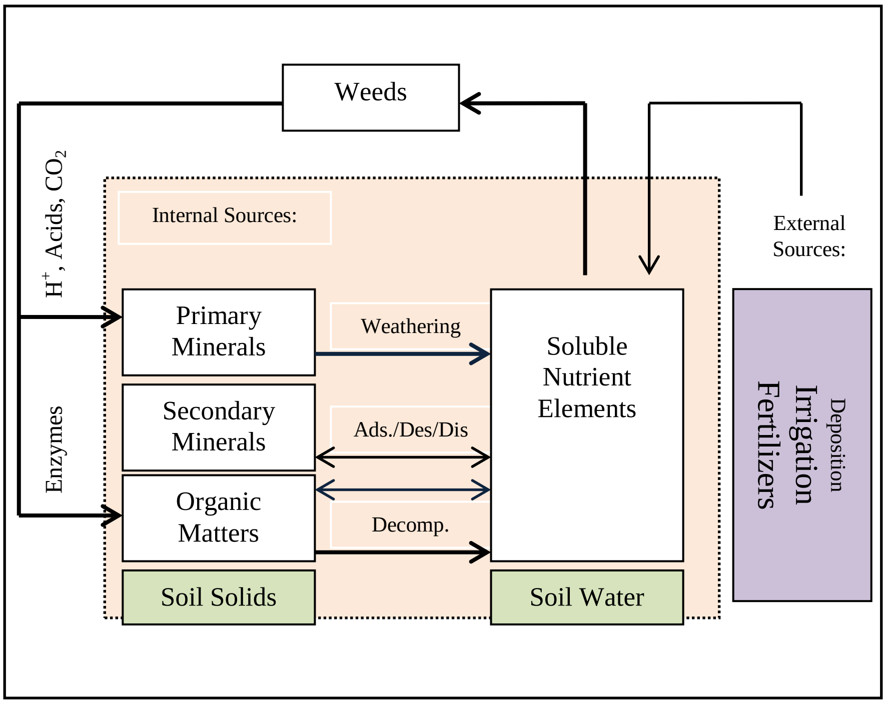

Fig. 2.1. The soil – water – nutrient element – weed relationship (Adapted from Salam, 2014).

The second mechanism is the dissolution of secondary minerals. This may include among which the dissolution of Mn-P stimulated by redox reaction. When the soil environment is flooded, Mn-P is reduced and dissolved to produce Mn^{2+} and P ions. The presence of Mn^{2+} is enhanced at low pH. Similarly, the hydroxide precipitates of Fe may dissolve in soils when the concentration of Fe^{2+} or Fe^{3+} is low. The dissolution may occur more readily at low pH.

The third mechanisms may in general occur relatively slowly, comprising two major mechanisms i.e. mineral matter weathering and organic matter decomposition (**Fig. 2.1**). Mineral matters and organic matters are two sources of nutrient elements in the soil environment; mineral matters come from volcanic materials containing mostly Si, Al, and O while organic matters come from the living things containing mostly C, H, and O. These materials may release soluble nutrient elements upon weathering or decomposition processes. The weathering of mineral matters is depicted previously in **Eq. 1.2** and the decomposition of organic matters in **Eq. 1.4**.

Like all other vegetation, weeds also excrete some substances into the soil environment which directly or indirectly related to the soluble nutrient elements in soil water and the adsorbed elements in soil solids. The first is H^+, which may of course acidify the soil ambience. The second is the organic acids, which may also acidify the soil ambience (Robert and Berthelin, 1986). Among the organic acids produced in the rhizosphere are of amino acids (aspartic and glutamic), of phenolic acids, of aliphatic acids (oxalic, malic, citric, and tartaric) (Robert and Berthelin, 1986). Soil microorganisms living in the rhizosphere also produce some organic acids including oxalic, citric, formic, 2-ketoglutamic, lactic, malic, and tartaric acids, and lichenic acids (Robert and Berthelin, 1986). The third is the evolved CO_2 by weed roots and microorganisms which may react with water molecule producing H^+ ions which may also acidify the soil ambience. The fourth is the soil enzymes which may intensify the soil organic matter decomposition. All these substances may drive the changes in the soil chemical properties.

2.2 The Release of Nutrient Elements from Soil Minerals and Organic Matters

Nutrient elements in the soil environment are in general of two categories; readily available and slowly available. Readily available nutrient elements are dissolved in soil water (free ions), relatively fast balanced by dissolved complexes or chelates and by those adsorbed onto the soil mineral and organic adsorption sites (exchangeable elements); while slowly available nutrient elements are those contained as part of the soil solid structures of primary and secondary (precipitate) minerals and organic matters.

Plant roots may quickly absorb free ions. Dissolved complexes, chelated, and adsorbed ions may quickly satisfy the depletion in the concentration of free ions in soil water following **Eq. 2.2**, **Eq. 2.4**, and **Eq. 2.6,** respectively.

$$M^{m+} \ + \ A^{a-} \ \leftarrow\rightarrow \ M_aA_m{}^0 \quad \text{.......} \quad \textbf{Eq. 2.2}$$

with

$$K \ = \ \frac{[M_aA_m^0]}{[M^{m+}][A^{a-}]} \quad \text{.......} \ \textbf{Eq. 2.3}$$

where M^{m+} is a nutrient element cation, A^{a-} is the complexing anion, $M_aA_m{}^0$ is the related complex ion, and K is the reaction constant.

$$M^{m+} \ + \ L^{l-} \ \leftarrow\rightarrow \ M_lL_m{}^0 \quad \text{.......} \quad \textbf{Eq. 2.4}$$

with

$$K \ = \frac{[M_lA_m^0]}{[M^{m+}][L^{l-}]} \quad \text{.......} \quad \textbf{Eq. 2.5}$$

where M^{m+} is a nutrient element cation, L^{l-} is the ligand, $M_lL_m{}^0$ is the related chelate, and K is the reaction constant.

$$\textbf{X-M} \ + \ \mathbf{N^{n+}} \ \leftarrow\rightarrow \ \textbf{X-N} \ + \ \mathbf{M^{m+}} \quad \textbf{.......} \quad \textbf{Eq. 2.6}$$

with

$$\mathbf{K} \ = \ \frac{[N^{n+}]}{[M^{+}]} \quad \textbf{.......} \quad \textbf{Eq. 2.7}$$

where X is the soil adsorption sites, M and N are nutrient element cations, and X-M and X-N are adsorbed nutrient elements. All of these reactions may buffer the concentrations of free ions in the soil water to satisfy their absorption by plant roots. The equilibrium concentration is controlled by the respective reaction constant. The relationship between these reactions is depicted in **Fig. 2.2**. Some examples of free and complex ions and organic chelates in soils are listed in **Table 2.1**.

The concentrations of free ions are relatively low compared to that absorbed by plants. The concentrations of free ions are even lower than the dissolved element in soil water. For example, the concentration of free Zn^{2+} is 40% of the total dissolved Zn and that of Cu^{2+} is even lower about 2% of the total dissolved Cu (Elliz and Knezek, 1982). The free K^{+}, Na^{+}, Ca^{2+}, and Mg^{2+} are higher, about 70 – 90% of the respective total dissolved elements. However, the amounts supplied by all dissolved nutrient elements are also relatively low and do not suffice the plant requirement.

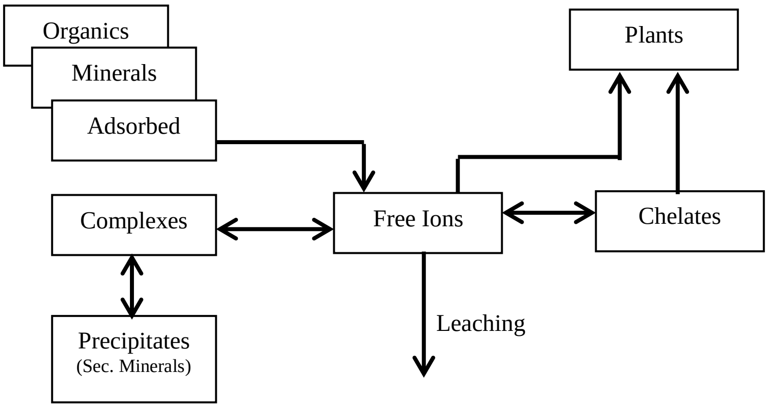

Fig. 2.2. The relationships between the mechanisms controlling the concentrations of nutrient elements in soil water (Adapted from Salam, 2017).

Therefore, the rest of the nutrient elements must be supplied by other sources of readily available nutrients and slowly available nutrient elements that include soil organic matters, soil secondary minerals (precipitates), and soil primary minerals (**Fig. 2.2**). Most of the nutrient elements in the soil environment are contained in the soil solids. These nutrient elements are not available or slowly available to plants. These nutrient elements must be converted into readily available forms before being available for plant absorption. Releasing these slowly available nutrient elements enables the use of these elements by plants and vegetation and allows them to get into nutrient element cycles. The mechanisms by which these elements are released are listed in **Table 2.2**. The chemical processes releasing particular nutrient elements are listed in **Table 2.3**.

Complementing the dissolved nutrient elements in the forms of free ions, complex ions, and chelates, the soil exchangeable ions are the most easily released nutrients of the soil solids. The detachment of adsorbed nutrients may progress through cation exchange described in **Eq. 2.6** controlled by K depicted in **Eq. 2.7**. This mechanism may quickly supply the nutrient elements in soli water depleted by plant root absorption. In addition to the related equilibrium constant, there are some other soil properties controlling this process including soil CEC and pH and soil solid preferences towards nutrient cations (**Table 2.2**). The release of nutrient cations is generally more difficult in soils with high CEC and high pH, particularly for nutrient cations with high valences that cause high affinities onto the soil solids. However, low concentration of nutrient cation in soil water may greatly drive their release from soil solids. Therefore, the absorption of nutrient elements by plant roots may significantly drive the release of adsorbed nutrient elements. The decrease in soil pH by root excretion of H^+ and organic acids may accelerate the release of the adsorbed nutrient element.

Table 2.1. Some examples of free and complex ions and chelates in soil water.

Cations	**Acid Soils**	**Alkaline Soils**
Na^+	Na^+	Na^+, $NaHCO_3^0$, $NaSO_4^-$
K^+	K^+	K^+, KSO_4^-
Mg^{2+}	Mg^{2+}, $MgSO_4^0$, Org* (Example Cu-Fulvic)	Mg^{2+}, $MgSO_4^0$, $MgCO_3^0$
Fe^{2+}	Fe^{2+}, $FeSO_4^0$, $FeH_2PO_4^+$	$FeCO_3^0$, Fe^{2+}, $FeHCO_3^+$, $FeSO_4^0$
Cu^{2+}	Org*, Cu^{2+}	$CuCO_3^0$, Org*, $CuB(OH)_4^+$, $CuB[(OH)_4]_4^0$
Ca^{2+}	Ca^{2+}, $CaSO_4^0$, Org*	Ca^{2+}, $CaSO_4^0$, $CaHCO_3^+$
Cr^{2+}	CrO_4^{2-}	CrO_4^{2-}
Cd^{2+}	Cd^{2+}, $CdSO_4^0$, $CdCl^+$	Cd^{2+}, $CdCl^+$, $CdSO_4^0$, $CdHCO_3^+$
Si^{4+}	$Si(OH)_4^0$	$Si(OH)_4^0$

* Adapted from Sposito (1989)

Table 2.2. The chemical mechanisms for releasing ions from their sources*.

No.	Chemical Processes	Sources of Free Ions	Dominant Controlling Factors
1	Decomplexation/ Chelation	Complex Ion/ Chelates	K**
2	Desorption	Exchangeable Nutrient Elements	K**, KTK, pH, Preference
3	Dissolution	Precipitates (Secondary Minerals)	K_{sp}**
4	Weathering	Mineral Structural Elements (Primary Minerals)	pH, Water Content, Mineral Structure, Mineral Chemical Composition
5	Decomposition	Organic Matter Structural Elements	pH, Water Content, Enzymatic Activities, Temperature, C/N Ratio

*Taken from Salam (2019)

**K is an equilibrium constant related to a particular chemical reaction, K_{sp} is an equilibrium constant related to the dissolution of a particular precipitate

Some precipitates or secondary mineral existing in the soil environment may include carbonates like $CaCO_3$, sulfates or sulfides like $Fe_2(SO_4)_3$ and FeS, hydroxides like $Fe(OH)_2$, and phosphates like Ca-P, Al-P, Fe-P, and Mn-P (**Table 2.3**). Some precipitates may dissolve under proper soil environment condition releasing free nutrient elements. The most important soil condition stimulating the process of dissolution is the lowering of free ion concentration due to some mechanism like plant root absorption and water leaching.

The dissolution of $CaCO_3$ may progress as described in **Eq. 2.8**.

$$Ca^{2+} + CO_3^{2-} \leftarrow\rightarrow CaCO_3 \quad \ldots\ldots \quad \text{Eq. 2.8}$$

$$K_{sp} = [Ca^{2+}]\,[CO_3^{2-}] \quad \ldots\ldots. \quad \text{Eq. 2.9}$$

The process of dissolution may continue as long as the concentration of Ca^{2+} is low so that it cannot suffice the value of K_{sp}. This process may degrade the amount of $CaCO_3$ and serve dissolved Ca^{2+} easily absorbed by plant roots. The presence of secondary minerals like $CaCO_3$ in soils is therefore of utmost importance as nutrient element sources in the soil environment. The absence of this kind of minerals may cause the absence of the related nutrient cations and nutrient element deficiencies.

Table 2.3. The chemical mechanisms for releasing ion from its various sources.

Nutrient Elements	Nutrient Sources	Chemical Processes	Soluble Forms
N	Organic Matters NH_4^+ in the interlayers of Mica and Vermiculite Exchangeable NH_4	Decomposition Weathering Ion Exchange	NH_4^+ NH_4^+ NH_4^+
S	Organic Matters Sulfides (Ex. FeS) Gypsum ($CaSO_4$)	Decomposition Oxidation Dissolution	S^{2-}, SO_4^{2-} SO_4^{2-} SO_4^{2-}
P	Organic Matters Al-P, Fe-P, Ca-P	Decomposition Ligand Exchange Dissolution	$H_2PO_4^-$, HPO_4^{2-} $H_2PO_4^-$, HPO_4^{2-} $H_2PO_4^-$, HPO_4^{2-}
K, Ca, Mg	Silicate Minerals (Ex. Feldspars) Carbonates, Sulfates	Weathering, Dissolution Dissolution	K^+, Ca^{2+}, Mg^{2+} Ca^{2+}
Fe, Mn, Zn, Cu	Hydroxide Precipitates Adsorbed on Oxides of Fe, Al, and Mn Chelated by Humus Exchangeable	Dissolution Desorption Dissociation Ion Exchange	Cations and Dissolved Chelates
B, Mo	Adsorbed by Oxides of Fe, Al and Clay Minerals	Desorption	H_3BO_3 MoO_4^{2-}

*Taken from Singer and Munns (1987)

Some other soil conditions may also influence the dissolution of some precipitates (secondary minerals). For examples, the lowering of soil reaction (pH) may trigger the dissolution of $Fe(OH)_2$ (**Eq. 2.10**), the increase in soil E may dissolve FeS and Fe-P (**Eq. 2.12** and **Eq. 2.13**). These examples demonstrate that the dissolution of secondary minerals is stimulated not only by its related nutrient element concentrations but also by the changes in other soil properties like soil pH and soil E. The decrease in soil pH is shown to stimulate not only the nutrient release through cation exchange but also through dissolution of soil secondary minerals.

$$\mathbf{Fe(OH)_2 \leftrightarrow Fe^{2+} + 2\,OH^{-}} \quad \textbf{....... Eq. 2.10}$$

$$\mathbf{K = [Fe^{2+}]\,[OH^{-}]^{2}} \quad \textbf{....... Eq. 2.11}$$

The decrease in soil E may reduce the related nutrient element in soil secondary minerals like $Fe_2(HPO_4)_3$ and release the nutrient element cations into the soil solution. The trivalent Fe cation ion the structure of $Fe_2(HPO_4)_3$ is released as Fe^{2+} ion in soil water. Therefore, Fe^{2+} is more readily available in flooded soils like paddy soils, while Fe^{3+} in dry soils is not available because its association among which with P.

$$\mathbf{Fe_2(HPO_4)_3 + 2\,e_{-} \leftrightarrow 2\,Fe^{2+} + 3\,HPO_4^{2-}} \quad \textbf{....... Eq. 2.12}$$

On the other hand, S is not available in flooded soil because it presents as FeS precipitates. The S may be oxidized upon the increase in soil E by draining the flooded soils following **Eq. 2.13**. FeS may dissolve producing Fe^{3+} and SO_4^{2-}.

$$\mathbf{FeS + 4\,H_2O \leftrightarrow Fe^{3+} + SO_4^{2-} + 8\,H^{+} + 9\,e^{-}} \quad \textbf{....... Eq. 2.13}$$

In addition to soil secondary minerals (precipitates), there are also primary minerals containing various kinds and amounts of nutrient elements. Some primary minerals present in the soil environment and their chemical weathering are listed in **Table 2.4**. The primary minerals may release their structural nutrient elements through the process of weathering (**Table 2.2** and **Table 2.3**). One example of the weathering process is the release of structural K from K-feldspar (Orthoclase, $KAlSi_3O_8$) as shown in **Eq. 2.14**.

$$\mathbf{KAlSi_3O_8 + 4\,H_2O + 4\,H^{+} \rightarrow K^{+} + Al^{3+} + 3\,Si(OH)_4} \quad \textbf{....... Eq. 2.14}$$

Free K^{+} is released into the soil water increasing the soil water K concentrations. This reaction is a non-equilibrium reaction and so it will progress and speed up in the presence of water and H^{+} ions.

Table 2.4. Chemical weathering of some primary and secondary minerals.

No.	Chemical Reaction	Minerals Reactants/Products
1	$SiO_2(s) + 2\ H_2O \leftrightarrow H_4SiO_4$	Quartz → ....
2	$CaCO_3(s) + H_2O \leftrightarrow Ca^{2+} + HCO_3^- + OH^-$	Calcite → ....
3	$CaCO_3(s) + H_2CO_3 \leftrightarrow Ca^{2+} + 2\ HCO_3^-$	Calcite → ....
4	$Al_2O_3.3H_2O(s) + 2\ H_2O \leftrightarrow 2\ Al(OH)_4^- + 2H^+$	Gibbsite → ....
5	$Mg_2SiO_4(s) + 4\ H_2CO_3 \leftrightarrow 2\ Mg^{2+} + 4\ HCO_3^- + H_4SiO_4$	Forsterite → ....
6	$Fe_2SiO_4(s) + H_2CO_3 \leftrightarrow 2\ Fe^{2+} + 4\ HCO_3^- + H_4SiO_4$	Fayalite → ....
7	$Mg_6Si_8O_{20}(OH)_4(s) + 12\ H^+ + 8\ H_2O \leftrightarrow 6\ Mg^{2+} + 8\ H_4SiO_4$	Talk → ....
8	$Mg_3Si_2O_5(OH)_4(s) + 6\ H^+ \leftrightarrow 3\ Mg^{2+} + 2\ H_4SiO_4 + H_2O$	Talk → ....
9	$MgCO_3(s) + 2H_2O \leftrightarrow HCO_3^- + Mg(OH)_2(s) + H^+$	Magnesite → Brusite
10	$Al_2Si_2O_5(OH)_4(s) + 5\ H_2O \leftrightarrow 2\ H_4SiO_4 + Al_2O_3.3H_2O(s)$	Kaolinite → Gibbsite
11	$NaAlSi_3O_8(s) + \frac{11}{2}\ H_2O \leftrightarrow Na^+ + OH^- + 2\ H_4SiO_4 + \frac{1}{2}\ Al_2Si_2O_5(OH)_4(s)$	Albite → Kaolinite
12	$NaAlSi_3O_8(s) + \frac{9}{2}\ H_2O + H_2CO_3 \leftrightarrow$ $Na^+ + HCO_3^- + 2\ H_4SiO_4 + \frac{1}{2}\ Al_2Si_2O_5(OH)_4(s)$	Albite → Kaolinite
13	$CaAl_2Si_2O_8(s) + 3\ H_2O \leftrightarrow Ca^{2+} + 2\ OH^- + Al_2Si_2O_5(OH)_4(s)$	Anortit → Kaolinite
14	$CaAl_2Si_2O_8(s) + 3\ H_2O + H_2CO_3 \leftrightarrow$ $Ca^{2+} + 2\ HCO_3^- + Al_2Si_2O_5(OH)_4(s)$	Anortit → Kaolinite
15	$4\ Na_{0.5}Ca_{0.5}Al_{1.5}Si_{2.5}O_8 + 6\ H_2CO_3 + 11\ H_2O \leftrightarrow$ $2\ Na^+ + 2\ Ca^{2+} + 4\ H_4SiO_4 + 6\ HCO_3^- + 2\ Al_2Si_2O_5(OH)_4(s)$	Plagioclase (Andesine) → Kaolinite
16	$5\ KAlSi_3O_8(s) + 2\ H_2CO_3 + 12\ H_2O \leftrightarrow$ $2\ K^+ + 2\ HCO_3^- + 6\ H_4SiO_4 + KAl_3Si_3O_{10}(OH)_2(s)$	K-Feldspar (Orthoclase) → Mica
17	$7\ NaAlSi_3O_8(s) + 6\ H^+ + 20\ H_2O \leftrightarrow$ $6\ Na^+ + 10\ H_4SiO_4 + 3\ Na_{0.33}Al_{2.33}Si_{3.67}O_{10}(OH)_2(s)$	Albite → Na-Montmorillonite
18	$KMg_3AlSi_3O_{10}(OH)_2(s) + 7\ H_2CO_3 + \frac{1}{2}\ H_2O \leftrightarrow$ $K^+ + 3\ Mg^{2+} + 7\ HCO_3^- + 2\ H_4SiO_4 + \frac{1}{2}\ Al_2Si_2O_5(OH)_4(s)$	Biotite → Kaolinite
19	$Ca_5(PO_4)_3F(s) + H_2O \leftrightarrow Ca_5(PO_4)_3(OH)(s) + F^- + H^+$	Fluor apatite → Hydroxyapatite
20	$KAlSi_3O_8(s) + Na^+ \leftrightarrow K^+ + NaAlSi_3O_8(s)$	Orthoclase→ Albite
21	$CaMg(CO_3)_2(s) + Ca^{2+} \leftrightarrow Mg^{2+} + 2\ CaCO_3(s)$	Dolomite → Calsite
22	$MnS(s) + 4\ H_2O \leftrightarrow Mn^{2+} + SO_4^{2-} + 8\ H^+ + 8e^-$	Manganese Sulfide → ......
23	$3\ Fe_2O_3(s) + 4\ H_2O + 2\ e^- \leftrightarrow 2\ Fe_3O_4(s) + 8\ H^+ + 2\ OH^-$	Hematite → Magnetite
24	$FeS_2(S) + \frac{15}{4}\ O_2 + \frac{7}{2}\ H_2O \leftrightarrow Fe(OH)_3(s) + 4\ H^+ + 2\ SO_4^{2-}$	Pyrite → Ferrooxides
25	$PbS(s) + 4\ Mn_3O_4(s) + 12\ H_2O \leftrightarrow Pb^{2+} + SO_4^{2-} + 12\ Mn^{2+} + 24\ OH^-$	Galena → ....

Adapted from Garrels and Christ (1965); Lindsay (1979); Stumm and Morgan (1981)

Some factors clearly govern the process of the primary mineral weathering in the soil environment (**Table 2.2**) the most important of which are soil moisture content and soil pH. All of the chemical weathering listed in **Table 2.4** shows the importance of water molecule. None of these reactions occur in the absence of water. As stated previously, **Eq. 2.14** shows that the weathering of orthoclase is speeded by the presence of water molecule. Shown in **Eq. 2.14** and **Table 2.4**, the presence of H^+ also speeds up the chemical weathering. Lowering the soil pH may surely increase the rate of soil mineral weathering. The importance of soil pH in mineral weathering is also previously shown in **Table 1.3**.

It is always true that the nutrient elements in soil water are not supplied only by inorganic sources like soil primary and secondary minerals but also by organic sources. Soil organic matter may reach the amount of 5% in mineral soils and therefore it may serve significant amounts of nutrient elements in the soil environment particularly for such nutrient elements as N, S, and P. The soil organic matters may decompose and release these nutrient elements in the forms of NH_4^+, NO_3^-, SO_4^{2-}, and orthophosphates ($H_2PO_4^-$ and HPO_4^{2-}), respectively (**Table 2.3** and **Table 2.4** and **Fig. 1.7**, **Fig. 1.8**, and **Fig. 1.9**). These nutrient elements may compensate their depletion caused by plant root absorption or other mechanisms.

The decomposition of organic matters in the soil environment is controlled by several important factors. As shown by **Eq. 1.4**, the soil enzymatic activity and soil moisture are the two most important factors. The rate of organic matter decomposition is positively related to the activity of soil enzymes such as phosphatases, proteases, and arylsulfatases and soil moisture content. This means that the release of the organic matter structural elements can be speeded by increasing the soil enzymatic activities and soil water content. The absence of water may stop and the absence of soil enzymes may retard the soil organic matter decomposition. Gianfreda (2015) states that all processes and functions that occur in the rhizosphere are dominated by the activities of plant roots, rhizosphere microorganisms and root-microorganism interactions, and enzymes are recognized as main actors of all activities occurring in rhizosphere environments. In general, rhizosphere enzymes show higher activities than those in bulk soil because the rhizosphere soil is richer in organic C substrates. Enzymes produced and released by roots alter the availability of nutrients in the rhizosphere through the hydrolysis of C-substrates and organic forms of nutrients such as N, P and S.

In addition to soil enzymes and water, there are other factors controlling the rate of organic matter decomposition i.e. soil pH, soil temperature, and soil C/N ratios. Soil enzymes cause a direct effect while soil water, soil pH, soil temperature, and C/N ratios give an indirect effect of the enhancement of organic matter decomposition. As stated in Salam (2014), soil water, soil N, and soil temperature influence the growth of soil enzyme producing microorganisms. In general the soil microbial population and activity, and thereby the activities of soil enzymes, increase with the increase in water content, N content, and soil temperature. In particular for phosphatases, their activities below the optimum pH increase with the increase in soil pH. Optimum pH is the value of pH at which the activity of phosphatases is maximum.

2.3 The Effects of Weeds on Nutrient Element Release from Soil Minerals and Organic Matters

Chemicals released by weed roots may directly and indirectly affect the soil properties that might intensify the releases on nutrient elements from soil solids. The depletion in soil pH in the root zones of weeds may directly increase the process of soil mineral weathering releasing nutrient elements into the soil water. Salam et al. (2019) report that several weeds stimulate the release of K from soil minerals. The effectiveness of weed plants in stimulating the release of soil K were*:* *A. Pintoi* > *A. gangetica* > *Widelia sp*. > *P. conjugatum* > *P. purpureum. A. pintoi* is suggested to be the most effective in stimulating the release of K from soil minerals as proven by the positive values of Δ Exch. K [Δ Exch. K = Final Exch. K (After Planting) – Initial Exch. K (Before Planting). This phenomenon is related to its higher Root-To-Shoot Ratio compared to others.

The increase in soil water cations is not only attributed to the weathering of soil minerals but also to the decomposition of soil organic matter directly speeded by various soil enzymes excreted by weed roots and their associated microorganisms. Therefore, the increase in soil exchangeable K in the root-zones of *A. pintoi* reported by Salam et al. (2019) might have also been related to this phenomenon.

Combined with decrease in soil CEC in response to the decrease in soil pH, the increase in nutrient element concentration in soil water may indirectly cause the increase in soil exchangeable cations. However, the presence of weed-roots absorbing cations may cause the real exchangeable cations in soils to decease. This phenomenon is reported by Salam et al. (2019), the soil exchangeable K was lower in the presence of weeds like *A. gangetica*, *Widelia sp*., *P. conjugatum*, and *P. purpureum. A. pintoi i*s different, demonstrating its effectiveness in stimulating the release of soil mineral K as shown by its value of Δ Exch. K. However, in the long run the presence of weeds may also directly increase the soil C and organic matter content through their dead and decomposing materials. The increase in soil organic matter may increase the soil CEC which might increase the capacity of soils to retain cations. In the short run, the soil organic C and organic matter content are shown not affected by the presence of weeds (Ontia, 2018).

In addition to indirectly affect the soil CEC, organic C, and organic matter, the presence of weeds may also indirectly affect the soil base saturation, which is directly related to the soil exchangeable bases and soil CEC. The increase in soil water concentration of cations may drive the increase in the soil exchangeable cations by the process of adsorption. Combined with the decrease in soil CEC by the decreasing soil pH in the root-zones, these processes may increase the soil base saturation.

Key Questions

1. Explain how weeds cause direct and indirect effects on soil chemical properties like soil pH, CEC, and BS!
2. Explain how the weed-root-excreted H^+ and organic acids as well as the evolved-CO_2 acidify the weed rhizosphere!
3. Explain how weed roots stimulate the soil mineral weathering and organic matter decomposition!
4. What characteristics of weeds that make them very influential in the soil environment? Explain!
5. What is the importance of Root-To-Shoot Ratio for competitive vegetation like weeds? Explain!
6. How does the soil pH affect the soil CEC and soil BS?
7. How do the soil enzymes affect the soil organic matter decomposition? Explain!
8. Explain the relationship between the soil – water – nutrient element and weeds!
9. Explain the mechanisms for the nutrient element losses in the soil environment other than by weed root absorption!
10. Explain all the reactions that balance the nutrient losses in the soil environment! Show them in a diagram!
11. What is the dissolution process? Give an example and explain!
12. Explain the dissolution of Mn-P in the soil environment! Explain all the controlling factors of this reaction!

13. Explain the weathering of soil primary minerals! Why is it so important for the soil chemical and fertility?
14. Explain the decomposition of soil organic matter? Why is it so important for the fertility of soils? Which nutrients released through this soil chemical process?
15. Explain all forms of nutrient elements in the soil environment! Explain how they relate one to another!
16. Explain the easiness of each nutrient element forms to be absorbed by weed roots!
17. Which forms of the soil nutrient elements in the soil environment readily available to weeds? How are these forms balanced when their concentrations in the soil water are somehow depleted?
18. Which forms of the soil nutrient elements in the soil environment are slowly available to weeds? How do these forms relate to the weed root absorption?
19. Explain the nutrient element complexes, complexation, and complexation constant!
20. Explain the chelation, chelates, and dechelation of nutrient elements!
21. Explain the relationship between all the mechanisms controlling the free ions of nutrient elements!
22. Compare the concentrations of free ions, total dissolved, and total contents of soil nutrient elements!
23. What is cation exchange? Explain all the factors controlling this reaction in the soil system!
24. Explain the dissolution of precipitates of carbonates, sulfates, sulfide, and phosphates!
25. Explain the most important factors controlling the concentrations of free nutrient elements in soil water!
26. Explain the importance of soil pH in controlling the dissolution process in the soil environment!
27. What is soil E? How does this variable control the dissolution of FeS and $Fe_2(HPO_4)_3$?
28. Explain the weathering of orthoclase! Explain also all the factors controlling this reaction!
29. Explain the importance of pH in controlling the weathering of primary minerals!
30. Explain how the soil organic matters decompose and release nutrient elements in the soil environment! What nutrient elements are released?
31. Explain all the factors controlling the soil organic matter decomposition!
32. Explain the importance of water and enzymes in the soil organic matter decomposition! What about other factors like soil pH, soil T, and soil C/N ratios?
33. How does the soil pH affect the activities of phosphatases?
34. Explain how weeds directly and indirectly influence the soil chemical properties!

Chapter 3

The Important Facts about Tropical Weeds

Human life has never been free from the presence of weeds that directly or indirectly disturb the human activities. The most important direct negative effects of weeds may include the decrease in the quantity and quality of crop products that may cause direct negative effects on the farmer’s economy. Some other negative effects are the presence of weed allelopathy that may poison the main crops, the difficulties in manual and mechanical crop harvesting, the role of weeds as hosts of plant pests and diseases, as well as the decrease in land values due to weed infestation (Sembodo, 2010). Weeds may also disturb lands for conservation and recreation, lower land esthetics, decrease the environmental quality, and disturb the animal, human, and wildlife health and existence.

The worst impact of weeds in agriculture is directly related to the economy of small and big farmers. Reported by Bridges (1999), about 80% of the worst impact of weeds occurs in agricultural crop production and the rest 20% occurs in forestry, pasture, recreation land, and real estates. The negative effect of weeds may be higher than that had been predicted. The real effect is not easy to calculate due to the difficulty in estimating the negative effects on sectors other than agriculture.

The negative effect is in general originated from two sources, i.e. the decrease in farmer's benefit and the increase in production cost. The decrease in the quantity and quality of crop production may directly decrease the farmer's income due to the decrease in selling price. The increase in production cost is caused by the more intensive weed controls that include cost for labors and expenses for herbicide application and crop harversting.

The effect of weeds on the environment may be of two kinds. The first is the negative effect caused by the methods of weed control applied, particularly the manual control that may cause more intensive soil erosion as well as the chemical control that may polute the environment, particularly soil and water, and may depress non-target species, particularly the predators and parasites of pests and pathogenic plants. The second is the disturbance on the composition of flora that may destabilize the ecosystem. This is because most weeds are not indigenous vegetation, which may displace indigenous vegetation due to their much faster growth. This process may change the composition and balance of flora and fauna of a particular region, which may eventually cause a chain effect that may be noticed after years. For example, the indigenous species of Kalimantan forest *Melastoma beccarianum* may be displaced by *Acacia mangium* purposively introduced. Seeds of *Acacia mangium* may grow earlier and faster compared to those of *Melastoma beccarianum* particularly in the presence of high light intensity (Osunkoya et al., 2005).

The ability of weeds to displace indigenous vegetation is a consequence of their fast and competitive growth characteristics, prolific seed production and propagation, as well as by their allelopathic characteristics. *Alang-alang* (*Imperata cylindrica*) (**Fig. 3.1**) may quickly dominate particular lands due to its allelopathic characteristic. An in vitro observation showed that the allelopathy of *alang-alang* may have depressed the height and the length of seedlings, and lowered the dry-weight of corn (Sriyani et al., 1996). Ge et al. (2017) shows the allelopathic effect of root extract of *Alternanthera philoxeroides* on the inhibition of the growth of native plant species through toxic effects on soil enzyme activities and the microbial community. He shows that the relative abundance of microorganisms decreased including *Burkholderia*, Gp6, Gp1 and Gp4 in the applied treatments at genus level as compared to control treatment.

As pointed out previously, weeds also excrete several substances among which are H^+ and organic acids. These substances may lower the soil pH and cause the changes in the adjacent soil chemical and fertility properties. The decrease in soil pH may cause the increase in soil metal elements released from the speeded soil mineral weathering. The presence of organic acids may also cause parts of the metal elements to dissolve in soil water. The increase in soil organic matters by the presence of weeds may increase the soil CEC, which also indirectly influence the dissolved metal elemens.

Even though the impact of weeds related to their controls and their root excretion like alellophatic substances and organic acids is significant, the negative effects of weeds on animal and human health are not much in the current literature. Among those reported are the allergic reaction caused by *Ambrosia artemisiifolia* and *Rhuss spp.* and the poisoning effect *of Solanum nigrum* and *Rhuss spp*. on animals. Data of weed effect on human and animal heath in Indonesia is limited, less than those in some developed nations. It was not less than 280.000 sheeps and 264.000 goats were predicted dead every year in the United States of America caused by poisonous weed consumption. Some weeds like *Cynodon dactylon* (*Grintingan*)*, Eleusine indica* (*Lulangan*), dan *Sorgum halapense* (*Glagah*), as well as *Mimosa invisa* (*Kucingan*) and *Cyperus rotundus* (*Teki*) may cause allergy and wounds on animals and *Ipomoea triloba* (*Mantangan*) may cause diare on goats (Sembodo, 2010). Some of these weeds are depicted in **Fig. 3.1** and **Fig. 3.2**.

A high amount of labors, time, and fund are also needed yearly to control weeds, not because of the weed effects on crop production, but of the value of natural beauty of lands. For example, the weed control in recreation lands, golf courses, dams for recreation, etc. The presence of weeds may decrease the values of the natural beauty of these lands and lower their selling prices. The presence of weeds in golf courses may enhance the cost of maintenance significantly. Other impact difficult to predict is the destruction of esthetic value caused by the presence of weeds around roadsides, buildings, offices, campuses, sport fields, rail-road sides, irrigation ditches, etc. In addition to decrease the natural beauty, the presence of weeds may also enhance the maintainance cost.

3.1 The Concept of Weeds

Weeds are often defined as unwanted plants, misplaced plants, or plants with unknown benefits. These definitions show human subjectiveness and thereby the weed definition is dependent on human background and interest. Therefore, plants classified as weeds are various. Bridges (1999) mentions this phenomenon as social perspectives of weeds, therefore, plants determined as weeds for one society may be important plants for others.

The term weed arises due to human needs. Historicaly, this term is used to identify dan classify plants not wanted by human in any places like houseyards, recreation areas, or other places determined what plant are allowed to exist. Radosevich et al. (1997) states that this view is an anthropogenic concept and, therefore, weed arises from human views and needs. Weeds are also defined as plants existing with no values and in general grow fairly fast (Merriam-Webster, 2017). *Weed Science Society of America* (WSSA) also defines weeds as all unwanted plants or plants disturbing human activities and interests. Navas (1991) defines weeds as plants that are able to develop their population so that they are able to enter particular habitats and depress the main plants ecologically or esthetically wanted. Ross dan Lembi (2008) defines weeds as plants that are competitive, persistence, disturbing, and destroying. Therefore, weeds stimulate human to control. All these views intergrate human views on weeds based on human interests, particularly related to plants and weeds as components of ecosystems, particularly ecosystem of agricultural lands.

Out of the above views, it can be concluded that any particular plant can be classified as weed under specific condition determined by human interests. Any particular plant is classified as weed not based on where and in what condition this plant grows. Human perception and interest are more determining and, therfore, any particular weed is not always classified as weed because its role may be different depending on condition and situation (Sriyani, 2010).

3.2 Weeds as Pioneer Vegetation

Weeds are competitive and may exist in extreme condition due to their root excretion like allelopathy and organic acids. Other fact shown by weed researchers is that most of the important weed in Indonesia and other parts of the world is included as C-4 plants (Holm et al., 1977 dan Ziska, 2003). This fact is the main reason for their fast growing character and high efficiency in utilizing sunlight energy. C-4 plants in general show high phostosynthetic efficiency, and optimum photosynthesis temperature compared to C-3 and CAM plants. These characteristics cause weeds to grow faster and occupy empty room earlier than other plants. Weeds are pioneer plants.

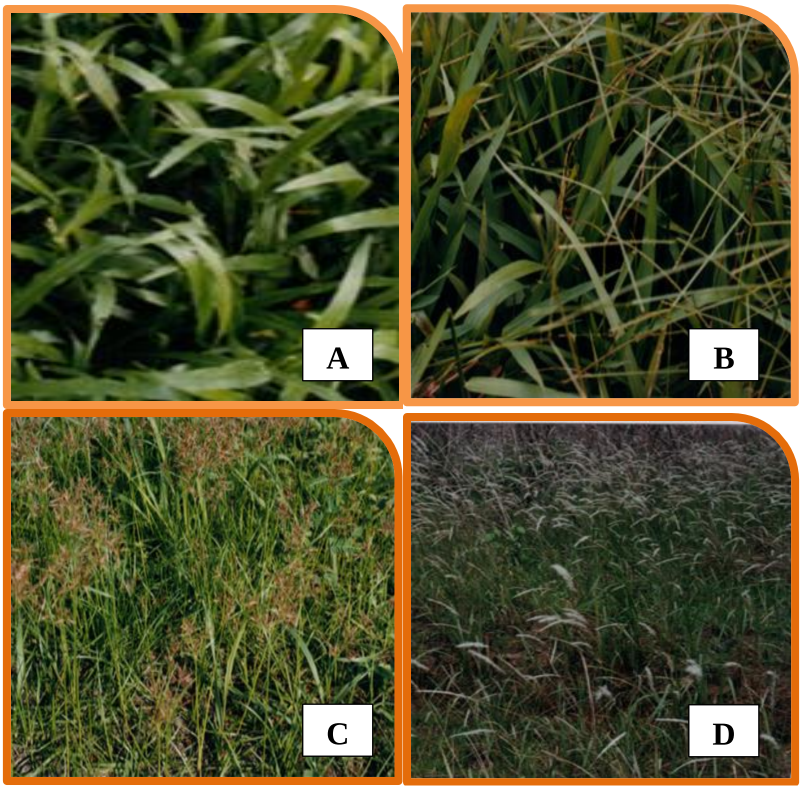

Fig. 3.1 Selected tropical grass-weeds of Indonesia
(A - *Axonopus compressus* (SW) Beauv. , B - *Paspalum conjugatum* Berg., C - *Cyperus rotundus* L., and D - *Imperata cylindrica* (L.) Beauv.) (Sriyani et al, 2013).

Fig. 3.2 Selected tropical broad-leaf weeds of Indonesia
(A - *Mimosa invisa* Mart. Ex Colla, B - *Mikania micrantha* Kunth., C - *Chromolaena odorata* (L.) King & Robins, and D - *Centella asiatica* (L.) Urb.).

Ecologically, weeds are considered important component of an ecosystem. Their existence is a part of plant community succession. Upon disturbance on an ecosystem caused by a particular anthropogenic or natural phenomenon like agriculture, forest clearing, forest fires, or drought, plant community may encounter succession, called as secondary succession, controlled by climate and soil fertility (Radosevich et al., 1997). Similar composition of forest vegetation may arise after a series of vegetation changes through the processes of forest recovery. However, a radical changes caused by natural disasters may emerge a physical spaces in the new ecosystem for plant colonization. This space is usually fastly occupied by pioneer plants like weeds. Weeds may dominate the spaces for years or hundreds of years. This normal process of colonization may seriously affect the existence of more economical plants.

Some weeds are pioneer plants due to their fast growing characteristics and their ability to propagate extensively with short life cycle. *Alang-alang* (*Imperata cylindrica*) is a very good example. This weed may produce 44 new rhizomes of 13 m long with as many as 646 tubers in 18 weeks of growth (Sriyani, 1993). An experiment in di Gunung Madu Plantation, Central Lampung, shows that a three month growth of on tubers of *teki* (*Cyperus rotundus*) in the absence of other weeds produced as many as 524 new tuber. This data show that weeds demonstrate the ability to quickly produce vegetative and generative organs such as rhizomes or tubers.

The biological invasion grows with modern transportation, global trade, transportation of germ plasms for research and development, biological conservation, and also tourisms. Biologists and weed scientists are now aware that the spread of weeds is not only by winds or water, but also by human. Human spread most beneficial plants from one area to others. This activity may sometime cause disasters. For example, *alang-alang* was imported into the United States of America from tropical lands for land conservation to cope with erosion and landslide problems but after years became a serious weed in some states of the country like Florida and Louisiana (Tabor, 1949). Kogan and Jepson (2007) argue that biological invasion influence not only the local species and agroecosystem but also the food safety and security as well as public health. *Acacia nilotica (Prickly Acacia)*, a native plant of the subtropics of Africa, Middle East, and India, was brought to Australia for an esthetical plant and later for a shading plant for animals in pasture but later become weed in animal pasture (Bolton, 1989). This plant is also a serious weed in the National Park of Baluran, East Java, while *Meremia peltata* invaded the National Park of South Bukit Barisan, West Lampung, and endangered the local plants. The invasion of *Acacia nilotica* is also reported to disturb the ecosystem, lower the existing biodiversity, and endanger the population of wild bulls (*Bos javanicus*) (Siregar dan Tjitrosoedirdjo, 1999).

Most of plants introduced into Indonesia were important crops like rubber, oil palm, cacao, soybean, corn, and cassava (Tjitrosoedirdjo et al., 2016). However, some plants introduced become invasive like *eceng gondok (Eichornia crassipes)*, *akasia arabika*, *kirinyuh (Chromolaena odorata)*, and *sembung rambat (Mikania micrantha)*. Most of the 75 invasive plants reported by Tjitrosoedirdjo et al. (2016) have long been known as weeds in agricultural lands and some are important weeds in Indonesia like *Imperata cylindrica* (*alang-alang*), *Eichornia crassipes* (*eceng gondok*), *Mimosa pudica* (*putri malu*), and *Mikania micrantha* (*sembung sambat*) shown in **Fig. 3.2**. Some weeds also exist in non-agricultural lands called environmental weeds, which may negatively affect plant biodiversity. Hejda et al. (2009) conclude that most invasive weeds may decrease the species population and biodiversity of plant community. Therefore, the introduction of plants needs previous intensive study on the plant biology and physiology.

3.3 General Effects of Tropical Weeds on the Soil Environment

As pioneer plants during succession, weeds may preserve the equilibrium and sustainability of an ecosystem. The presence of weeds in the environment may physically lower the soil erosion and chemically increase the soil organic matter content and accelerate the nutrient cycles. Weeds are also environmentally present as foods for animals, shades for birds and predators for pests and diseases, as well as genetic sources for plant breeding (Adkins, 1997). Some other uses of weeds have been investigated and applied for human welfare, among which the use of weeds as raw materals for medicines and cosmetics, raw materials for foods and feeds for animals, and also their uses in creative industry and arts. Some other uses are as raw materials for biopesticides. Rhizomes of *alang-alang* (*Imperata cylindrica*) and leaves of *Oxalis corniculata* (*blimbingan*) have long been known as fever medicine. *Pegagan* (*Centella asiatica)* has been used for a fat burner in a diet and is developed for medicine of cancers.

Good weed management had been shown to drastically decrease the soil erosion in hilly coffee plantation of West Lampung (Sriyani et al., 1999). The amount of soil eroded in manual weed control plot (manual weeding) was 25.270 kg ha^{-1} 6-month^{-1}. However, if the land was covered by natural plants, the soil erosion was drastically reduced to 124 kg ha^{-1} 6-month^{-1}. The rate of erosion was even lower in the experimental unit covered with *Paspalum conjugatum* to be 29 kg ha^{-1} 6-month^{-1} or about 99% lower (**Table 3.1**).

These phenomena show that the use of *P. conjugatum* and natural weeds decreased the levels of soil erosion in coffee plantation. However, the total coverage of land with weeds may cause environmental problems. Farmers must intensively manage weeds so that they may not disturb the main plants. The presence of weeds may cause more pests and deseases because lands are shaded and moisturized. Limiting weed coverage only in particular parts of lands like particular strips may solve this problem so that plant maintenance and harvesting are not inhibited.

Table 3.1. The decrease in soil erosion rate in coffee plantation of West Lampung by weed coverage.

Soil Concervation Method	Erosion Rate	
	kg ha^{-1} 6 $months^{-1}$	%
Control (Local Farmers)	25.270	100
Paspalum conjugatum	29	0.11
Natural Weeds	124	0.49

Sriyani et al. (1999)

Even though not as significant as those fully covered, the use of various soil covers in strips (one strip of soil cover every 3 strips of crops) lowered the soil erosion in coffee plantation of West Lampung (**Fig. 3.3**). The erosion was reduced by 70-80% in lands with strip of *Arachis pintoi*, *Axonopus compressus*, and *Cymbopogon citrates* compared to those without strips of soil covers. Periodic cutting of weeds on strips about 40 cm also decrease the soil erosion rates twice better than those not cut (**Fig. 3.3**). This phenomena indicate that, if properly managed, weeds can be used to conserve the agricultural land particularly to depress the soil erosion.

Other than the use to conserve soils, particularly in decreasing the soil erosion rates, weeds are also empoyed to increase the soil fertility. *Setaria plicata*, *Paspalum conjugatum*, *Crotalaria lappacea*, *Asystasia gangetica*, and *Widelia montana* show high potences to increase the soil organic C, soil CEC, and soil pH (Sembodo et al., 2012). Salam et al. (1997a) also reports that *alang-alang* (*Imperata cylindrica*) neutralized the pH of the root zone of soil poluted with Pb and decreased the solubilities of Fe, Cu, and Pb. *Alang-alang* was also reported to increase the activities of acid and alkaline phosphatases that are important in accelerating the decomposition of organic P compounds producing inorganc P easily absorbed by plant roots (Salam et al., 1997a).

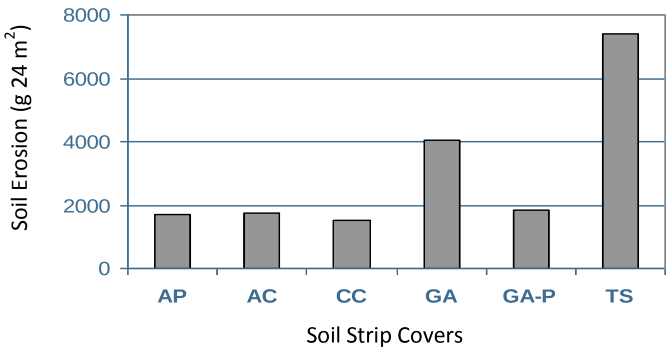

Fig. 3.3. Soil erosion rates of coffee plantation in West Lampung treated with strips of weeds - AP *Arachis pintoi*, AC *Axonopus compressus*, CC *Cymbopogon citrates*, GA uncut natural weeds, GA-P cut natural weeds, TS without strip (Sriyani et al., 2009).

As pioneer plants, weeds may easily adapt to the soil condition and quickly grow and accumulate biomass (**Fig. 3.4**). The production of high biomass may enable the use of weeds to improve the soil fertility. Some species of tropical weeds are potential as biomass producers (Sembodo et al., 2012). Among these weeds are *Crotalaria lappacea*, *Asystasia gangetica*, *Chromolaena odorata*, and *Widelia sp.* of broad-leaf weeds and *Imperata cylindrica*, *Setaria plicata*, and *Paspalum conjugatum* of grasses. However, the effect of each weed at improving the soil fertility, particulary Total N, Organic C, and CEC, is different (**Tabel 3.2**). *Crotalaria lappacea* and *Asystasia gangetica* are shown to produce high biomass and increase soil organic C and CEC, while *Widelia sp.* significantly improves the soil available P. Therefore, the presence of weeds improved not only the soil organic matter but also other soil chemical properties and also soil physical properties.

The presence of weeds is also reported to increase the soil enzymatic activities including those of acid and alkaline phosphatases, β-glucosidase, and arylsulfatases (Salam et al., 2001). Weeds also increase the soil available P (Salam et al., 2001). Some weed species are also reported to be bioindicators in bioassay. Bioassay is a method to measure response of a particular living organism to determine the existence or concentration of a chemical in a substrate (Satelmann, 1987). Bioassay to detect herbicides usually employs herbicide sensitive plants. In addition to detect the concentration of herbicides and to predict the herbicide resistence, bioassay is also used to know the resistence of weeds on herbicides.

For example, the resistence of *Setaria viridis* on herbicide trifluralin (Beckie et al., 1990). The method is also used in allellopathy research. For example, the use of bioassay to evaluate the allelochemicals of sweet potato (*Ipomoea batatas*) at inhibiting the growth of *Cyperus esculentus* (Harrison dan Peterson, 1994) and *Cyperus rotundus* (Peterson dan Harrison, 1995).

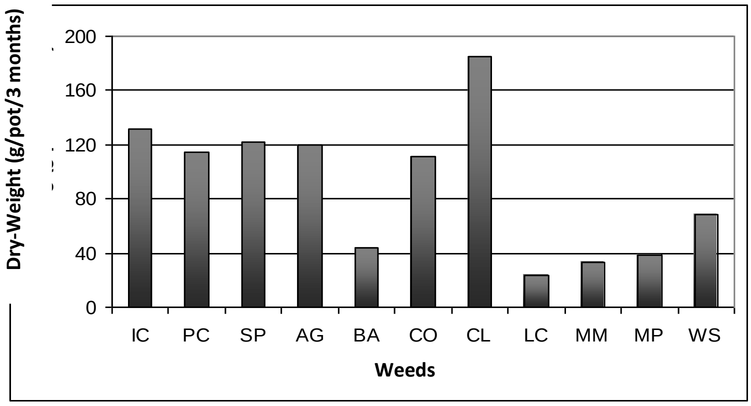

Fig. 3.4. The increase in soil biomass as affected by weeds (IC *Imperata cylindrica*, PC *Paspalum conjugatum*, SP *Setaria plicata*, AG *Asystasia gangetica*, BA *Borreria alata*, CO *Chromolaena odorata*, CL *Crotalaria lappacea*, LC *Lantana camara*, MM *Mikania micrantha*, MP *Mimosa pudica*, and WS *Widelia sp.* (Sembodo et al., 2012).

3.4 Methods of Weed Control

Weed management comprises every aspects used to make sure that the negative effects of weeds are minimum. The negative effects may relate to crop production, crop quality, and other aspects of human activities. Weed control may refer to the method to eliminate or decrease the population of weeds in a particular land. This means that weed control, which is intended to decrease the weed population, is only one important component of weed management. As pointed out by Bridges (1999), weed management must include the following aspects: the inclusion of ecological principles, the use of weed – plant competition principles, consideration on both economy and environment, integration of all available control methods that may include selective herbicides, and control of weed management by professionals.

Table 3.2. The effects of weeds on some chemical properties of soil from Great Giant Pinapple plantation Central Lampung.

Weeds	Total N ($g\ kg^{-1}$)	Avail. P ($mg\ kg^{-1}$)	Org. C ($g\ kg^{-1}$)	CEC ($cmol_c\ kg^{-1}$)
Control (without Weeds)	1.0	11.07	6.4	4.78
Crotalaria lappacea	1.2	7.09	10.8	5.13
Asystasia gangetica	0.9	9.16	11.0	6.66
Chromolaena odorata	1.0	10.13	7.7	4.68
Widelia sp.	1.0	18.36	9.0	5.58
Imperata cylindrica	0.9	7.29	8.4	4.75
Setaria plicata	1.0	9.69	9.5	4.93
Paspalum conjugatum	1.0	7.90	9.6	5.23

Sembodo et al. (2012)

The cost for weed management and weed control comprises a significant amount of farmer's expenditure. Hundreds billions dollar is spent yearly for this purpose around the world, including that for the procurement of control tools and machines, herbicides, and other chemicals as well as for labors. In Indonesia, the expenditure in 2006 alone for herbicide procurement amounted to 99 million euros or about 1.4 trillion rupiahs (CropLife Asia, 2007). These figures indicate that weeds are so important part in agriculture that they need particular attention. The high expenditure in weed control shows that farmers concern about the negative effects of weeds on crop production, environment, health, and natural beauty.

Weed control techniques may ecologically also affect the soil environment. Some soil properties may be influenced by the presence or the absence of weeds. Some chemicals employed in weed management may also directly or indirectly affect the soil properties.

Weed control are in general classified into six different methods, i.e. preventive control, culture technique control, physical-mechanical control, biological control, chemical control, and integrated control. Each method possesses its own benefits and drawbacks.

Preventive Weed Control

The principle of preventive weed control is to limit weed investation and to depress their growth and spreading so that other methods of weed control is not necessary or at least minimized (Sriyani, 2010). Some steps are included in the preventive weed control, among which are the use of weed-free seeds or seedlings, the use of weed-free agricultural tools and other production facilities, good sanitation in areas for agriculture, and the implementation of laws for the transportation of materials and quarantine of plants and animals.

Weed Control with Culture Technique

In a culture technique, weed control is conducted by availing an optimum growing environment for the crop plants, which is not suitable for weeds so that the growth of weeds is inhibited (Sriyani, 2010). This theory is closedly related to good agricultural practices like the use of good seeds or seedlings, the use of good and competitive plant variety, the management of planting method, distance, and time to ensure optimum growth of crops, the practice of planting rotation to inhibit particular weed dominance, the use of mulch and soil conditioners or companion crops and multiple cropping, and adequate plant maintainance like proper fertilizarion and irrigation. The use of herbicide-resistant crop plants may also important at any time herbicides are applied without endangering the crop plants.

This method, along with the preventive method, is in general considered the first barrier to control weeds in agricultural system. These methods are economically efficient because they include the process of land preparation. The drawbacks of these methods are the necessity to make good planning and coordination, the necessity to have basic knowledge on ecology and characteristics of the existing weeds, and the results are not instantly observed. However, if properly conducted, these methods may lower the problems of weeds. The attenuation of weed problem may then lower the plant mainitenance cost because these methods need limited control employing other methods of weed control or may not need other method of weed control due to the limited and insignificant weed population.

Mechanical and Physical Control of Weeds

The principles of mechanical and physical weed control is to destroy or to eliminate the physics of weeds with the objective to kill or inhibit the growth and propagation of weeds (Sriyani, 2010). This method has been so popular for centuries and is a common practice for farmers and plantation. It is popular because this method is the easiest and probably relatively cheap and the result is fairly instant. Included in this method are hand weeding or foot-stepping, weeding with some tools like blade, shovel, hoe and cutting machines, weed burning or flooding, as weel as soil tillage.

However, even though popular and easy for farmers, this method shows some weaknesses, among which it may destroy crop rooting system and may ease the soil erosion. If conducted with tractors or machines with weed cutters, this method may also cause soil compaction, particularly if conducted with high frequences for a long time. Weed burning may also cause air polution and of course exhaust the soil carbon pools. Other weakness of this method is that weed may quickly regrow particularly those with really short life cycles like *alang-alang (Imperata cylindrica)* and *Asystasia sp.* and weeds that produce abundance seeds like *Ageratum conyzoides*. Sriyani (2010) reports that the growth of weeds 8 weeks after controlled with this method (weed clearing) regrow much faster that those controlled with herbicides.

Biological Weed Control

Using this method, weeds are controlled by employing natural enemies of weeds. This method works based on the understanding that every organism has its own enemy in its original habitat to maintain its population equilibrium. In general researchers agree that in its new habitat any plant tends to become weed because plant grows and propagates relatively quickly and dominates, and then disturb the new ecosystem. In addition due to their fast gowth, the ability of weeds to dominate new habitat is also caused by the absence of its natural enemy.

Therefore, biological weed control is conducted by introducing weed natural enemies to make new ecosystem equilibrium so that weed may not cause problem.

The positive thing of this method is the permanent effect of the control so that after treatment no more intervention to lower the weed population once the equilibrium is attained. The increase in weed population may always be followed by the increase in natural enemys population because their feeds is enough. On the other hand, the weeds may soon decrease and cause the decrease in their natural enemys population because of less feeds available. This trend will again stimulate the increase in weed population and this cycle will continue with time. This is a perfect equilibrium that occurs in an ecosystem which control the population of weeds and their natural enemies and neither one dominates and causes problem in an ecosytem.

Weed biological control has been widespreadly practiced in some countries. As many as 391 biocontrol agents with 150 target weeds had been released in 1990 in five most active countries in biocontrol, i.e. The United States of America, South Africa, Canada, Australia, and New Zealand (McFadyen and Wilson, 1997). Australia was the most active country in developing and applying weed biocontrol. Julien dan White (1997) report that there were 174 biocontrol projects by CSIRO Australia with 101 weed species targets with a total of 178 different species as biocontrol agents. Out of the 174 projects about 34% was successfull, out of the 101 weed targets about 48% was successfully controlled, and out of the 178 biocontrol agents 34% was considered effective. Some of the successfull biocontrol was the control of cactus *Opuntia sp.* using the larva of *moth Cactoblastis cactorum*; the control of *kiyambang* (*Salvinia molesta*) using beetle *Cyrtobagous salviniae*; the control of *Kirinyuh* (*Chromolaena odorata*) using caterpillar *Pareuchaetes pseudoinsulata*; and the control of *Alternanthera philoxeroides* using beetle *Agasicles hygrophila*.

The release of biocontrol agents in Indonesia had been conducted for several important weeds in agricultural lands. Some of them were imported from Australia, among which are caterpillar *Parauchaetes pseudoinsulata* to control *Kirinyuh* (*Chromolaena odorata*), beetle *Neochetina bruchi* and *Neochetina eichorniae* to control *eceng gondok* (*Eichornia crassipes*), beetle *Cyrtobagous salviniae* to control *kiyambang* (*Salvinia molesta*), and stem borer *Carmenta mimosa* to control *putri malu* (*Mimosa pigra*).

Chemical Weed Control

Chemical control of weeds is the method to control weeds by using lethal chemical substances, organic or inorganic. The chemical control of weeds using herbicides is now probably the most popular method, both in Indonesia and in the world, together with the mechanical physical technique. The total selling of herbicides in Indonesia for the year of 2006 reached 246.8 millions euros or about 3.5 trillion rupiahs, 43% of which was the selling of insecticides, 15% was of fungicides, while the selling of herbicides was 40% or about 99.1 millions euros or about 1.4 trillions rupiahs (Croplife Asia, 2007).

There are some reasons for the popular use herbicides by farmers: efficient use of labor and time, economical (cheap control cost), plenty of available choices and easily obtained in the market, able to control weeds difficult to control by the mechanical-physical techniques like perennial weeds, and give a clear result with good controlling effects. A great deal of research data show that herbicides were able to depress weed growth for a period 12 weeks or 3 months after application, comparable to the method of mechanical physical control (weed clearing) which needs more time, labors, and funds. Glyphosate 620 AS and 480 AS were able to depress weed dry-weight of oil palm, rubber, coffee, and cacao until 12 weeks after application (WAA), meanwhile sulphonate 480 AS and 240 AS as well as paraquate applied for no-tillage land preparation of upland rice was also able to depress the weight of weed until 7 WAA. In paddy fields siklosuphamoron and sihalofop butil were able to control weeds until 12 WAA (Sriyani et al., 1998; Sriyani 1999; Sriyani et al., 2001; Sriyani et al., 2003; and Sriyani et al., 2004).

However, the use of herbicides may also give negative effects on human life and environment. This occurs due to various reasons among which: inappropriate handling and application, user negligence of not using approriate safety tools during application, inaccurate dose and concentration, wrong time of application, and inappropriate types of herbicides for particular weeds. Recently, the continuous use of herbicides for more than 50 years globally has caused the development of several herbicide-resistant-weed species, which makes the management of weeds are more complicated and expensive.

The use of herbicides must fulfil five accuracies, i.e. accurate target weeds, accurate types of herbicides, accurate dose of herbicides, accurate time of herbicide application, and accurate method of herbicide application. Farmers must first make an accurate identification of problem weeds. This step is very important to accurately choose approriate herbicides for particular weeds. In fact there are various herbicides with various different active ingredients with different physiological characteristics and effectiveness towards weeds. In 2008, there were 1.082 trademarks of pesticides among which 200 were trademarks of herbicides with more that 30 active substances (Komisi Pestisida Indonesia, 2008). Therefore, to accurately determine herbicides to apply, knowledge on weed types and on the method to choose accurate herbicides are of great importance. It is also important to determine accurate herbicide dose and concentration as recommended in herbicide label. Lower doses may lower herbicide effectiveless, while higher dose may waste herbicide and may also contaminate the environment (Sriyani, 2010). Herbicides must also be applied in time. In general, the best time to apply herbicides is during weed growth phase at which weeds are most vurnerable at suitable environmental condition. In general it needs several hours (about 2-5 hours) for herbicides to enter plant tissues, therefore, farmers must avoid raining time to apply herbicides. Herbicide is generally applied most accurately in a clear sunny morning with no wind. Herbicides must also be applied with an approriate technique using appropriate application tools for particular land condition and weed types and is also affected by the skills of operators in operating application tools so that the herbicide applied is evenly distributed.

It is obvious that the success and safety of chemical weed control using herbicides is dependent on various things all of which are related to the knowledge and skills of farmers and also farmers awareness to control safety aspects in applying and handling herbicides. However, based on experience, farmers like completely clear lands and, therefore, they tend to apply herbicides repeatedly more that actually needed. Miscalculation of herbicide dose and concentration, low understanding of the working mechanism of herbicides and of the negative effect of herbicides on land quality, crop productivity, and the probability of weed resistance on herbicides are some of the weaknesses in applying chemical weed control (Sriyani, 2009). Therefore, efforts must always be conducted to educate farmers on the importance of safety and the negative effects of herbicides on human life, and enviromental quality in using herbicides without sacrifying land and crop productivity.

Efforts to ban farmers not to use herbicides is not possible because there is condition where applying herbicides is the last choice to help farmers. Therefore, the best approach is to manage the use of herbicides wisely by enhancing knowledge and skills among farmers. Thereby, farmers may control weeds more effectively by using various herbicides combined with other methods of weed controls so that the effectiveness of weed control stays high and at the same time the negative effects of herbicides are minimized and also limit the soil erosion particularly during rainy seasons (Sriyani, 2010).

Key Questions

1. What are the negative effects of weeds on crop production and farmer's profit? Explain!
2. What is allelopathy and how does it affect the production of crop plants? Explain!
3. How does the presence of weeds directly or indirectly pollute the soil and water environment?
4. How do weeds disturb the natural ecosystem?
5. What characteristics of weeds may determine their ability to invade and displace indigenous plants?
6. Why does *alang-alang* quickly grow, propagate, and dominate the new ecosystems?
7. Explain the weed-root excretion and its effect on the soil properties! Give some examples!
8. Explain the effects of weeds on human and animal health! Give some examples of this phenomenon!
9. What is the definition of weeds and explain how it is developed! What factors mostly influence the definition?
10. Explain why weeds are so progressive and invasive? What characteristics causing this characteristic? Explain!
11. Why are C-4 plants, like most weeds, very competitive? Explain! What are the consequences?
12. Why weeds are considered an important component in an ecosystem? Explain! How is role and position of weeds among the vegetation in an ecosystem?
13. Explain plant succession! Why and how does succession occur in the ecosystem?
14. Why do weeds in general become pioneer plants? Explain!
15. What is biological invasion? How does it happen in an ecosystem? Explain!
16. Explain the effects of weed presence on soil erosion and the changes in some soil chemical properties like organic C, pH, and CEC!
17. How does *alang-alang* affect the soil pH and enzymatic activities?
18. Why do weeds act as biomass producers in the environment? Explain!
19. What are the difference between weed management and weed control? Which one is more important?
20. Explain the superiorities and the drawbacks of the methods of weed controls: preventive, culture technique, mechanical-physical, biocontrol, chemical, and integrated!

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21. Which method of weed control is safe and efficient? Explain and compare with the most popular control method!
22. To safely applying the chemical weed control, farmers must master five accuracies. Explain!

Chapter 4

Effects of Forest Conversion

Land-use conversion may cause tremendous effects on plant cover, soil biodiversity, and soil properties. Salam (2014; 2017) shows that forest conversion from primary forest to secondary forest and finally to coffee plantation and the more intensive uses of cultivated lands caused significant changes in weed dominances and soil chemistry and fertility. Lampung that was originally covered by the primary forest has changed to the secondary forest and a big part of it had in the last five decades been converted to plantations and other uses such as residential areas and cultivated lands. The composition of West Lampung area, for example, is shown in **Table 4.1**, comparing the composition between the existing land-uses in 1978, 1984, and 1990, only about 12 years duration from 1978 to 1990. This trend alone tells about the very significant changes in plant cover, soil biodiversity, and soil chemistry and fertility since every land-use may show different covers, biodiversity, and soil chemical and fertility properties.

Clearly shown in **Table 4.1** that in 1978 the primary forest covered about 32.60% of the area. Six years later, the coverage decreased to 21.39% in 1984 and to 12.72% for the following 12 years in 1990 (Salam et al., 1998b). The decreases were also observed in grasslands and shifting cultivation lands. Grassland decreased from 18.44% after 12 years from 1978 to 1.12% in 1990. The secondary forest decreased from 16.20% in 1978 to 10.79% in 1984. A significant increase in the secondary forest in the period of 1984 to 1990 was probably due to primary forest conversion to secondary forest or replanting by reboisation project conducted by the goverment. On the other hand, the monoculture plantation, particularly those planted with coffee, increased drastically after six years from 20.83% in 1978 to 41.77% in 1984 (Salam et al., 1998b). The coverage of mixed plantation also increased drastically from less than 1% in 1978 – 1984 to almost 20% in 1990. The increase in coverage was also observed for paddy fields, residencial areas, and ponds. Observation in the field showed also that the land conversion were still progressing and were intensified by the development of human population and economic pressures.

Table 4.1. The changes in the land-use percentages in West Lampung, Indonesia, in the period of 1978 – 1990* (after Salam, 2014).

No.	Land-Use	1978	1984	1990
1	Primary Forest	32.60	21.39	12.72
2	Secondary Forest	16.20	10.79	18.05
3	Grass Lands	18.44	16.98	1.12
4	Dry Lands (Food Plants and Vegetables)	2.20	1.07	0.12
5	Dry Lands (Shifting Cultivation)	4.81	0.33	0.00
6	Plantations (Monoculture)	20.83	41.77	41.11
7	Plantations (Mixed)	0.93	0.95	19.26
8	Paddy Fields	2.92	5.02	5.35
9	Ponds	0.03	0.01	0.07
10	Residence Areas	1.03	1.70	2.20

*Adapted from Salam et al. (1998b)

The changes in land-uses may surely affect the land and vegetation cover including weed types and coverage. These changes may change the microclimate and the soil biodiversity and eventually change the soil biology and microbial population and activities and the soil chemistry and fertility. Deforestation from the primary forest to secondary forest and coffee plantation had been reported to change the weed dominance (Salam et al., 1998b; Oki et al., 1999), the soil chemistry, biochemistry, and fertility (Salam et al., 1998b; Salam et al., 1999a; 1999b; Salam et al., 2001), heavy metal solubility (Salam, 1999; Salam, 2017). Some soil fertility indices like soil CEC, C and N contents, and enzymatic activities were in general higher in primary forest that those in secondary forest and coffee plantation and cultivated lands (Salam et al., 1998b).

4.1 Effects on Weeds and Other Vegetation

Changes in plant cover and microclimate may change the weed and vegetation dominance. Salam et al. (1998b) report that the primary forest of Budi Syukur in West Lampung was dominated by vegetation of Family *Ficus* like *Ficus septica*, *F. ampelas*, and *F. variegata*, and those of Family *Mevaceae* (*Hibiscus spp*.). Also found at lower frequencies and densities were *Shorea spp*., *Hopea spp*., *Dipterocarpus sp*., and *Dryobalanops spp*. In the primary forest of other locations the dominant vegetation were *Shorea* spp., *Hopea spp*., *Dipterocarpus sp*., and *Dryobalanops spp*. The dominant vegetation of the secondary forests at all locations were *Ficus septica*, *F. ampelas*, and *F. variegata*, and the Family of *Mevaceae* (*Hibiscus spp*.). Tomato, beans, and paddy were grown in the cultivated lands.

The differences in the dominant vegetation had been reported to significantly affect the soil chemistry and fertility of soils. This suggestion is supported by abundant research results (Salam, 1996; Salam et al., 1997c ; Salam et al., 2001; Rumpel et al., 2015; Baumert et al., 2018). For example, land-use change of bushes to continuous cassava plantation in Gunung Batin North Lampung, Indonesia, also resulted in the significantly decrease in soil CEC, organic matter content, and available P (**Table 4.2**); also the decrease the availabilities of micronutrients (Salam et al., 1997c). Treatment with cover vegetation for more than 3 years significantly affected some soil chemical properties of coffee plantations (**Table 4.3**). *Paspalum conjugatum* or natural vegetation caused higher values of organic C, total N, available P, and enzymatic activities than did the control treatment with only coffee plants. *Paspalum conjugatum* was also observed to give higher effects that did natural vegetation. The same effect but with lower values was also observed in subsoils (Salam, 1996; Salam et al., 2001). The natural vegetation comprises some dominant vegetation or weeds i.e. *Chromolaena odorata*, *Clibadium surinamense*, *Cludemia hirtam*, *Imperata cylindrica*, *Melastoa affine*, *Mikania micrantha*, and *P. conjugatum* (Oki et al., 1999).

Table 4.2. The changes in soil pH, organic C, total N, and available P of cassava plantation in Gunung Batin Central Lampung Indonesia* (After Salam, 2014).

Period of Cultivation (Years)	pH	Organic C (g kg^{-1})	Total N (g kg^{-1})	Available P (mg kg^{-1})
0**	4.7	43.0	2.60	5.03
1 - 5	4.5	20.0	1.00	24.7
6 - 10	4.4	12.8	0.80	7.70

*Adapted from Salam et al. (1999b); **Bushes adjacent to the plantation.

4.2 The Effects on Soil Enzymatic Activities

To obtain energy from organic matters, soil organisms including microorganisms, macroorganisms, and plant roots produce some enzymes. These enzymes work on the bio-cycles of some nutrients in the soil – plant system (Tabatabai, 1982; Tate III, 1987). Like any other enzymes, as biocatalysts these soil enzymes accelerate the soil biochemical reactions that change reactants to form new products without themselves involve in the reactions. After any enzymatic reactions, the soil enzymes may return to their original forms and may re-participate in the same biochemical reactions. There are several enzymes produced by microorganisms, macroorganisms (for example earthworms), and plant roots (Hayano, 1973; Alexander, 1977; Ross and Cairns, 1982; Frankenberger, Jr. and Dick, 1983; Baruah and Mishra, 1984; Satchell et al., 1984; Satchell and

Martin, 1984; Nasution, 1986; Tate III, 1987; Park et al., 1992; Sakai and Tadano, 1993; Joner et al., 1995; Joner and Jakobsen, 1995; Dharmakeerti and Thenabadu, 1996; Vinotha et al., 2000; Supriatin et al., 2007). Some of these enzymes live in soils for several days, and some may live for several weeks or months, depending on their forms and susceptibility to decomposition by protease – enzymes that accelerate the decomposition of enzyme proteins.

Table 4.3. The effects of vegetation on some soil chemical properties of coffee plantations in West Lampung Indonesia* (after Salam, 2014).

	pH		Organic C (g kg^{-1})		Total N (g kg^{-1})		Available P (mg kg^{-1})	
	1997	**1999**	**1997**	**1999**	**1997**	**1999**	**1997**	**1999**
A. No Vegetation (Control)								
Topsoil	4.00	3.49	23.1	21.1	1.80	1.50	6.05	2.78
Subsoil	3.87	4.27	11.7	7.8	0.90	1.10	4.67	3.48
B. Grass (*Paspalum conjugatum*)								
Topsoil	4.94	3.87	30.5	29.2	1.30	2.70	4.67	3.52
Subsoil	4.66	4.89	26.1	26.9	2.00	1.90	4.67	3.11
C. Natural Vegetation								
Topsoil	4.58	3.97	12.4	26.7	1.30	2.40	5.36	3.52
Subsoil	4.47	4.56	11.4	20.6	1.10	1,40	4.67	2.81

*Adapted from Salam et al. (2001)

Deforestation may greatly affect the soil enzymatic activities. In general the activities of soil enzymes were reported to be lower in the degraded land-uses like cultivated lands and higher in coffee plantation and the highest were in secondary and primary forest (Salam et al., 1998b). The influence of deforestation on the activities of acid and alkaline phosphatases, urease, and β-glucosidase in West Lampung, Indonesia, is shown in **Table 4.4**. These findings are consistent with the finding by Acosta-Martinez et al. (2007) from North Central Porto Rico (Caribbean) that the activity of β-glucosidase was greater in: forest = pasture > agriculture lands. These findings are also consistent with the previous findings by Trasar-Cepeda and Gil-Sotres (1988). They report that the activity of acid phosphatase was higher in woodland (forest) than that in meadow (secondary forest) and cornfield (cultivated land). More than two decades ago, Ho (1979) also reports that the activity of acid phosphatase was significantly greater in soils of pure red alder and red alder–Douglas-fir forests than that in pure conifer forests or in the pasture. Garcia-Morote et al. (2012) also observe in semi-arid Mediterranean ecosystems of southern Spain that mature woodland showed higher enzymatic and microbiological activities than the younger woodland; the advanced communities of *Juniperus* trees and *Rosmarinus* shrubs exhibited higher enzymatic and microbial activities than did grasslands.

Several other researchers also report some supporting findings. Acosta-Martinez et al. (2008) reports that the activities of some soil enzymes (i.e. β-glucoaminidase, β-glucosidase, alkaline phosphatase, and arylsulfatase were higher (up to 4-fold) in soil under pasture and under trees compared to the soils for vegetable production, related to the higher soil organic C in parture (2-3-fold) and mango (*Mangifera indica*) tree (1.6-fold) compared to soil under vegetable production (15.8 g kg^{-1}) and quenepas (*Melico bijugatus*) trees (15.9 g kg^{-1}). Speir et al. (1980) observe that the degradation of sulfatase in planted soils were slower than those in fallowed soils. They argue that this phenomenon was related to the enzyme temperature-dependent denaturation in the fallow soils.

The activities of enzymes like phosphatases in forest soils were higher than those in agriculture lands (Sakai and Tadano, 1993; Salam et al., 1997d; 1998b). Previously, Duxbury and Tate III (1981) show that, compared to a fallow field, the activities of some soil enzymes were significantly enhanced by grasses and sugarcane plants. Some researchers also show that the activities of alkaline and acid phosphatases were higher in the root zones and decreased to the directions of bulk soils uninhabited by plant roots (Joner and Jakobsen, 1995). Reddy et al. (1987) show higher activities of several soil enzymes in the rhizosphere soils than those in the non-rhizosphere soils. Rao et al. (1990) also report that rhizosphere soils showed higher activities than other soils: 26–158% for acid phosphatase, 66–264% for alkaline phosphatase, and up to 292% for dehydrogenase. Salam et al.

(1999b) also show that the activities of enzymes were dependent on types of plants and length of land cultivation. Root and bacterial phosphatase activities are influenced by tree species (Cabugao et al., 2017).

Forest fires are also reported to influence the soil enzymatic activity. Saa et al. (1993) report that wildfires significantly lowered the activity of acid phosphatase and caused an intense mineralizing effect on organic P, and hence profoundly increased the inorganic P fractions. However, the controlled fire did not affect acid phosphatase and only slightly affected the organic P mineralization and the soil inorganic P fractions. Wildfires are reported to greatly affect the soil organic C and total N. Abelle and Engel (2013) note that burned areas had significantly greater soil C and total N than did unburned areas across communities on the landscape of Mojave Desert.

Table 4.4. The effects of land-use conversion on some soil enzymatic activities in Sekincau, West Lampung, Indonesia* (After Salam, 2014).

	Soil Depth	Acid Phosphatase	Alkalin Phosphatase	β-Glucosidase	Urease
	cm	µg *p*-Nitrophenol g^{-1} h^{-1}			µg Urea $g^{-1}h^{-1}$
Primary Forest	0 – 20	1,092	ND	158	206
	20 – 40	427	349	38	95
Secondary Forest	0 – 20	419	220	79	138
	20 – 40	387	190	39	88
Coffee Plantation	0 – 20	352	209	142	166
	20 – 40	89	33	26	77
Dry Land	0 – 20	238	153	73	108
	20 – 40	72	14	19	63

*Adapted from Salam et al. (1998d); ND Not Determined

The phenomena of lower-activities of soil enzymes in degraded land-uses are related to some soil environmental factors like soil water and temperature, soil C and N, and soil pH. The activities of soil enzymes are generally higher in soils with high temperature and higher water contents or with the increase in soil C or organic matter and N contents, and the increase in soil pH. The changes in the soil environment that cause the changes in these soil properties may also drive the changes in soil enzymatic activities.

Soil water and soil temperature are important soil physical properties and are both closely related and significantly affect the soil enzymatic activities. The activities of soil enzymes increase with the increase in soil water contents and/or temperature until particular values, after which the soil enzymatic activities decline. In case of soil water, the declining pattern is due to the limitation of O_2 diffusion into the soil system which then lowers the respiration by soil microorganisms. The resulted decreases in the populations and activities of soil microorganisms then decrease the production of soil enzymes. In the case of soil temperature, the declining pattern is suggested to be influenced by the enzyme denaturation or the decrease in the activity of soil organisms at temperature higher than the maximum value. Forest degradation might have caused the changes in these two important soil physical properties. Forest degradation may decrease the soil water content and increase the soil temperature.

In a laboratory experiment, Salam (1998a) treated an air-dry Oxisol sample with distilled water at 0 to 20 – 120%. The activity of phosphatase was measured after a one-week incubation at room temperature and produced data shown in **Fig. 4.1**. The activity of phosphatase increased in the presence of 20 – 40% water and reached a maximum value at 40%. The activity of phosphatase then decreased after the maximum activity and the lowest was found at the highest water addition of 120%.

Salam (2014) explains that the experiment was conducted in the absence of plant roots and soil macroorganisms (earthworms). Therefore, the increase in soil phosphatase activity was attributed to the presence of soil microorganisms. The presence of water until 40% (about the soil field water capacity) may have increased the populations and activities of soil microorganisms and, hence, increased the production of soil enzymes. To some extent the presence of more water may have also dissolved part of the adsorbed soil enzymes previously inactive. Above 40%, water filled more soil pores and, hence, limited the O_2 diffusion needed for respiration by microorganisms. The energy obtained by soil microorganisms then somehow became more limited. Consequently, as shown in **Fig. 4.1**, the activity was lower at water contents higher than 40%. This phenomenon is also documented by some other workers (Klein and Koths, 1980; Tabatabai, 1982; Baligar et al., 1988; Yusnaini et al., 2002).

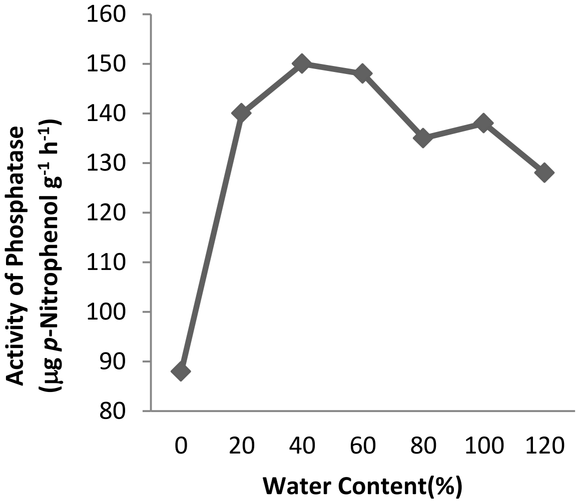

Fig. 4.1. Effect of soil water on the phosphatase activity (Salam, 1998a).

A great deal of researches demonstrate that the changes in the soil enzymatic activities were well-correlated with the changes in the soil organic C and total N. These observations clearly indicate the importance of soil C and N for soil microorganisms, that produce most of the soil enzymes. Organic C is an energy source for soil microorganisms and macroorganisms like earthworms while N is needed to form proteins. Therefore, the presence of lower C and N in the degraded lands may cause lower populations and activities of soil microorganisms and macroorganims and, thereby, produce less amounts of enzymes. Several experimental data support this thesis (Salam et al., 1998; Brzostek et al., 2012). The results indicate that the soil enzymatic activities can be enhanced by addition of organic C (Klein and Koths, 1980; Nannipieri et al., 1980; Harrison, 1983; Trasar-

Cepeda and Gil-Sotres, 1987; Bonmati et al., 1991; Tate III et al., 1991; Martens et al., 1992; Salam, 1996; Deng and Tabatabai, 1996; Salam et al., 1998b; 1999a; 1999b; Brzostek et al., 2013).

For example, it is reported that planting soils of a coffee plantation with *Paspalum conjugatum* or natural vegetation (mixed vegetation of *Chromolaena odorata*, *Clibadium surinamense, Cludemia hirtam, Imperata cylindrica, Melastoma affine, Mikania micrantha*, and *P. conjugatum*) significantly increased the soil organic C and total N content after 3 years. The increase in soil organic C and total N accordingly increased the soil enzymatic activities as shown in **Table 4.5** (Salam, 1996; Salam et al., 2001). Salam et al. (1999a; 1999b) state that the activity of phosphatase increased in correlation with the increase in soil organic C and total N contents. Reported by Brzostek et al. (2013) that the exudation of C by tree roots also stimulated the microbial activity and the production of extracellular enzymes in the rhizosphere.

Table 4.5. The effects of vegetation on some soil enzymatic activities of coffee plantations in West Lampung Indonesia* (After Salam, 2014).

Soil Layer	Ac. Phosp.		Alk. Phosp.		β-Gluc.		Arylsulf.	
	1997	1999	1997	1999	1997	1999	1997	1999
A. No Vegetation (Control)								
Topsoil	123	107	36	44	123	67	458	48
Subsoil	73	109	19	24	76	67	206	72
B. Grass (*Paspalum conjugatum*)								
Topsoil	322	145	104	45	157	117	97	149
Subsoil	281	126	74	30	100	63	21	157
C. Natural Vegetation								
Topsoil	271	156	36	54	168	129	165	143
Subsoil	284	122	27	26	191	60	139	148

*Adapted from Salam et al. (2001); in μg *p*-Nitrophenol g^{-1} h^{-1}

The forest conversion was also reported to affect the shifting in the optimum pH for phosphatases (Salam et al., 1998; Salam, 2014). Optimum pH is a particular pH at which the activity of phosphatase is highest. Land-use conversion from the primary forest to the secondary forest, coffee plantation, and cultivated lands shifted the optimum values for phosphatases to higher values (**Fig. 4.2**). The value of the optimum pH in the primary forest was the lowest i.e 5.0 and that in the coffee plantation was the highest i.e 6.3 (Salam et al., 1998b). Geiger et al. (1998) also observed such phenomenon; Cu caused a shift in the optimum pH of β-glucosidase towards lower pH values.

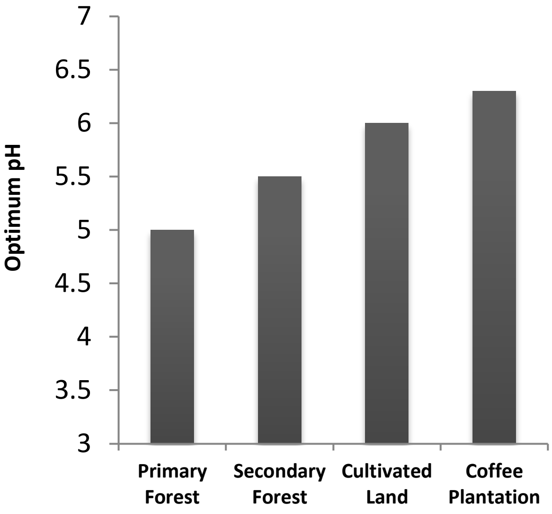

Fig. 4.2. The shifting of optimum pH by forest clearing and land-use conversion (Salam et al., 1998b).

Soil researchers suggest that soil pH may greatly affect the soil enzymatic activities, particularly more important for phosphatases. Soil pH determines the magnitude of their activities and types in soils (Malcolm, 1983; Nakas et al., 1987; Rojo et al., 1990; Reddy et al., 1991; Trasar-Cepeda et al., 1991; Salam et al., 1998b; 1998e; Sarapatka et al., 2004). Sarapatka et al. (2004) document that acid phosphatase activity in the root zones of various species and cereal cultivars was negatively correlated with increasing pH and available phosphorus level in the nutrient medium. Frankenberger and Johanson (1982) also show the dependence of other enzymes i.e. urease and phosphodiesterase activities on soil pH. The activities of soil enzymes may change accordingly as a result of ionization and deionization of the functional sites of the enzyme proteins with the increase in soil pH.

This behavior was clearly demonstrated by phosphatases in tropical soils. Salam et al. (1998b) treated tropical soil samples of some deforested locations in West Lampung, Indonesia, at a series of buffered pH of 3 to 12. The results are shown in **Fig. 4.3**. Similar patterns were also documented by Trasar-Cepeda et al. (1991) and Nakas et al. (1987). Ekenler and Tabatabai (2003) suggest that acid phosphatase was the most sensitive and arylsulfatase the least sensitive to changes in soil pH.

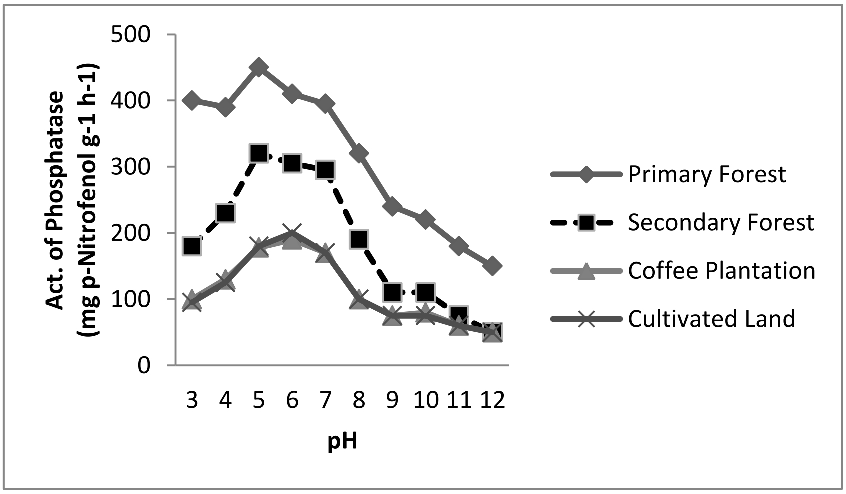

Fig. 4.3. The relationship between phosphatase activity and pH in soils of different land-uses from West Lampung Indonesia (Adapted from Salam et al., 1998b).

Salam (2014) argues that the lower activity of phosphatase at low pH is probably due to the ionization of H^+ ion on the functional groups of enzyme proteins. As the soil pH rises, the ionization of enzyme functional groups progresses and so does the activity of phosphatase. At this range of soil pH, the activity of phosphatase increases with the increase in soil pH until the related optimum pH, in which the activity of phosphatase is highest, the activity declines to an asymptotic value at higher pH. The cause of this phenomenon is unclear. The negative effect of high pH on the populations and activities of particular enzyme producers is probable.

The increasing pattern of phosphatase activities at low pH and decreasing pattern at higher pH above the optimum pH were also previously reported by several workers (Frankenberger and Johanson, 1982; Malcolm, 1983; Trasar-Cepeda and Gol-Sotres, 1988; Rojo et al., 1990; Trasar-Cepeda et al., 1991). Using two series of soils from The United States of America i.e. Aridic Calcixeroll and Umbric Dystrochrept, Rojo et al. (1990) varied the pH and measured the phosphatase activity. These soils showed different optimum pH values. Aridic Calcixerol showed an optimum pH at about pH 10.5 while Umbric Dystrocherept showed an optimum pH at pH 5.5, similar to those reported by Salam et al. (1998b). Rojo et al. (1990) conclude that the alkaline phosphatase dominated alkaline soils like Aridic Calcixeroll whose pH was 8.4 and acid phosphatase dominated acid soils like Umbric Dystrochrept whose pH was 4.3. Differences in the optimum pH of these soils and also of Indonesian soils are depicted in **Fig. 4.4**. A similar pattern was also reported for urease (Gianfreda et al., 1992). The activity of urease increased with the increase in soil pH until the pH value reached 7.0 and then decreased.

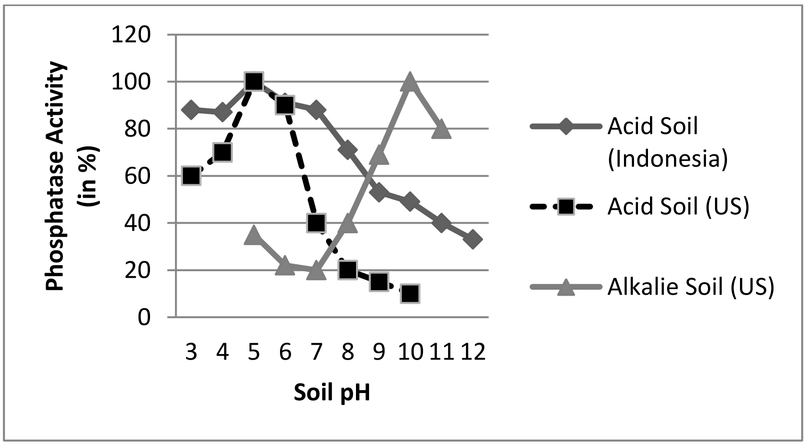

Fig. 4.4. The differences in the optimum pH between acid and alkaline soils (Redrawn from Rojo et al., 1990 and Salam et al., 1998b).

The degree of phosphatase activity with respect to soil pH is different from one soil to another, depending on the types of land-use systems and on the sampling locations. Observation showed that the difference was closely correlated with the contents of organic C and total N. The activity of phosphatase in soils collected from the primary and the secondary forests were in most cases higher than those collected from the coffee plantation and the cultivated lands whose organic C and total N were lower. The activity of phosphatase was also higher in soils collected from Bukit Ringgis and Sekincau than those collected from Tri Mulya, Tri Budi Syukur, and Pura Mekar. However, the pattern of phosphatase activity with respect to soil pH was similar for all soils, independent of land-use systems and sampling locations (**Fig. 4.4**).

Kumar and Wagenet (1984) also report the effect of $CaCO_3$ addition on the activity of urease. The activity of urease decreased significantly upon $CaCO_3$ addition. The decrease in the urease activity reached a value of 29 -68% at $CaCO_3$ addition of 8%. Kumar and Wagenet (1984) argue that the decrease was attributed to the inactivation of urease by amorphous $CaCO_3$. The effect of $CaCO_3$ on the increase in soil pH was also possible to affect the urease activity. The changes in soil pH may also change the dominant microorganisms, especially fungi and bacteria; fungi prefer acid soil environment while bacteria prefer neutral or alkaline soil environment. This phenomenon may affect also the populations and activities of the urease producing microorganisms.

The above observations clearly show that forest conversion such as that occurred in West Lampung, Indonesia, induced a very significant influence on the soil environment. Related to the soil enzymatic activities, forest conversion changes not only the soil enzymatic activities but also the optimum pH values.

4.3 Effects on Soil Chemistry and Fertility

The changes in microclimate and soil microbial population and activities by deforestation may drastically alter the soil chemical and fertility. Salam (2014) shows that the changes in coverage of forest to monoculture plants and cultivated lands may change the status of soil properties. Forest conversion in general degraded significantly four of the important soil chemical properties, i.e. organic matter and total N contents, available P, and CEC (**Table 4.6**). The soil CEC of the primary forest in 1998 was 43.2 $\text{cmol}_c\ \text{kg}^{-1}$ while that of the secondary forest at the time was lower i.e. 18.5 $\text{cmol}_c\ \text{kg}^{-1}$, about the value of subsoil CEC of the primary forest. The soil CEC of the coffee plantation and the cultivated land were about the same, 11.4 and 14.4 $\text{cmol}_c\ \text{kg}^{-1}$, respectively. These values were much lower than those of the primary and the secondary forests.

Table 4.6. Effects of land-use conversion on some soil chemical properties in Bukit Ringgis, West Lampung, Indonesia* (after Salam, 2014).

	Soil Depth (cm)	Elev. (m)	pH (H_2O 1:1)	Org. C (g kg^{-1})	Tot. N (g kg^{-1})	Av. P (mg kg^{-1})	CEC ($\text{cmol}_c\ \text{kg}^{-1}$)
Primary Forest	0 – 20	1,550	4.4	60.4	5.5	4.0	43.2
	20 – 40		4.8	25.0	2.3	1.5	18.2
Secondary Forest	0 – 20	1,400	5.4	41.4	3.4	2.1	18.5
	20 – 40		4.9	21.7	2.0	1.5	13.7
Coffee Plantation	0 – 20	1,120	4.9	28.5	2.3	1.5	11.4
	20 – 40		4.9	10.1	1.2	1.0	12.5
Cultivated Land	0 – 20	1,100	4.4	15.8	1.7	1.5	12.4
	20 – 40		4.3	7.5	0.8	0.7	1.2

*Adapted from Salam et al. (1998b)

The decrease in soil CEC is related to the decrease in soil organic C and organic matter contents (Soil Organic Matter = 1.7 x Organic C) (**Table 4.6**). Organic matter is one of the important sources of soil negative charges emerged from organic matter functional groups like carboxylics, hydroxyls, and phenolics. Speeded organic matter decomposition by land-use conversion might have significantly degraded these functional groups. Therefore, the degradation of soil CEC is well-correlated with the soil C content. In relation to this phenomenon that occurred by organic matter decomposition, the soil total N and available P were also degraded in relation to the decrease in soil C content (**Table 4.6**). Salam (1999) also report that the availabilities of micronutrients in the same locations also decreased by land-use conversion, in correlation with the decrease in soil organic C, total N, and CEC (Salam, 1999). Salam et al. (1999b) also document that the available P decreased by land-use conversion from bushes to sugarcane and pineapple plantation (**Table 4.7**). The available P in bushes is higher than those in soils monoculturally planted with sugarcane or pineapple.

Table 4.7. The available P in sugarcane and pineapple plantations of Central Lampung Indonesia* (After Salam, 2014).

No	Period of Cultivation (Years)	Available P (mg kg^{-1})
	A. Sugarcane Plantation:	
1	0**	8.44
2	3	7.19
3	9	8.16
4	13	23.1
5	20	63.6
	B. Pineapple Plantation:	
1	0***	199.0
2	5	3.17
3	10	3.17
4	15	11.0
5	20	21.5

*Adapted from Salam et al. (1999b); **Bushes adjacent to plantations; *** newly opened

Similar phenomena were observed in the middle terrace of Lampung (Salam et al., 1999a). The land-use conversion significantly changes the soil chemical properties of soils (**Table 4.8**). Table 4.8 clearly shows that the soil organic C, CEC, and exchangeable K were significantly higher in the secondary forest and the plantation than that in the intensively cultivated land like the cassava and the paddy fields. For example, the organic C and CEC in the forest of Mulyasari were 36.6 g kg^{-1} and 14.3 cmolc kg^{-1} while those in the cassava plantation were 9 g kg^{-1} and 4.9 cmolc kg^{-1}, about 25% and 34%, respectively. The land-use conversion in Tulung Boho Central Lampung also showed similar pattern (**Table 4.9**). The soil pH, Organic C, CEC, and Exchangeable K were higher in the secondary forest than those in the other land-use systems. The organic C and CEC in the cassava plantation were much lower than those in the secondary forest, about 53% and 18%, respectively. Salam et al. (1999a) also report that the soil CEC and exchangeable K are well correlated with the soil Organic C with r = 0.68 and 0.63, respectively, indicating the importance of soil Organic C.

Table 4.8. The changes in some soil properties by land-use conversion in Mulyasari Central Lampung*.

Land-Use	pH	Organic C (g kg^{-1})	CEC (cmolc kg^{-1})	Exch. K (mg kg^{-1})
Secondary Forest	5.2	36.6	14.3	73.4
Rubber	5.0	20.9	12.5	38.4
"Sengon"	4.4	11.7	5.6	29.5
Mixed Graden	4.5	21.4	6.8	58.1
Cassava	4.3	9.0	4.9	8.42
Cassava and Corn	4.5	13.8	5.7	29.5
Paddy	4.4	13.4	5.1	8.42

*Adapted from Salam et al. (1999a)

Table 4.9. The changes in some soil properties by land-use conversion in Tulung Boho Central Lampung*.

Land-Use	pH	Organic C ($g\ kg^{-1}$)	CEC ($cmolc\ kg^{-1}$)	Exch. K ($mg\ kg^{-1}$)
Secondary Forest	4.8	24.9	25.9	62.4
Swamp	3.9	19.4	7.7	74.1
Pineapple	4.0	11.8	4.7	3.9
"Sengon"	4.4	16.7	2.7	31.2
Mixed Garden	4.0	10.4	3.1	42.9
Cassava	4.1	13.2	4.7	62.4
Corn	4.7	9.7	1.7	23.4

*Adapted from Salam et al. (1999a)

Key Questions

1. Explain the magnitude of land-use conversion in West Lampung in the period of 1978 - 1984 – 1990? What happen to the primary forest, secondary forest, monoculture plantation, residential areas, etc.? What is your prediction now and in the near future? Explain!
2. What are the effect of land-use conversion on plant covers, weed dominance, and soil chemistry and fertility? Explain!
3. What are the effects of land-use conversion on the soil enzymatic activities? Explain!
4. What was the vegetation dominating the primary forest and the secondary forest? Explain!
5. Explain the effects of long-term land cultivation with cassava on the soil chemistry and fertility!
6. Explain the effects of narural vegetation and *Paspalum conjugatum* on the soil enzymatic activities in coffee plantation of West Lampung!
7. Why do the living things such as microorganisms, macroorganisms, and plant roots produce enzymes? What enzymes are produced by these living things?
8. What is the function of soil enzymes? Explain their roles in nutrient cycles!

9. Explain the lifetime of soil enzymes in relation to proteases existing in the soil environment?
10. Does deforestation affect soil enzymes? Explain!
11. Explain the magnitude of the soil enzymatic activities in different land-use system like primary forest, secondary forest, monoculture plantation, and cultivated land!
12. Explain the difference of soil enzymatic activities in wood land versus meadow and cornfield!
13. Explain the relationship between the functions of plant roots and the soil enzyme production!
14. Explain the effect of fire on enzymatic activities!
15. Explain the effect of soil water content on the soil enzymatic activities! Does it relate to the existence of the enzyme producers?
16. How is the relationship between the soil total N and the organic C content with the soil enzymatic activities? Explain why!
17. Explain the effect of the existence of weeds in coffee pantation on the soil enzymatic activities!
18. How does the forest converstion affect the optimum pH of phosphatase? What is optimum pH?
19. How is the effect of Cu on the optimum pH of phosphatase?
20. How does the soil pH affect the soil enzymatic activities? Explain the chemical reasons behind this phenomenon!
21. How does the soil pH affect the soil phosphatase activities? Explain the chemical reasons behind this phenomenon!
22. What is the effect of $CaCO_3$ on urease activities! Why?
23. What chemical properties are affected by land-use conversion? Why?
24. How does the land conversion affect the soil micronutrient metals in the soil environment?
25. Explain the relationship between the soil organic C and total N with the soil CEC and exchangeable K!

Chapter 5

Effects of Tropical Weeds on Soil pH and Enzymatic Activities

Roots of all vegetation are unique in that they release some chemicals into the adjacent soil environment among which are H^+ ions, organic acids (**Table 5.1**), and soil enzymes which are very important to suffice the nutrient elements needed for their growth from various nutrient sources both of organic matters and mineral matters. Hydrogen ion is released in exchange of nutrient element cations absorbed by vegetation roots. Combined with those of organic acids, these H^+ ions may lower the soil pH, which may then intensify the release of plant nutrient elements adsorbed on or contained in the structure of the primary and secondary minerals. The evolved CO_2 by the respiration in the vegetation roots may also intensify the decrease in soil pH and the release of nutrient elements from mineral sources.

Root excretion may not only intensify the release of nutrients from mineral (non-organic) sources, but also from organic sources due to the presence of root-excreted soil enzymes and increased microbial and microfaunal activities (Luo et al., 2014; Salam, 2014). Soil enzymes like phosphatases, arylsulfatase, proteases, etc may avail nutrient elements from organic sources. In general, soil enzymes catalyze the transformation of structural organic matter elements that are not available to root absorption to inorganic free nutrient elements that are available to plant root absorption. The greater the activities of soil enzymes in the soil environment the greater the plant nutrient elements needed by plants are sufficed from organic sources of nutrients. Therefore, the capacity of vegetation roots in obtaining plant nutrient elements from soils is supported not only by the root excretion of H^+ and organic acids as well as the evolution of CO_2, but also by the root production of soil enzymes.

Table 5.1. Organic acids related to soil organisms1).

No.	Condition/Location	Organic Acids
1	Rhizosphere	CO_2, HNO_3, Protein, Amino Acids (Aspartic, Glutamic); Vitamin, Polysacharides (Polygalacturonic Acid); Sugar and Sugar Acids Phenolic Acids, Aliphatic Acids (Oxalic, Malic, Citric, Tartaric); Growth Inhibitors, Pheromones, and Repelling Substances
2	Microorganisms	Oxalic, Citric, Formic, 2-Keto Glukonic, Laktic, Malic, Tartaric Acids, and Lichen Acids
3	Various Conditions	Oxalic and Citric Acids
4	Aerobic	Phenolic Acids
5	Anaerobic	Acetic, Butiric, Formic, Fumaric, Succinic, and Laktic Acids
6	Below plant residues and canopy	Alliphatic Acids (Oxalic, Citric, Malic); and Phenolic Acids (Galic, Vanilic, Hydroxybenzoic)

1) After Robert and Berthelin (1986)

As mentioned previously, weeds are different from other vegetation in that this vegetation is more competitive and destructive. Weeds may have higher root-to-shoot ratios (Salam et al., 2019) and therefore may produce more H^+, organic acids, CO_2, and enzymes. By these reasons, weeds may release more structural mineral and organic matter nutrient elements such as those reported by Salam (1989; 2019). The production of H^+ by weeds with higher root-to-shoot ratios is reported higher than those with lower root-to-shoot ratios (Salam et al., 2019).

5.1 Effects on Soil pH

Soil pH is one of the two most important environmental variables along with the soil E, which is a measure of the electron concentration in the soil environment. As a measure of H^+ concentration, soil pH may increase and decrease dependent of the dynamic of H^+ ions. The shifting of soil pH is caused by some natural or anthropogenic acidification or alkalization processes. Among the natural soil acidification process is the formation of carbonic acid as a result of the reaction between water and carbondioxide molecules produced in the respiration of hydrocarbon in plant roots, soil macroorganisms, and soil microorganisms. The reaction is shown chemically in **Eq. 5.1** as follows:

$$\mathbf{CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \; \ldots\ldots\; Eq. 5.1.}$$

The resulting carbonic acid is not stable in the soil environment; therefore, it easily dissociates to produce H^+ ions. The increase in H^+ concentration in the soil water will acidify soils and decrease the soil pH. The more the CO_2 produced during the respiration, the more H^+ is produced in the soil environment, and so the higher the decrease in soil pH.

The above acidification is very common in the rhizosphere soils. Yang et al. (1996) report that the soil pH in the soybean rhizosphere of Alfisols was lower than that in the bulk soil in the extent of 0.07 – 0.65 units. The acidification of the soil rhizosphere is also intensified by the excretion of H^+ ions by plant roots during absorption of nutrient cations to preserve the electrical balance in the soil system (Tisdale et al., 1985). Long-term soil culture with cassava (*Mannihot utilisima*) was also reported to lower the soil pH (Salam et al., 1999b).

Acidification of the rhizosphere is dependent on the types of vegetations. Salam et al. (1997e) observed in Oxisol Gedongmeneng that the root zones of *Alang-alang* (*Imperata cylindrica* L.) showed a higher pH value than those of pigweed (*Amaranthus spinosus* L.), Green Kyllinga (*Cyperus kyllingia* L.), and

Amaranth (*Amaranthus tricolor* L.). The pH in the root zones of these vegetation were 6.25, 5.03, 5.01, and 5.64, respectively.

One good example of anthropogenic acidification is related to the intensive use of Urea in agriculture. Urea is an important commercial source of N commonly used, particularly in Indonesia. Since it contains one of the major plant nutrients, the use of Urea is huge, and in greater amount than those of other major nutrients such as P and K. However, the use of Urea may cause acidification as seen chemically in **Eq. 5.2** as follows:

$$NH_2CONH_2 + H_2O \rightarrow CO_2 + 2\ NH_3 \quad .... \quad \textbf{Eq. 5.2.}$$

The Urea molecule is hydrolyzed to produce carbondioxide and ammonia molecules. The carbondioxide molecules may then react with water molecules to produce H^+ ion as indicated by **Eq. 5.1**. Ammonia molecules after being protonated to be an ammonium ion will encounter nitrification to produce H^+ ions (**Eq. 5.3**) as follows:

$$2\ NH_4^+ + 2\ O_2 \rightarrow NO_3^- + 2\ H^+ + H_2O \quad .... \quad \textbf{Eq. 5.3.}$$

The above two processes (**Eq. 5.2** and **Eq. 5.3**) may eventually decrease the soil pH. A long term effect of the use of Urea on soil pH is shown in **Table 5.2**. The soil pH is shown to decrease with the increase in the amounts of Urea treatments. For example, the long-term use of Urea at 200 kg Urea N ha^{-1} lowered the soil pH from 5.09 to 4.66, about 0.43 units. Greater decrease occurs when the Urea treatment is done in the field with intensive soil tillage.

According to Boulman et al. (1995), the decrease in soil pH with Urea treatment is attributed to two reasons: (a) the production of H^+ ions due to Urea hydrolysis and (b) the decrease in exchangeable Ca and Mg due to replacement by NH_4^+. The decrease in soil pH due to long-term application of Urea has been reported to increase the soil exchangeable Al and Al saturation and also to decrease the exchangeable Ca and Mg (Schroder et al., 2011). Because Al^{3+} is a potential source of acidity, this condition will worsen the soil pH. However, Boulman et al. (1995) report that the decrease in pH by Urea treatment was lower than that by the use of ammonia (NH_3).

Soil acidification may also happen intentionally in response to the need of agriculture management. For example, soils in the pineapple plantations owned by PT Great Giant Pineapple in Central Lampung, Indonesia, are acidified by using sulfur powder to manage particular plant deseases at low pH. This practice has acidified the soils to relatively low values (Salam et al., 1999b).

Table 5.2. The decrease in soil pH as affected by long-term treatment with Urea *.

Soil Tillage	**Urea N (kg ha^{-1})**		
	0	100	200
Intensive Soil Tillage	5.03	4.83	4.44
Minimum Soil Tillage	5.18	4.96	4.78
No Tillage	5.06	4.89	4.75
Average	5.09	4.89	4.66

*Adapted from Salam et al. (1998c)

One example of alkalination is liming, which may significantly increase the soil pH (Barber, 1981; 1984; Kamprath, 1984; Thomas and Hargrove, 1984; Liu et al., 2004; Salam, 2019). The liming materials will encounter a series of chemical reactions in soil water and will end with the increase in soil pH. For example, $CaCO_3$ in soil water may dissosiate to form Ca^{2+} and CO_3^{2-} ions. Ca^{2+} ions will displace exchangeable H and Al attached to the soil colloid surfaces, while CO_3^{2-} ions will react with water molecules to form HCO_3^- and OH^-. OH^- ions will neutralize H^+ and Al^{3+} ions to form water and $Al(OH)_3$ precipitates. The decrease in H^+ and Al^{3+} ions will then increase the soil pH

To a lesser extent, the use of P-fertilizer may also gradually increase the soil pH as shown in **Fig. 5.1**. The effect of P-fertilizer on soil pH can be explained by the dissolution of calcium phosphates, the minerals used to make commercial P-fertilizers. In the present of water and H^+ ions, this mineral will decompose to release Ca^{2+} ions, orthophosphates, and OH^- ions as shown in the following reaction (**Eq. 5.4**):

$$\mathbf{Ca_3(PO_4)_2 + 2\,H_2O + 2\,H^+ \leftrightarrow 3\,Ca^{2+} + 2\,H_2PO_4^- + 2\,OH^-} \quad .... \quad \textbf{Eq. 5.4}$$

This decomposition reaction consumes H^+ ions and produces OH^- ions; therefore, it increases the soil pH. In general, the higher the concentrations of H^+ ions or the lower the soil pH, the more intensive the decomposition of calcium phosphates.

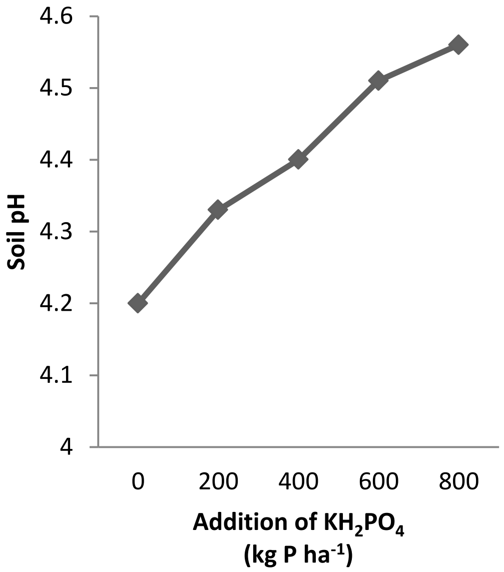

Fig. 5.1. The effect of P-fertilizer on soil pH (Adapted from Salam, 1997b).

The presence of weed roots may definitely lower the soil pH. Progressive growth and development of weeds may produce significant amount of H^+ ions in exchange with the nutrient cations absorbed by weed roots. Combined with the excreted organic acids, weeds may decrease the soil pH more significantly. The decrease may be greater considering during the oxidation of hydrocarbon in weed roots to obtain energy that evolve great amount of CO_2. All of these may cause weed roots become more effective to lower the ambient soil pH.

However, the resulted pH is dependent of the particular weeds. The more progressive weeds may cause lower pH as shown by Salam et al. (1997e) for four different weeds. Salam et al. (1997e) observed in Oxisols Gedongmeneng that the root zones of *Alang-alang* (*Imperata cylindrica* L.) showed a higher pH value than those of Amaranth (*Amaranthus tricolor* L.), pigweed (*Amaranthus spinosus* L.), and Green Kyllinga (*Cyperus kyllingia* L.), i.e. 6.25, 5.64, 5.03, and 5.01, respectively. These data show that pigweed (*Amaranthus spinosus*), and Green Kyllinga (*Cyperus kyllingia* L.) acidify the soil more significantly.

5.2 Effects *of Alang-Alang*

Alang-alang (*Imperata cylindrical* L.) is unique. Instead of producing H^+ ions, the presence of this weed alkalinized soils. Salam et al. (1997e) observe in Oxisol Gedongmeneng that the root zones of *alang-alang* (*Imperata cylindrica* L.) showed a higher pH value than those of pigweed (*Amaranthus spinosus* L.), Green Kyllinga (*Cyperus kyllingia* L.), and Amaranth (*Amaranthus tricolor* L.). The pH in the root zones of these vegetation were 6.25, 5.03, 5.01, and 5.64, respectively (**Fig. 5.2**). The significant difference in the pH measurement (0.64–1.24 units) indicates that *Alang-alang* possesses an extraordinary adaptability. Its adaptability is also observed by the higher activities of phosphatases in *alang-alang* root zones than those in the other vegetations (**Fig. 5.3**).

Theoretically, the soil pH in the root zones of tropical weeds is lower due to significantly higher amounts of cations than those of anions present in soil water so that weeds root excrete more H^+ than OH^-. The higher pH in the root zones of *alang-alang* indicates that this weed absorb more anions than cations. Consequently, roots of *alang-alang* excrete more OH^- than H^+.

Other observations show that grasslands show higher humus contents and, thereby, grasslands show higher CEC and base saturation and generally more fertile and also show higher pH (Harpstead et al., 1988). The leaves of grasses are more alkaline, contain more Ca and Mg and, thereby, cause higher pH than do the needle leaf plants. The leaves of broad leaf plants show higher pH than do needle leaf plants, but show lower pH than grasses (Harpstead et al., 1988).

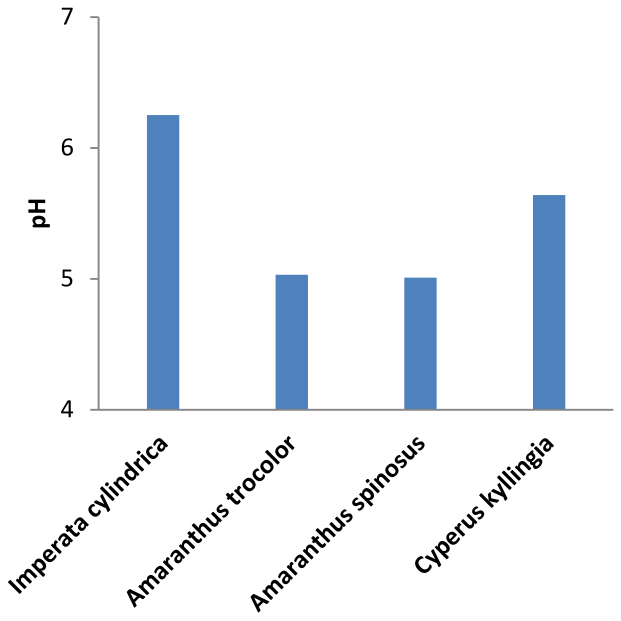

Fig. 5.2. Effect of amaranth and soil tropical weeds on soil pH.
(Adapted from Salam et al. (1997e), IC = *I. cylindrica*, AT = *A. tricolour*, AS = *A. Spinosus*, CK = *C. Kyllingia*)**.**

5.3 Effects on Soil Enzymatic Activities

All vegetation may enhance the soil enzymatic activities since their roots may directly produce various soil enzymes. Data in **Fig. 5.3** show that the presence of weeds may vary the activities of soil acid phosphatase and alkaline phosphatase in soil of Gedongmeneng (Oxisol). The activity of acid phosphatase is higher than that of alkaline phosphatase indicating that this soil is dominated by acid phosphatase. The activity of phosphatase is however dependent of the weeds. *Alang-alang* (IC) is the most effective phosphatase producers among the four weeds, followed by *Amaranthus tricolor*, *Cyperus kyllingia*, and *Amaranthus spinosus*; both for acid and alkaline phosphatases. Kotroczo et al. (2014) also suggests that the soil phosphatase and β-glucosidase show similar seasonal dynamics. Both enzymes show the highest activities in spring coincidently related to the high soil moisture and high root activity. Therefore, it is obvious that the plant-induced changes to soil enzyme activities are driven primarily by readily available, labile carbon provided by root turnover and root exudation rather than by aboveground detrital inputs.

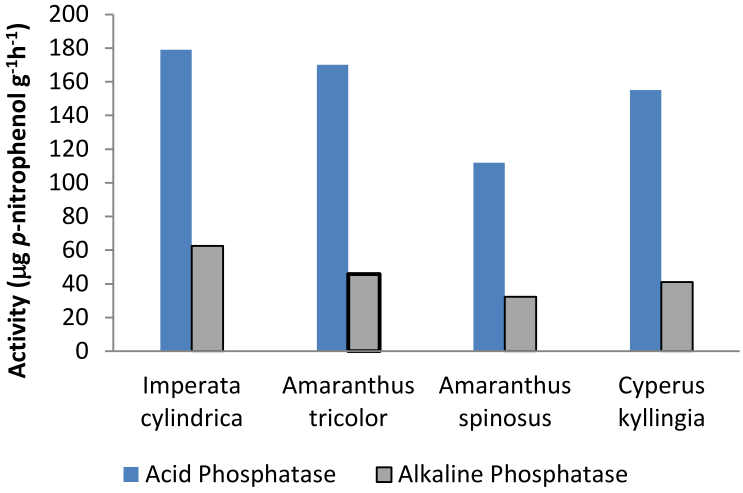

Fig. 5.3. Effect of amaranth and tropical weeds on the activities of acid and alkaline phosphatases (Adapted from Salam et al. (1997e), IC = *I. cylindrica*, AT = *A. tricolour*, AS = *A. Spinosus*, CK = *C. Kyllingia).*

Due to the influence of plant rootings, the activities of soil enzymes are also reported to be soil-horizontal-distance and depth dependent. Joner and Jakobsen (1995) report that the activities of acid and alkaline phosphatases at 10 – 20 cm were lower than those at 0 – 10 cm away from cucumber roots. Some researchers also showed that topsoils were also shown to have higher activities of soil enzymes than did subsoils, partially due to the presence of plant roots (Duxbury and Tate III, 1981; Salam et al., 1998b; 1999a). Naseby and Lynch (1997) find that the microbial biomass and measured enzyme activities of alkaline phosphatase, phosphodiesterase, arylsulfatase, and urease decreased with soil depth. However, a close relationship between topsoil and subsoil enzymatic activities (Salam et al., 1998b; 1999a; Salam et al., 2001) may to some extent indicate that enzymes are produced in topsoils but may be partially leached through the soil profiles by percolating water to subsoils. The relationship between the activity of phosphomonoesterase and the distance to the plant root surface is depicted in **Fig. 5.4.**

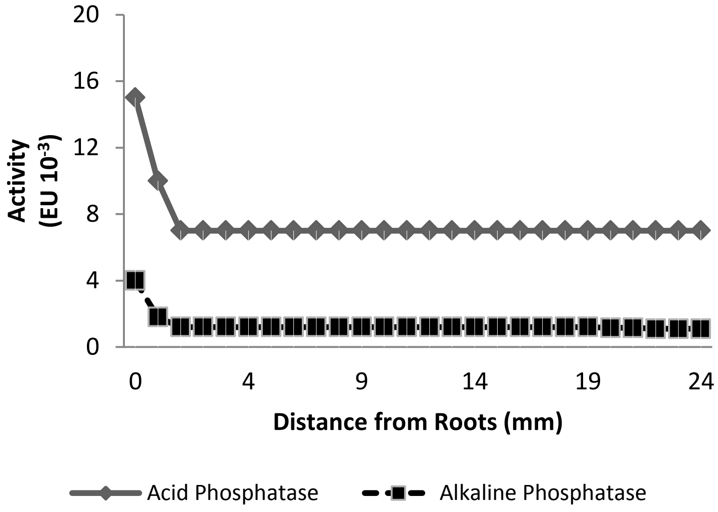

Fig. 5.4. The average activities of acid and alkaline phosphatases close to the plant root surface of cucumber (Drawn from Joner et al., 1995).

In addition to the direct effect, the presence of weeds may indirectly affect the soil enzymatic activities. The changes in soil pH caused by the changes in H^+ concentration in soils may alter the soil enzymatic activities. This is probable because the changes in soil pH may probably affect the main enzyme producers such as bacteria and fungi (Fernandez-Calvino et al., 2012) and increase soil microbial and microfaunal activities (Luo et al., 2014). As has been suggested by several workers (Singer and Munns, 1987; Harpstead et al., 1988; Garbuio et al.,

2011) bacteria may live better in neutral and alkaline soils, while fungi may live better in acidic soils. Therefore, the decrease in soil pH may lower the populations and activities of bacteria and increase those of fungi. It has been reported recently that liming at 0-5 cm top-layer of Typic Hapludox in Brazil increased not only the soil pH but also the population, activity, and bacteria/fungi ratio (Garbuio et al., 2011).

As discussed previously, soil researchers also suggest that soil pH may greatly affect the soil enzymatic activities, particularly more important for phosphatases. Soil pH determines the magnitude of their activities and types in soils (Malcolm, 1983; Nakas et al., 1987; Rojo et al., 1990; Reddy et al., 1991; Trasar-Cepeda et al., 1991; Salam et al., 1998b; 1998e; Sarapatka et al., 2004). Sarapatka et al. (2004) document that acid phosphatase activity in the root zones of various species and cereal cultivars was negatively correlated with increasing pH and available phosphorus level in the nutrient medium. Frankenberger and Johanson (1982) also show the dependence of other enzymes i.e. urease and phosphodiesterase activities on soil pH. The activities of soil enzymes may change accordingly as a result of ionization and deionization of the functional sites of the enzyme proteins with the increase in soil pH.

This behavior was clearly demonstrated by phosphatases in tropical soils. Salam et al. (1998b) treated tropical soil samples of some deforested locations in West Lampung, Indonesia, at a series of buffered pH of 3 to 12. The results are shown previously in **Fig. 4.3**. Similar patterns were also documented by Trasar-Cepeda et al. (1991) and Nakas et al. (1987). Ekenler and Tabatabai (2003) suggest that acid phosphatase was the most sensitive and arylsulfatase the least sensitive to changes in soil pH.

Salam (2014) argues that the lower activity of phosphatase at low pH is probably due to the ionization of H^+ ion on the functional groups of enzyme proteins. As the soil pH rises, the ionization of enzyme functional groups progresses and so does the activity of phosphatase. At this range of soil pH, the activity of phosphatase increases with the increase in soil pH until the related optimum pH, in which the activity of phosphatase is the highest, the activity declines to an asymptotic value at higher pH. The cause of this phenomenon is unclear. The negative effect of high pH on the populations and activities of particular enzyme producers is probable.

The increasing pattern of phosphatase activities at low pH and decreasing pattern at higher pH above the optimum pH were also previously reported by several workers (Frankenberger and Johanson, 1982; Malcolm, 1983; Trasar-

Cepeda and Gol-Sotres, 1988; Rojo et al., 1990; Trasar-Cepeda et al., 1991). Using two series of soils from The United States of America i.e. Aridic Calcixeroll and Umbric Dystrochrept, Rojo et al. (1990) varied the pH and measured the phosphatase activity. These soils show different optimum pH values. Aridic Calcixerol shows an optimum pH at about pH 10.5 while Umbric Dystrocherept shows an optimum pH at pH 5.5, similar to those reported by Salam et al. (1998b). Rojo et al. (1990) conclude that the alkaline phosphatase dominates alkaline soils like Aridic Calcixeroll whose pH is 8.4 and acid phosphatase dominates acid soils like Umbric Dystrochrept whose pH is 4.3. Differences in the optimum pH of these soils and also of Indonesian soils are depicted in **Fig. 4.4**. A similar pattern was also reported for urease (Gianfreda et al., 1992). The activity of urease increases with the increase in soil pH until the pH value reaches 7.0 and then decreases.

In conclusion, the presence of weeds may directly and indirectly influence the activities of soil enzymes. Weeds may directly excrete various enzymes into the soil environment and thereby, as pointed out by soil workers, directly increase the activities of enzymes in soil. Weeds may also change the rhizosphere chemical and physical environment like soil pH and thereby stimulate the main enzyme producers to develop their populations and activities including producing soil enzymes. The changes in the soil chemical environment may also affect the activities of soil enzymes like phosphatases and ureases.

Key Questions

1. What is root excretion? What compounds are excreted by roots? What are the purposes of root excretion?
2. How does the plant root excretion lower the soil pH? Explain!
3. Explain the relationship between the root excretion and the enhancement of nutrient release from soil minerals and soil organic matters!
4. What are the differences between weeds and other vegetation in affecting the soil chemical properties? Explain Why!
5. How do plant roots enhance the soil mineral weathering and organic matter decomposition?
6. Explain how the evolved CO_2 around plant roots acidify the soil environment and increase the nutrient element release from soil solids!
7. Explain the various organic acids in the soil environment! Explain their effects on soil pH and the resulted enhancement of nutrient element release from soil solids!
8. Why does the long-term culture of soils with cassava lower soil pH? Explain!

9. How does urea cause lower soil pH? Explain the chemical transformation of urea in the soil environment!
10. Explain the anthropogenic acidification that occurs in the soil environment!
11. Explain the anthropogenic acidification by S in pineapple plantation of Lampung!
12. What is alkalination? What is liming? Explain the chemical transformation of the liming material in the soil environment to enhance the soil pH!
13. Explain the liming effect of phosphatic rocks!
14. How is the effect of *alang alang* roots on soil pH? Why?
15. How is the distribution of enzymes in the soil environment based on the distance from the main producing roots? How is the distribution in topsoil and subsoil? Why?
16. How do the soil bacteria and fungi respond to the changes in soil pH? How does the effect of liming on soil bacteria and fungi and the soil enzymatic activities?
17. What are the effects of pH changes on soil enzymatic activities? Explain!

Chapter 6

Effects of Tropical Weeds on Soil Carbon, Phosphorus, Nitrogen, and Sulfur

Like all vegetation, weeds are one of the several agents important in the carbon cycle or C-Cycle. Weeds absorb a great amount of atmospheric CO_2 and combine it with H_2O absorbed from soils to produce hydrocarbon and its derivates contained in organic matters. Similar to that of C, N, P, and S also encounter cycles called N-Cycle, P-cycle, and S-Cycle, respectively. Nitrogen, P, and S are absorbed by weed roots from soil solution as NO_3^-, HPO_4^{2-}, and SO_4^{2-}, respectively. Combined with hydrocarbon, these nutrient elements may form proteins. Therefore, the whole mass of weeds contain a great amount of carbon that whenever released in the soil environment it may increase the soil organic C and organic matter (organic matter is about 1.7 times of organic C), as well as organic N, organic P, and organic S.

Organic C, N, P, and S are released into the soil environment by two mechanisms, through direct and indirect mechanisms. First, organic C is continuously released through weed rooting system as organic acids. In addition to acidify the ambient soils, the release of organic acids may surely increase the soil organic C. Second, organic C, N, P, and S can be enhanced indirectly through the decomposition of dead weed parts like dead roots and shoots. The hydrocarbon composed by weeds through photosynthesis may encounter a reverse reaction so-called decomposition that may produce more stable organic matters containing C and CO_2 that may react with water forming HCO_3^- and also inorganic N, P, and S. All organic matters may finally decompose producing CO_2, NO_3^-, HPO_4^{2-}, and SO_4^{2-} and complete the nutrient-cycles. Competitive and progressive weeds may contribute significantly to the increase in soil organic C and organic matter and probably to the soil nutrients..

6.1 Nutrient Cycles

The influence of weeds on soil C, N, P, and S is closely related to the cycles of these nutrient elements in the soil environment (**Fig. 6.1, Fig. 1.7, Fig. 1.8, and Fig. 1.9**). The so-called C-cycle is the transformation of organic matters to their more simple constituents that are available for plant root absorption continued by the absorption of these constituents by plant roots and the following formation of organic substances through photosynthesis in the plant-leaf chlorophylls (**Fig. 6.1**). The destruction of organic matters into their constituents that are available to plant involved microorganisms called decomposers. Decomposers are of great importance in the C-Cycle that also involve Producers (plants with chlorophylls), Consumers (animals and humans), and Decomposers (microorganisms). Without Decomposers, organic matters contributed by vegetation like weeds may accumulate in the environment causing various problems because the cycle is not completed.

Soil microorganisms are small in size and are present in soils in great numbers. The general rule is that the smaller the sizes of the microorganisms the greater their numbers (Singer and Munns, 1987). The smaller size also causes the more significant role in the environment. One gram of soil may contain around one million to one billion soil microorganisms. Therefore, soil microorganisms may greatly affect the soil dynamics. Most of the soil microorganisms are useful in agriculture. However, some of them are also pathogen that may give negative effects on plants.

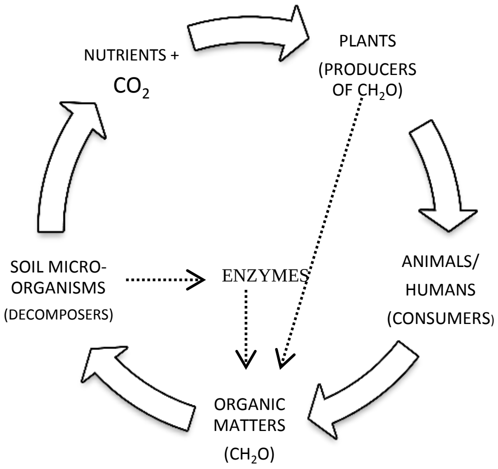

Fig. 6.1. The Carbon-Cycle (After Salam, 2014).

Because its important role in the destruction of organic matters, soil microorganisms are important not only in the C-Cycle (**Fig. 6.1**) but also in the cycles of other nutrient elements (**Fig. 1.7**, **Fig. 1.8**, and **Fig. 1.9**). In the absence of soil microorganisms, nutrient elements in the residues of plants, animals, and humans will accumulate and cannot be utilized in the nutrient cycles. This phenomenon will cause a big problem because, in addition to the organic matter accumulation, it will also stop the nutrient cycles. In this situation, the supplies of nutrient elements for plants will be disturbed. Therefore, soil microorganisms become one of the most important factors in the soil management for agriculture and environment.

The decomposition of organic matters is speeded by the presence of soil enzymes produced by microorganisms and other producers like vegetation roots and earthworms. Several workers suggest that soil microorganisms produce enzyme more significantly in the soil environment (Duxbury and Tate III, 1981; Ross and Cairns, 1982; Frankenberger, Jr. and Dick, 1983; Jha et al., 1992; Joner and Jakobsen, 1995; Vinotha et al., 2000). Some of the soil enzymes also involve directly in the release of important nutrient elements such as N, P, and S. Some of these soil enzymes are phosphatases, proteases, and arylsulfatase. These enzymes work on soil organic matter decomposition to release ions of N, P, and S, respectively, that are available to root absorption.

Carbon is released in the form of CO_2 as organic matters containing N, P, or S decays accelerated by the presence of their respective enzyme, i.e. proteases, phosphatases, and arylsulfatase. Carbondioxide molecules produced in the reaction are finally consumed by plants, and along with water molecules absorbed from soils, the CO_2 molecules are transformed into new organic matters. This means that all the above enzymes participate in the C-cycle.

Phosphatases involve in the destruction of organic matters containing P in their structures called Organic P. The released P in the soil environment will then eventually re-absorbed by plant roots and re-utilized to produce new organic P. The chain of transformation from Organic P to inorganic P by decomposition process and absorption of inorganic P through its re-synthesis in plants to produce new organic matters and back to the decomposition of organic matters to produce inorganic P is called Phosphorus Cycle or P-Cycle. The P-Cycle is previously shown in **Fig. 1.7**. The enzymatic reaction of organic P decomposition catalyzed by phosphatases is previously depicted in **Eq. 1.4**.

The cycle of sulfur or S-Cycle, P-Cycle, and N-Cycle in the soil – plant system is just similar to the C-Cycles. Sulfur, P, and N in the form of SO_4^{2-}, HPO_4^{2-}, and NO_3^- in soil water are absorbed by vegetation roots and are transported to particular plant parts to form proteins. Since S is needed to form wax in plants, S is reduced to form – S – S – bonds or – S – H functional group of proteins. Protein-S will then enter the food chain through consumptions by animals and humans. The residues of plants, animals, and humans will enter the soil system and will encounter decomposition process to form inorganic form of S available to plant root absorption such as SO_4^{2-}. The S-Cycle is previously depicted in **Fig. 1.8.**

The destruction of organic S not available to plants to inorganic SO_4^{2-} readily available to plant root absorption involves enzyme arylsulfatase produced by soil microorganisms. The enzymatic reaction in the decomposition of organic S is shown in **Eq. 6.2** as follows (Tabatabai, 1982).

$$R—OSO_3^- + H_2O \rightarrow R—OH + H^+ + SO_4^{2-} \quad .... \quad \textbf{Eq. 6.1}$$

Eq. 6.1 clearly shows that the decomposition of organic S also needs the presence of water molecules. Therefore, moistening the organic S is important to release S from the organic materials. Unlike the decomposition of organic P, the decomposition of organic S will acidify the soil system because this reaction produces H^+ ions. The soil containing organic S may become more acidic with time of decomposition.

Like C, N is originated from atmosphere (**Fig. 1.9**). The atmosphere actually contains approximately 78% N_2 which is not available to vegetation. Unlike C, which is directly absorbed by plants as CO_2 through leaf or stem stomata, N can be absorbed by plant roots in a particular form after encountering relatively long processes. Atmospheric N initially enters the bodies of bacteria and particular vegetation roots in the soil – plant system through a process called N Fixation. The bacteria involved in the fixation are called Nitrogen Fixing Bacteria (Rendig and Taylor, 1989). Among these bacteria there is *Rhizobium sp*. that live symbiotically with the roots of legumes.

In the soil environment N is finally transformed to be NH_4^+ and NO_3^-, which are available for vegetation root absorption and are utilized by plants to form various structural and functional substances. These structural and functional N in plant tissues and in microorganisms are finally changed into inorganic N that can be absorbed by plant roots after encountering decomposition processes. A part of the inorganic N also volatilizes into the atmosphere, particularly in a reductive soil environment. All the processes of N transformation from N_2 in the atmosphere to NH_4^+ and NO_3^- in soil water, and then their absorption by plant roots and transformation to be structural and functional substances in plant tissues and microorganisms, and then their ultimate decomposition back to form inorganic N (NH_4^+ and NO_3^-) that are available to vegetation roots build a cycle. This cycle is called Nitrogen Cycle or N-Cycle as shown previously in **Fig. 1.9**.

The organisms that can fix the atmospheric N is the Nitrogen Fixing Bacteria; so-called due to their ability to fix and incoorporate atmospheric N into their bodies. A part of these bacteria such as *Rhizobium sp*. lives symbiotically with particular vegetation roots. Legumes and peanuts are two of these particular plants. In this symbiosis, vegetation supplies nutrients and water needed by bacteria, while bacteria supply N for plants. In addition to these bacteria that live symbiotically, there are also free nitrogen fixing bacteria in soils living outside of plant root nodules. Among these bacteria are *Azotobacter* and *Azospillum*. These bacteria may fix atmospheric N. This N is eventually available to plants after the bacteria are dead and decayed.

The protein-N is not available to plants and, therefore, plants cannot utilize it before this protein-N is converted into inorganic forms that are available to plants. Various soil microorganisms decompose and detach the protein-N in the form of NH_3, which will encounter an ammonification process upon reaction with water to form NH_4^+. Ammonium is easily absorbed by plant roots. However, NH_4^+ usually cannot suffice the plant need of N except for paddy plants.

Ammonium ions are then oxydized by particular bacteria through a two step reactions called nitrification. This reactions change of NH_4^+ to NO_2^- with *Nitrosomonas* as the oxydizing agent and of NO_2^- to NO_3^- with *Nitrobacter* as the oxydizing agent (Bartlett, 1981). These reactions follow **Eq. 6.2** and **Eq. 6.3**.

$$\mathbf{2\,NH_4^+ + 3\,O_2 \rightarrow 2\,NO_2^- + 4\,H^+ + 2\,H_2O} \quad \text{.......} \quad \textbf{Eq. 6.2}$$

$$\mathbf{2\,NO_2^- + O_2 \rightarrow 2\,NO_3^-} \quad \text{.......} \quad \textbf{Eq. 6.3}$$

The above reactions can be summarized as shown by **Eq. 6.4** as follows.

$$\mathbf{2\,NH_4^+ + 2\,O_2 \rightarrow NO_3^- + 2\,H^+ + H_2O} \quad \text{.......} \quad \textbf{Eq. 6.4}$$

This reaction shows that the nitrification process needs the presence of enough O_2. The nitrification does not occur in waterlogged soils because the absence of O_2. This reaction also suggests that the soil porosity controls the nitrification process. **Eq.6.4** also shows that the nitrification acidify soils as indicated by the production of H^+ ions.

Wu et al. (2011) report that the Ammonia Oxidizing Bacteria sharply increased about 50 times in soils fertilized with long-term N. This indicates that nitrification process occurs faster in the presence of N fertilizers. For example, the presence of Urea increases NH_3 which very quickly becomes NH_4^+ upon hydrolysis. The decomposition of urea that produces NH_3 progresses as shown in **Eq. 6.5** as follows (Tabatabai,1982).

$$\mathbf{NH_2CONH_2 + H_2O \rightarrow CO_2 + 2\,NH_3} \quad \text{.......} \quad \textbf{Eq. 6.5}$$

The production of NH_3 and, hence NH_4^+, is higher in the presence of enough water and is accelerated by the presence of enzyme Urease, the activity of which was reported to increase with the increase in applied Urea-N (Kumar and Wagenet, 1984; Moyo et al., 1989) (**Fig. 6.2**). This reaction also acidifies soils because of the CO_2 resulted by the reaction.

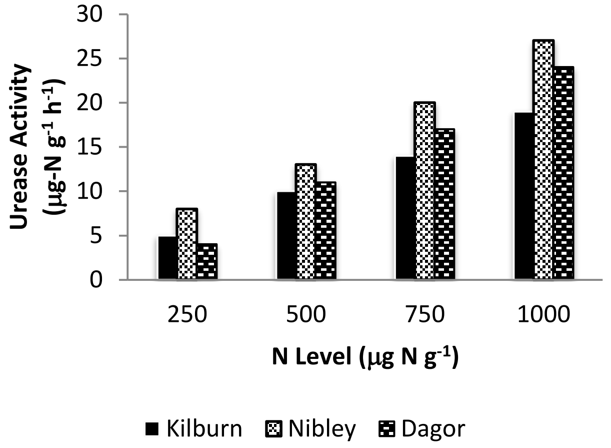

Fig. 6.2. The effect of Urea-N on the activity of Urease in three soils (Redrawn from Kumar and Wagenet, 1984).

The nitrification is beneficial to produce NO_3^- that is available to plants. However, a fast conversion of NH_3 to NO_3^- is not beneficial, since NO_3^- is not adsorbed by soil solids and is thus mobile in soils. Therefore, it is important to have a method to inhibit the nitrification process. Roots of particular plants may satisfy this need. For example, the of grass of *Brachiara humidicola* (Randle) Schweick excretes nitrification inhibiting substances. This substances may inhibit the work of nitrifying bacteria but may not affect other important soil microorganisms (Gopalakrishnan et al., 2009).

The inhibition can also be conducted on the work of Urease by Urease Inhibitors . Urease Inhibitors may inhibit the work of Urease so that the hydrolysis of urea and, hence, the production of NH_3 is limited (Broadbent et al., 1985; Hendrickson and O'Connor, 1987; Cai et al., 1989; Zhao and Zhou, 1991; Hendrickson and Doughlass, 1993; Sanz-Cobena et al., 2008). Some urease inhibitors are Phenylphosphorodiamidate (PPD), Trichloroethylphosphorodiamidate (TPD), Diethylphosphoro-triamide (DPT), Sarsaponin (SSO), N-(n-Butyl) Thiophosphoric Triamide (NBPT), and Hydroquinone (HQ). The effectiveness of urease inhibitors is determined by soil types, soil water contents, and culture conditions (Cai et al., 1989). Sanz-Cobena et al. (2008) use NBPT to inhibit the work of urease in a urea-fertilized soil under mediterranean conditions. They find that the NH_3 emissions from plots fertilized with urea and treated with NBPT was lower than those from plots treated with urea alone. The argue that this phenomenon was associated with a reduction in urease activity during the first 9 days after inhibitor application. The reduction in urease activity also promotes a decrease in the exchangeable NH_4^+ pool. Some researchers also use slow release fertilizers to cope with the production of NH_3 (Fan and Li, 2010).

Nitrate ions are the available form of N for plant absorption. However, nitrate ions may volatilize to the atmosphere through denitrification, particularly when soils are waterlogged or flooded with low redox potentials (Barlett, 1981; Holcomb et al., 2011) such as in paddy fields. Water-logging or flooding may cause a reductive condition and, hence, NO_3^- is reduced to form N_2 (Oxidation state of N is decreased from +5 in NO_3^- to 0 in N_2), which may easily enter the atmosphere. This process occurs in paddy soils when Urea is submerged in waterlogged paddy fields. Kliewer and Gillian (1995) report that soil management by raising water table may stimulate denitrification. In this situation, the production of NO_3^- decreases and its contamination potential to water environment also decreases. Its effects on soil acidification also decreases. However, this process may drive N losses as N_2 and N_2O through denitrification.

The use of hydrocarbon of organic matters by the living things is a part of a simple carbon cycle shown in **Fig. 6.3**. Hydrocarbon is initially produced by the reaction between carbondioxyde and water molecules during photosynthesis in the chlorophyls of plant leaves. During this redox reaction, C molecule is reduced with its oxidation state decreases from +4 in CO_2 (oxidized) to 0 in CH_2O (reduced) with the sun energy packed in it; while the oxidation state of O increases from -2 in CO_2 (reduced) to 0 in O_2 (oxidized). The hydrocarbon is finally used by organisms for its energy by the following reaction called respiration (**Eq. 6.6**).

$$\mathbf{CH_2O + O_2 \leftrightarrow H_2O + CO_2 + Energy} \quad \text{.......} \quad \textbf{Eq. 6.6}$$

During the above reaction, a reverse redox reaction changes the CH_2O to produce H_2O and CO_2. The oxidation state of C increases from 0 in CH_2O (reduced) to +4 in

CO_2 (oxidized) and that of O decreases from 0 in O_2 (oxidized) to -2 in H_2O (reduced). This biochemical cycle is mathematically summarized in **Table 6.1**.

Based on **Fig. 6.3** and **Table 6.1**, it is obvious that CH_2O or hydrocarbon is an energy source for organisms. Hydrocarbon produced during photosynthesis is used by organisms involving respiration, its reverse reaction. Hydrocarbon is decomposed into H_2O, CO_2, and energy during respiration. In the soil environment hydrocarbons may be exist in various forms. Bohn et al. (1985) listed some forms of organic matters as shown in **Table 6.2**.

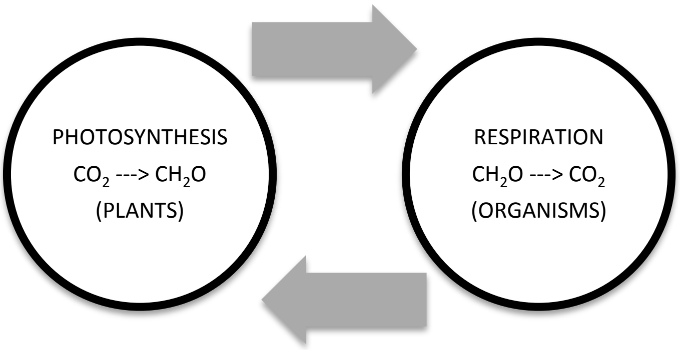

Fig. 6.3. The cycle of Carbon through photosynthesis and respiration (After Salam, 2014).

Microorganisms, macroorganisms, and plant roots use O_2 as the main electron acceptor. In the absence of O_2, both plant roots and macroorganisms cannot oxidize hydrocarbon bacause no chemical species will accept electrons released during the oxidation of hydrocarbon. However, soil microorganisms may continue the oxidation of hydrocarbon by employing some chemical species in soils as electron acceptors. Using any of these acceptors, soil microorganisms will obtain less energy and, consequently, conduct less activities. Bohn et al. (1985) showed some of these electron acceptors as listed in **Table 6.3**.

The above explanation suggests that the highest energy obtained by soil microorganisms is obtained when O_2 is used as the electron acceptor, as also used by plants roots and soil macroorganisms. In this situation, soil microorganisms may progressively develop their populations and increase their activities (Yusnaini et al., 2007). Their activities may be measured, among others, by measuring the CO_2 evolution and also enzymatic activities (Salam et al., 1998b; 1999a; 1999b; Yusnaini et al., 2007). The increase in the evolution of CO_2 as a result organic matter addition is shown in **Table 6.4**. Hellmann et al. (1997) report that the emission rates of carbondioxide (CO_2), and also methane (CH_4) and nitrous oxide (N_2O), increased successively during compost maturation. Green manure and chicken manure significantly increased the activities of soil microorganisms as shown by the increase in CO_2 evolution. The effect of the chicken manure was also shown to be more significant at increasing the soil microbial activities than did the green manure.

Table 6.1. The chemical reactions in photosynthesis and respiration.

	PHOTOSYNTHESIS
A	$CO_2 + 4e^- + 4 H^+ \rightarrow CH_2O + H_2O$ (Ox. State C: 4+ → 0)
D	$2 H_2O \rightarrow O_2 + 4e^- + 4 H^+$ (Ox. State O: 2- → 0)
R	$CO_2 + H_2O \rightarrow CH_2O + O_2$
	RESPIRATION
D	$CH_2O + H_2O \rightarrow CO_2 + 4e^- + 4 H^+$ (Ox. State C: 0 → 4+)
A	$O_2 + 4e^- + 4 H^+ \rightarrow 2 H_2O$ (Ox. State O: 0 → 2-)
R	$CH_2O + O_2 \rightarrow CO_2 + H_2O$

A = Electron Acceptor; D = Electron Donor, and R = Redox Reaction

Table 6.2. Some hydrocarbons as sources (electron donors) of energy for soil organisms.

1	Organic Matter (Individual) (Dry/Fresh)	Lignin ($C_{2.8}H_{2.9}O$) Cellulose ($C_{2.2}H_2O$)
2	Litters	(1/3 Lignin 2/3 Cellulose) $C_{1.7}H_{2.2}O \leftrightarrow 1.7C^{4+} + H_2O + 0.2 H^+ + 7e^-$
3	Organic Matter (whole)	$C_{2.2}H_{2.2}O \leftrightarrow 2.2C^{4+} + H_2O + 0.2 OH^- + 9e^-$

After Bohn et al. (1985)

Because the resulting energy will be much lower when the soil microorganisms use electron acceptors other than O_2, the use of organic matter as a source of energy for the living things in soils must be acompanied by implementing a good mechanism in availing O_2 into the soil system. One of the most important mechanisms to do this is by increasing the soil porosity.

Soil porosity indicates the part of soil volume not occupied by soil solids and may be expressed indirectly by the soil bulk density calculated by the following equation (Hillel, 1980; Singer and Munns, 1987) (**Eq. 6.7**).

$$\rho_b = \frac{M_s}{V_t} \quad \text{.......} \quad \textbf{Eq. 6.7}$$

Table 6.3. Primary and secondary electron acceptors in the soil system.

PRIMARY ELECTRON ACCEPTOR:	
1	$O_2 + 4e^- + 4\ H^+ \leftrightarrow 2\ H_2O$ (the only electron acceptor that can be used by plant roots; energy produced is highest)
SECONDARY ELECTRON ACCEPTORS: If O_2 is absence in soils due to diffusion limitation; energy produced will be lower; products will be toxic like NH_3 and NO_2^- > NO_3^-, H_2S > SO_4^{2-}, N_2 and N_2O volatilized)	
1	$FeOOH + e^- + 3\ H^+ \leftrightarrow 2\ H_2O$
2	$2\ MnO_{1.75} + 3e^- + 7\ H^+ \leftrightarrow 2\ Mn^{2+} + 3.5\ H_2O$
3	$SO_4^{2-} + 8e^- + 8H^+ \leftrightarrow S^{2-} + 4\ H_2O$
4	$NO_3^- + 5e^- + 6\ H^+ \leftrightarrow ½\ N_2 + 3\ H_2O$
5	$N_2O + 2e^- + 2\ H^+ \leftrightarrow N_2 + H_2O$
6	$H^+ + e^- \leftrightarrow ½\ H_2$
7	No Acceptors: organic molecules will be rearranged with a lower energy. For example, carbohydrates will be converted to C_2H_5OH or CH_3 or CO_2

After Bohn et al. (1985)

where ρ_b is soil bulk density, M_s is soil mass, V_t is soil total volume. The soil bulk density of mineral soils is about 1.32 g cm^{-3}. The lower the bulk density of soils indicates the more porous soils and the more easier for water or O_2 to diffuse into the soil system.

Table 6.4. The evolution of CO_2 as affected by the substitution of chemical fertilizers with organic matter *.

No.	Treament	mg CO_2-C kg^{-1}
1	Control	81
2	Organic Matter 0%	210
3	Green Manure 50%	141
4	Green Manure 75%	149
5	Green Manure 100%	154
6	Chicken Manure 50%	293
7	Chicken Manure 75%	268
8	Chicken Manure 100%	412

*Adapted from Yusnaini et al. (2007)

6.2 Effects of Land-Use Conversion

Deforestation transforms most of the primary forest into secondary forest, plantation, and cultivated land. As shown previously that this transformation shifts the dominant species of vegetation, including weeds, in West Lampung Indonesia. Along with this shifting, deforestation also lowers the contents of organic C and Total N. As shown in **Table 6.**5, transformation of primary forest lowers its topsoil organic C content to about 68.5% in secondary forest and to about 47.2% in coffee plantation, and to even much lower organic C content in intensively cultivated land to about 28.1%. Similar trend is also shown in subsoils. The total N also shows similar pattern, with the highest in the primary forest followed by the secondary forest, coffee plantation, and cultivated land; both in topsoils and subsoils.

This pattern clearly shows the acceleration of nutrient cycles in the soil environment after deforestation. A big part of C and N leaks out of the soil environment in the form of CO_2, NO_3^-, and N_2, which might finally cause the decrease in microbial population and activities as indicated by the decrease in soil enzymatic activities as shown in the previous sections. In addition, the sources of C and N also decrease caused by the changes in the dominant vegetation. A similar pattern is also shown by P (**Fig. 6.4**).

Table 6.5. The effect of land-use conversion on soil organic C and total N contents in Bukit Ringgis West Lampung Indonesia*
(After Salam, 2014).

	Soil Depth (cm)	Organic C (g kg^{-1})	Total N (g kg^{-1})
Primary Forest	0 – 20	60.4	5.5
	20 – 40	25.0	2.3
Secondary Forest	0 – 20	41.4	3.4
	20 – 40	21.7	2.0
Coffee Plantation	0 – 20	28.5	2.3
	20 – 40	10.1	1.2
Cultivated Land	0 – 20	15.8	1.7
	20 – 40	7.5	0.8

*Adapted from Salam et al. (1998b)

6.3 Effects of Weed Management

Soil organic C or organic matter content, Available P, Total N, and S are controlled by several factors, among which are types of land-uses, types of vegetation, and soil tillage system. The organic matter contents, organic C, Total N, and Available P in soils of the primary forest are reported to be much higher than those in the secondary forest and agriculture lands (**Table 6.5, Table 6.7**) (Salam et al., 1998b). Al these elements in the primary forest had been preserved by minimum disturbance and high litter inputs and organic matters of residues from various vegetation, while those in agricultural lands had been degraded by soil tillage and low organic matter inputs. Therefore, forest conversion may shift the soil fertility related to the contents of organic matters, organic C, total N, and available P.

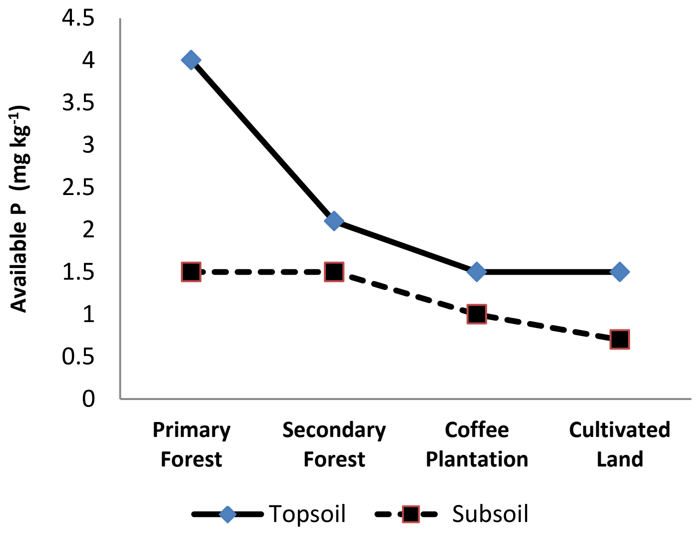

Fig. 6.4. The decrease in soil P by deforestation.

Soils of coffee plantation also show different organic C contents if planted with different weeds or managed by different tillage system. Those planted with grasses (for example *Paspalum conjugatum*) are reported to be higher in organic matter content than the lands with natural vegetation or lands of control without weeds (Salam et al., 2001). In general, soil tillage systems also affect soil organic matter content (**Table 6.6**). In general, organic matter and C are well-preserved in minimum soil tillage but drastically decreases in conventional tillage soils (Klein and

Koths, 1980; Trasar-Cepeda and Gil-Sotres, 1987; Joner and Jakobsen, 1995; Deng and Tabatabai, 1996).

One of the indicators of the decrease in soil organic C is the decrease in soil enzymatic activities in intensively tillage soils. Salam et al. (1998c) also show that the activities of acid phosphatase in minimum tillage or no tillage soils were higher than those in intensively tillage soils (**Table 6.6**). Previously, Klein and Koths (1980) also report that the activities of urease, protease, and acid phosphatase were all higher in no-tillage soils than those in plowed soils. Bergstrom et al. (1998a) also report that the activities of soil enzymes including dehydrogenase, urease, glutaminase, phosphatase, arylsulfatase, and β-glucosidase, increased in no tillage soils.

Table 6.6. The changes in soil phosphatase activity as affected by soil tillage*.

Soil Tillage	**Urea (kg ha^{-1})**		
	0	100	200
	.... µg *p*-Nitrophenol g^{-1} h^{-1}		
Intensive Tillage	157	142	140
Minimum Tillage	187	174	173
No Tillage	169	163	181
Average	171	160	165

*Adapted from Salam et al. (1998c)

6.4 Effects of Continuous Cropping

Cropping may change the contents of C, P, N, and S of soils through root excretion and plant residues. The amounts contributed by plants are dependent on the type and duration of cropping (**Fig. 6.5**). Continuous cropping with similar crops may build significant amount of these elements. Crops associated with N_2

fixing bacteria like legumes may easily build significant amount of soil N. However, soil treatment may reverse the pattern. Conventional tillage may in the long run decrease the soil C and other elements. Disposing plant residues out of treatment plots may also lower the soil content of these elements.

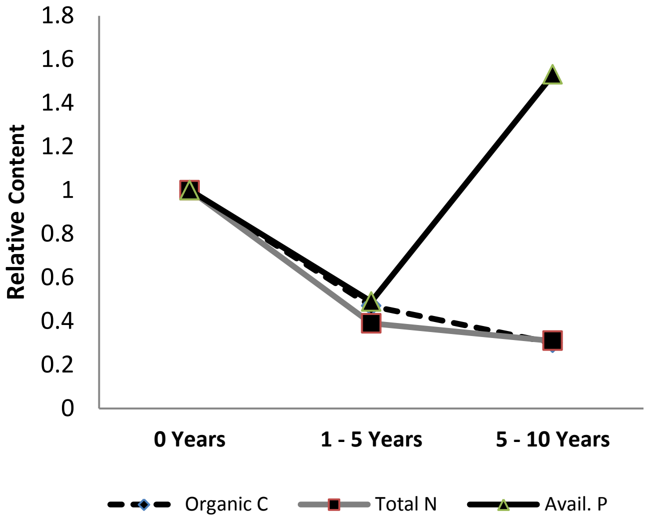

Fig. 6.5. The changes in soil C, total N, and available P in cassava plantation of Gunung Batin, Central Lampung (At 0 years organic C = 43, N = 2.6, and avail. P =5.03 mg kg^{-1}).

Salam et al. (1999b) observe the change in soil C, total N, and available P under cassava plantation cultivated for the periods of 0, 1-5, and 5-10 years in Gunung Batin Central Lampung Indonesia (**Fig. 6.5**). Unlike the available P, the contents of soil C and N significantly decreased with cassava plantation. Compared to the contents in the adjacent bushes never planted with cassava, the contents on C and N in soil that had been planted with cassava for 1-5 years were 47 and 39%, respectively and much lower in soil had been planted with cassava for 5-10 years, about 30 and 31%, respectively for C and N. The available P in 1-5 years land was lower, but in 5-10 years land was higher, probably due to P fertilization at the time of land clearing. The decrease in soil C and N is obviously due to intensively conventional tillage in the cassava plantation. The pattern of the changes in soil pH, organic C, Total N, and available P under continuous cropping was also observed in sugarcane and pineapple plantation in Central Lampung (**Table 6.7**). The pattern was not clear, probably due to the variation in crop management related to soil treatment.

Table 6.7. Selected soil chemical properties of cassava, sugarcane, and pineapple plantation of different time of cultivation*.

Plant	Years Cultivated	pH	Organic C (g kg^{-1})	Total N (g kg^{-1})	Avail. P (mg kg^{-1})
Cassava	SF Nearby	4.7	43.0	2.6	5.03
	1 – 5	4.5	20.0	1.0	24.7
	6 - 10	4.4	12.8	0.8	7.70
Sugarcane	SF Nearby	5.1	22.9	0.8	8.44
	3	5.2	18.6	0.8	7.19
	9	4.9	28.3	1.6	8.16
	13	5.5	14.6	0.7	23.1
	20	4.7	23.1	0.9	63.6
Pineapple	Just Opened	4.6	14.4	0.8	199
	1	4.3	12.3	0.7	3.12
	2	4.3	12.3	0.7	3.17
	3	4.0	15.2	0.8	11.0
	4	4.0	13.5	0.7	21.5

*Adapter from Salam (1999b); SF Secondary Forest

Salam (2014) suggests that the vegetation grown may be one reason for the differences in organic C and organic matter contents (Chan, 1997; Studdert et al.,1997; Salam et al., 2001). Some reports (Chan, 1997; Studdert et al., 1997) show that soil planted with grasses contained organic matters higher than soils planted with food plants. This observation indicates that grasses are potential to enhance or restore the fertility of soils with degraded organic C and organic matters (**Table 6.8**). Studdert et al. (1997) also report that the rotation of food plants with grasses significantly increases the soil organic C contents. The increase in organic matter content will be more significant if grass is more frequently used as a rotating vegetation.

Table 6.8. The differences in organic C and N contents of Vertisols planted with grasses and food plants * (After Salam, 2014).

	Soil 1		**Soil 2**	
	Food Plants	**Grasses**	**Food Plants**	**Grasses**
pH	7.27	6.87	8.01	7.80
Total Organic C (g kg^{-1})	7.90	13.4	4.4	7.1
Total N (g kg^{-1})	0.9	1.5	0.7	0.9

*Adapted from Studdert et al. (1997)

Salam et al. (2001) also found from a four years observation (1996 – 1999) in a coffee plantation of West Lampung, Sumatra, Indonesia, that the soil organic C and total N in coffee plots with *Paspalum conjugatum* were higher that those with natural vegetation or control (**Table 6.9**). A consistent phenomenon was observed for 3 consecutive years from 1996 through 1999. The local natural vegetation also showed a consistently higher organic C and total N that that of control coffee plantation without weeds for the 3 consecutive years.

6.5 Effects of C and N on Soil enzymatic Activities

Organic C in soils is a substrate for enzymatic activities. The more the substrate, in this case organic C or organic matters, is available in soils, the higher the activities of soil enzymes will be measured in the soil system (**Fig. 6.6**). Direct relationship between the activities of some soil enzymes and soil organic C or organic matter contents has been reported (Nannipieri et al., 1980; Harrison, 1983; Trasar-Cepeda and Gil-Sotres, 1987; Bonmati et al., 1991; Tate III et al., 1991; Martens et al., 1992; Salam, 1996; Salam et al., 1998b). As previously mentioned, Salam et al. (1998b) report that the activities of acid phosphatase, alkaline phosphatase, urease, and arylsulfatase in several land-use systems decreased in the order of primary forest, secondary forest, and agriculture lands, in a accordance with the decrease in the contents of organic matter in the respective land-uses. Tate III et al. (1991) also report that the activities of soil microorganisms and phosphatases in soil Horizon O rich in organic matter were 2 – 25 times higher than those in soil Horizon A with low content of organic matter. The enzymatic activities involved in the cycles of C, N, P, and S in the soil – plant systems in soil enriched with organic matter were shown to significantly higher than those in the control soils (Martens et al., 1992). This relationship is related to the roles of organic matters as energy sources for microorganisms producing soil enzymes.

Table 6.9. Changes in soil organic C and total N in hilly coffee plantation under different vegetation* (After Salam, 2014).

	Organic C (g kg^{-1})			**Total N (g kg^{-1})**		
	Control	NV	PG	Control	NV	PG
1996	22.3	28.8	34.7	1.7	2.2	2.7
1997	14.7	17.1	29.1	1.3	1.3	2.3
1998	16.4	18.9	28.9	1.1	1.8	1.1
1999	21.1	23.0	50.0	1.8	2.1	2.4

*Adapted from Salam et al. (2001); NV = Natural Vegetation, PG = *Paspalum conjugatum*

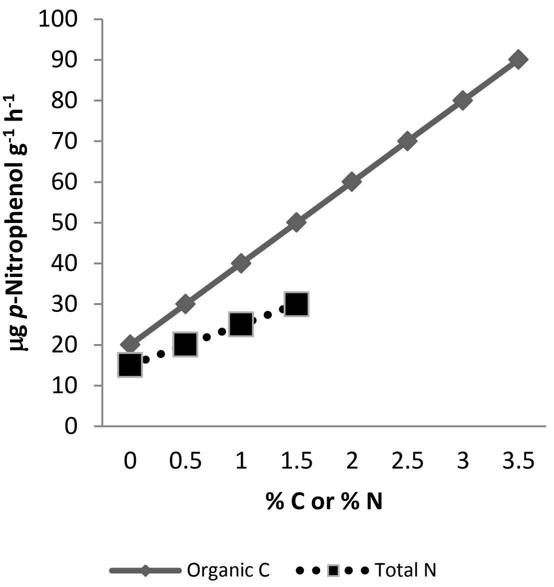

Fig. 6.6. The relationship between the soil enzymatic activities vs Organic C or Total N (Salam, 2014).

The work of soil enzymes on substrate, measured by *p*-Nitrophenol per soil mass per hour, is found to be linearly correlated with the amount of substrate as organic matter (Organic C and Total N) (Nannipieri et al., 1980; Baruah and Mishra 1984; Tate III, 1984; Salam et al., 1998b; 1999a); the higher the contents of organic matter the higher the rates of the biochemical reactions. This phenomenon (**Fig. 6.6**) is easily understood because the substrate is the energy source for microorganisms producing enzymes.

The positive relationship between the soil enzymatic activities and soil organic C or organic matter contents is related the role of organic matter as an energy source for soil microorganisms and macroorganisms. The populations and activities of microorganisms and macroorganisms increase with the increase in organic matter contents. Earthworms are found more frequently in topsoils, with higher soil organic matter contents, than that in underlying subsoils, that have lower organic matter contents. Earthworms also live better in soils of secondary forest, shrubs and *alang-alang* (*I. cylindrica*) lands compared to that of coffee plantation, that is intensively plowed with low organic matter content (Yusnaini et al., 2002). Higher population of earthworms then causes higher activities of soil enzymes. Jha et al. (1992) also report that the activities of enzymes including dehydrogenase, urease, and phosphatase in North East India were higher in the undisturbed regions than those in the regions that had been degraded due to higher populations of fungi and bacteria in undisturbed regions.

The relationship between the soil enzymatic activities and the soil organic C had been investigated (Klein and Koths, 1980; Nannipieri et al., 1980; Harrison, 1983; Trasar-Cepeda and Gil-Sotres, 1987; Bonmati et al., 1991; Tate III et al., 1991; Martens et al., 1992; Salam, 1996; Deng and Tabatabai, 1996; Salam et al., 1998b; 1999a; 1999b). In general, it is reported that the activities of soil enzymes are positively correlated with the organic C and soil organic matter content (Soil organic matter content = 1.5 – 2.0 times soil organic C). Bergstrom et al. (1998b) report a strong spatial relationship between organic C and the activities of phosphatase and arylsulfatase. Salam et al. (1999b) show that the organic C content in soils with various length of cultivation showed positive correlations with the activities of all investigated soil enzymes (acid phosphatase, alkaline phosphatase, β-glucosidase, and arylsulfatase) irrespective of the types of the cultivated plants, with r = 0.605* – 0.898**in the cassava fields, r = 0.351 – 0.527** in the sugarcane fields, and r = 0.419* – 0.542** in the pineapple fields, respectively. Yusnaini et al. (2007) report a good relationship between soil organic C and the activities of acid phosphatase (r = 0.790**) and alkaline phosphatase (r = 0.880**). Salam et al. (1998b) also previously report that the activities of soil acid phosphatase, alkaline phosphatase, β–glucosidase, and urease were positively correlated with soil organic C as shown in **Table 6.10**. The increase in soil organic C or organic matter content raises the activities of soil enzymes. Salam et al. (1999b) also show good correlation between organic C and some soil enzymes in cassava, sugarcane, and pineapple plantations (**Table 6.11**).

Some experimental facts show that the populations and activities of soil microorganisms are positively correlated with total N contents in soils (Salam et al., 1998b; 1999a; 1999b). The relationship is logical because N element is very important for the synthesis of proteins in microorganims. This relationship drives a linear relationship between the activities of soil enzymes and the total soil N contents because soil microorganisms are the main producers of soil enzymes. This relationship is depicted previously in **Fig. 6.6**.

Table 6.10. The correlation coefficients between soil organic C and enzymatic activities of soils in hilly areas of West Lampung*

Soil Enzymes	Topsoils	Subsoils
Acid Phosphatase	0.716*	0.823*
Alkaline Phosphatase	0.584	0.716*
β-Glucosidase	0.672*	0.404
Urease	0.734*	0.529

*Adapted from Salam et al. (1998b)

Table 6.11. The correlation coefficients between soil organic C and enzymatic activities in the middle terrace areas of Lampung*.

Soil Enzymes	Cassava	Sugarcane	Pineapple
Acid Phosphatase	0.898**	0.479*	0.542**
Alkaline Phosphatase	0.605*	0.527**	0.482**
β-Glucosidase	0.790**	0.379	0.419*
Arylsulfatase	0.887**	0.351	0.049

*Adapted from Salam et al. (1999b)

The above linear relationship has been repeatedly reported by some other researchers (Nannipieri et al., 1980; Harrison, 1983; Trasar-Cepeda and Gil-Sotres, 1987; Bonmati et al., 1991; Tate III et al., 1991; Martens et al., 1992; Salam, 1996; Salam et al., 1998b; Salam et al., 1999b; Margalef et al., 2017). Salam et al. (1998b) report that the activities of soil enzymes, including acid and alkaline phosphatases, urease, and arylsulfatase, decreased in the order of primary forest, secondary forest, and cultivated land, in accordance with the decrease in soil total N. Salam et al. (1999b) also show, from their study in soils with various lengths of cultivation in Central Lampung, Indonesia, that the total content of N in soils was positively correlated with all investigated soil enzymes in the cassava fields (r = 0.545* - 0.934**), with the activities of acid and alkaline phosphatases in the sugarcane fields (r = 0.455* and 0.837**, respectively), and with that of acid phosphatase in the pineapple fields (r = 0.481*). Salam et al. (1998b) also previously report that the activities of some soil enzymes (acid phosphatase, alkaline phosphatase, β-glucosidase, and urease) in West Lampung, Indonesia, were in general positively correlated with the soil total N as depicted in **Table 6.12**. Salam et al. (1999a) also report a linear relationship between the activities of acid phosphatase, alkaline phosphatase, arylsulfatase, and β-glucosidase and total N in the middle terrace area of Lampung with r = 0.59, 0.78*, 0.37*, and 0.43*, respectively. Similarly, Yusnaini et al. (2007) also find good correlations between the soil total N and the activity of acid phosphatase (r = 0.87**) and alkaline phosphatase (r = 0.97**). Salam et al. (1999b) also report good correlation between the total N and the activities of some soil enzyme in cassava, sugarcane, and pineapple plantations (**Table 6.13**).

Table 6.12. The correlation coefficients between soil total N and enzymatic activities in hilly areas of West Lampung.

Soil Enzymes	Topsoils	Subsoils
Acid Phosphatase	**0.692***	**0.711***
Alkaline Phosphatase	**0.620**	**0.611**
β-Glucosidase	**0.678***	**0.516**
Urease	**0.721***	**0.542**

Adapted from Salam et al. (1998b)

The presence of soil organic C is closely related to cover vegetation (Handayani and Prawito, 1998; Handayani, 2001; Salam et al., 2001; Pujiyanto et al., 2003), therefore, the activity of soil enzymes may correlate with the types of vegetation grown on the soils. Some workers report differences in enzymatic activities in soils with different vegetation (Duxbury and Tate III, 1981; Jha et al., 1992; Salam, 1996; 1997d; 1998b). Duxbury and Tate III (1981) report that activity of acid phosphatase significantly increased in soil covered with grasses. Salam et al. (1998b) also report that land-use conversion from the primary and secondary forest to agriculture lands drastically decreased the soil enzymatic activities. Jha et al. (1992) also report that the activity of phosphatase was higher in undisturbed forest soils compared to those in soils that had been disturbed. All these data indicate that the activities of soil enzymes are related to the contents of soil organic C controlled by plant covers.

Table 6.13. The correlation coefficients between soil Total N and enzymatic activities in soils continuously cultured with cassava, sugarcane, or pineapple*.

Soil Enzymes	Cassava	Sugarcane	Pineapple
Acid Phosphatase	0.934**	0.455*	0.481*
Alkaline Phosphatase	0.545*	0.8577**	0.296
β-Glucosidase	0.786**	0.189	0.241
Arylsulfatase	0.859**	0.241	0.269

*Adapted from Salam et al. (1999b)

Therefore, it is obvious that addition of organic C into the soil system may enhance the activities of soil enzymes. Salam et al. (1998e) report that an addition of organic C (cassava leaf, *alang-alang* leaf, chicken dung, or goat dung) into the soil system of Ultisol from Tanjungan, South Lampung, Sumatra, Indonesia, clearly increased the activities of acid and alkaline phosphatases for incubation times of up to 4 weeks. However, at incubation time of 16 weeks, addition of the organic matters indeed decreased the enzyme activities in soil.

Key Questions

1. What is nutrient cycle? Explain it with an example! What is its urgence for the sustainability of soil environment?
2. Explain the C-cycle and its role in the soil environment! How does this cycle apply to the management of waste and agriculture?
3. Explain the N-cycle and is role in the soil environment! How does this cycle apply to the management of waste and agriculture?
4. Explain the P-cycle and its role in the soil environment! How does this cycle apply to the management of waste and agriculture?
5. Explain the S-cycle and its role in the soil environment! How does this cycle apply to the management of waste and agriculture?
6. Explain the producers, consumers, and decomposers in the nutrient cycle! Explain how to manage these components efficiently and effectively!
7. What is the role of enzymes in the nutrient cycles? What happen if enzymes are absent in the soil environment?
8. Explain the various producers of enzymes in the soil system! How to increase the production of enzymes in soils?
9. What is phosphatase? How does this soil enzyme work on decomposing soil organIc P and releasing inorganic P?
10. What is arylsulfatase? How does this soil enzyme work on decomposing soil organIc S and releasing inorganic S?
11. What is protease? How does this soil enzyme work on decomposing soil organIc N and releasing inorganic N?
12. What is *Rhizobium sp*? What is the role of this microorganism in the soil system? How does this microorganism relate to the nutrient cycles?
13. Explain the two mechanisms of C increase in soils caused by the presence of weeds! Which one is more dominant?
14. Explain the role of microorganisms in nutrient cycles in the soil environment! Give example!
15. What is ammonification? Explain it with the related chemical reaction! Why this reaction is so important in the soil system?
16. What is nitrification? Explain it with the related chemical reaction! Why this reaction is so important in the soil system?
17. Nitrification is not always good in the soil system. Explain!
18. What is urease? What is its important role in the soil environment? Why its presence in agriculture is unwanted?
19. Why must ureases in agricultural lands be inhibited?
20. What is the role of urease inhibitors? Give examples!
21. Why is nitrate not effective if given into in flooded soils like paddy fields?

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22. What is oxidation, reduction, and redox reactions of hydrocarbons? How do these reactions relate to the soil environment?
23. What are the electron acceptors and electron donors in soil system? Give some examples and their roles in the soil environment!
24. What are the alternative electron donors in the soil system? Are these compounds are limited in the soil environment?
25. What are the effects of deforestation on soil total N and organic C or soil organic matter?
26. What are the effects of deforestation on soil P? Explain why!
27. How do weeds and natural vegetation in coffee plantation maintain the soil organic C and total N?
28. How does the tillage system affect soil organic C and organic matter content? Explain with examples!
29. Why are the activities of soil enzymes higher in no tillage than those in tillage soils? How does this phenomenon relate to soil physical and chemical properties of soils!
30. How does the the effects of continuous cropping on soil C, total N, and available P? Explain!
31. What are the differences of the effect on soil organic C of grasses versus food plants?
32. What are the effects of deforestation on the activities of soil enzymes? Give examples!
33. Explain the relationship between the soil depth vs the soil enzymatic activities! Explain why!
34. Explain the relationships between the soil enzymatic activities vs the soil organic C and total N content? Describe it with graph!
35. What are the effects of plant covers on soil enzymes? Explain why!

Chapter 7

Effects of Tropical Weeds on Soil Potassium

As previously stated, the weed root excretion may lower the soil pH and increase the soil enzymatic activities. These chemical changes may bring about the changes in other soil chemical and fertility properties. Among the most important change is the increase in dissolved and exchangeable K of soils. Of course with a prerequisite that the related soils contain adequate organic and inorganic sources of K easily transformed into readily available form for plants by chemical weathering and enzymatic decomposition.

The accumulation of H^+ ions may cause the soil K-mineral dissolution. In the presence of H^+ and water, orthoclase, which is one of the K sources of silicate minerals may detach its structural K increasing the dissolved K in the soil solution and in turn may enhance the soil exchangeable K. Any other sources of K may also dissolve increasing these available forms of K in the soil environment. Some researchers report that the release of K and other nutrient elements from soil mineral increases with the decrease in soil pH (Salam, 1989). This suggests that any chemical reactions that may decrease the soil pH may in turn drive the detachment of K from soil minerals. The chemical reactions may be naturally driven like root excretion and antropogenically origin like soil contamination by acid industrial waste.

Root excretion may also enhance the organic matter decomposition through the soil enzymatic reactions. Various soil enzymes produced by roots and by microorganisms and macroorganisms associated with root existence, like phosphatases, arylsulfatases, and proteases, may speed up the decays of organic matters containing the functional K. The amounts of soil enzymes produced by these living things may determine the amount of K released into the soil environment. Any factors that may support these living things may enhance the increase in soil enzymatic activities and the release of K into the soil environment.

The enhancement of K released by the root-related production of H^+ and enzymes is expressed in the increase in dissolved K and exchangeable K. Salam et al. (2019) report that the enhancement of exchangeable K by weed presence is related to the characteristics of weeds, among which is the Root-To-Shoot Ratio (RST). Weeds with high RST like *Arachis pintoi* may drive more intensive release of K from K-sources in the soil environment (Ontia, 2018; Salam et al., 2019).

7.1 The Release of Potassium from Soil Minerals

Potassium in soils is contained in mineral and organic matters, which are not easily available to plant root absorption. Some of K reserves in soil are listed in **Table 7.1**, which mainly exist as silicate minerals, like feldspars, and organic matters. Potassium is absorbed by plant roots as K^+ ions and therefore the structural K in the silicate minerals must be released as K^+ to be available to plants. The mechanism by which K^+ ions are released into the soil solution from mineral K is called dissolution or chemical weathering. Similarly, organic K must be released as K^+ into the soil solution through a chemical mechanism called decomposition. Therefore, the soil K in the soil environment is not only supplied by mineral sources but also by organic sources. The root excretion may enhance the soil available K from soil minerals particularly in young soils with enough K-minerals and from soil organic matters containing K. Inputs of organic matters into soils from root excretion and plant residues are therefore very important to enhance the soil K availability. Infertile soils may have sufficient K if treated with enough organic matters.

Table 7.1. Plant nutrient reserves in soil and their releasing mechanisms*.

Nutrient Elements	Reserve Forms	Releasing Mechanisms	Dissolved Forms
N	Organic Matters	Decomposition	NH_4^+
	NH_4^+ in Mica and Vermiculite Interlayers	Dissolution	NH_4^+
	Exchangeable NH_4	Cation Exchange	NH_4^+
S	Organic Matters	Decomposition	S^{2-}, SO_4^{2-}
	Sulfides (Ex. FeS)	Oxidation	SO_4^{2-}
	Gypsum ($CaSO_4$)	Dissolution	SO_4^{2-}
P	Organic Matters	Decomposition	$H_2PO_4^-$, HPO_4^{2-}
	Al-P, Fe-P, Ca-P	Ligand Exchange	$H_2PO_4^-$, HPO_4^{2-}
		Dissolution	$H_2PO_4^-$, HPO_4^{2-}
K, Ca, Mg	Silicate Minerals (Ex. Feldspars)	Weathering, Dissolution	K^+, Ca^{2+}, Mg^{2+}
	Carbonates, Sulfates	Dissolution	Ca^{2+}
	Organic Matters	Decomposition	K^+
Fe, Mn, Zn, Cu	Hydroxide Precipitates	Dissolution	Cations and Dissolved Chelates
	Adsorbed by Oxides of Fe, Al, and Mn	Desorption	
	Chelates	Dissociation	
	Exchangeable	Ion Exchange	
B, Mo	Adsorbed by Oxides of Fe and Al and Clay Minerals	Desorption	H_3BO_3 MoO_4^{2-}

*Taken from Singer and Munns (1987)

The plant nutrient elements are released as free ions into the soil solution through several mechanisms (**Table 7.1**) controlled by several factors as listed in

Table 7.2. Potassium adsorbed on soil solids called exchangeable K is released through desorption process and controlled by equilibrium constant (K), cation exchange capacity (CEC), soil pH, and solid preference towards cations. Exchangeable K is released when its concentration in soil solution is lowered by some mechanisms like plant root absorption and leaching. The release is more difficult when the soil CEC and pH are high and the soil preference towards K is high. Therefore, the release of the exchangeable K is easily enhanced by lowering the soil pH, increasing the concentration of competing cations, and lowering the soil solution concentration of K^+.

Table 7.2. The mechanisms of plant nutrient release and their controlling factors.

No.	Chemical Processes	Sources of Free Ions	Dominant Controlling Factors
1	Decomplexation	Complex Ions	K*
2	Dissolution	Precipitates	K_{sp}*
3	Desorption	Exchangeable K	K*, CEC, pH, Preference
4	Weathering	Mineral Structural K	pH, Soil Moisture, Mineral Structure, Mineral Chemical Composition
5	Decomposition	Organic Structural K	pH, Soil Moisture, Enzymatic Activity, Temperature, C/N Ratio

*K is an equilibrium constant related to the related chemical reaction, K_{sp} is an equilibrium constant related to the dissolution of a precipitate

The structural K in the soil minerals is more difficult to release. This element is released through mineral weathering which is controlled by several factors among which are soil pH and soil moisture. As those for all primary minerals, the weathering of K containing minerals is enhanced by the presence of water and H^+ ion. Therefore, the release of K from soil minerals can be enhanced by lowering soil pH in the presence of water. The elimination of the released K^+ from soil solution through some mechanisms like plant root absorption and leaching may also speed up the mineral weathering.

The weathering of orthoclase ($KAlSi_3O_8$) may exemplify the above mechanisms. The weathering of this K-mineral as shown in **Fig 1** may progress in the presence of water molecule and H^+ ion. Following the mass action law, the reaction may speed up in the presence of high amounts of water molecule (moist soils) and H^+ ion (acid soils) and low concentration of K^+ (and also those of Al^{3+} and $Si(OH)_4$). This means that the weathering process can be enhanced by moistening the soil sample and/or lowering the soil pH and/or eliminating K^+ (and also Al^{3+} and $Si(OH)_4$). However, intensive weathering of orthoclase may end up with the existence of more stable secondary minerals not containing K, like montmorillonite, kaolinite, and gibbsite.

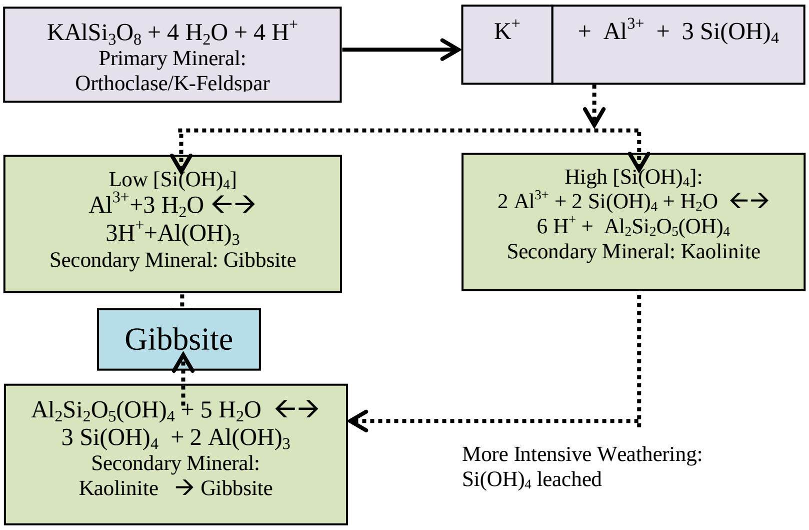


Fig. 7.1. The release of K^+ in the weathering of K-containing primary minerals.

There are several forms of K present in the soil environment but not all forms of K in soils are available to plants and are classified into Slowly Available, Slightly Available, and Readily Available. The soil K in the mineral structure is Slowly Available (**Table 7.3**). Those classified as Slowly Available (primary minerals) is about 100 to 3000 times greater than those on the soil exchange sites (Exchangeable K). Therefore not all K is available and can be absorbed by plant roots. To use this source, this slowly available K must be released from the structure of the minerals through weathering processes.

Table 7.3. The forms and availability of K in the soil environment*.

	Sources	**Classification**	**Concentration**
1	Primary Minerals: - K Feldspars - Muscovit - Glauconit - Biotite	Slowly Available	0.1 – 3% (20.000 – 60.000 kg ha^{-1})
2	Fixed-K	Slightly Available	0 → 100 kg ha^{-1}
3	Exchangeable K	Readily Available	200 kg ha^{-1} (Fertile Soils)
4	Dissolved K	Readily Available	1–50 ppm (Soil Solution) (0.4-20 kg ha^{-1})
→ Total varies depending on parent materials and weathering stage → Granitic Soils > Calcareous Soils → Old Soils (Latosol) < Young Soils			

*Adapted from Corey (1964)

The relationships between all forms of soil K is depicted in **Fig. 7.2**. As explained previously, the primary minerals and organic matters are the main sources of K in the soil environment. Under several controlling factors, these sources encounter weathering and decomposition processes releasing K^+ into the soil solution. Potassium ions in the soil solution will then encounter different fates: absorption by plant roots, leaching, and adsorbed by soil exchange sites. The readily available K^+ and the exchangeable K may also shift into the Slightly Available fixed K. The input of K from fertilizers may contribute the dissolved K through reaction similar to those of the primary minerals and organic matters.

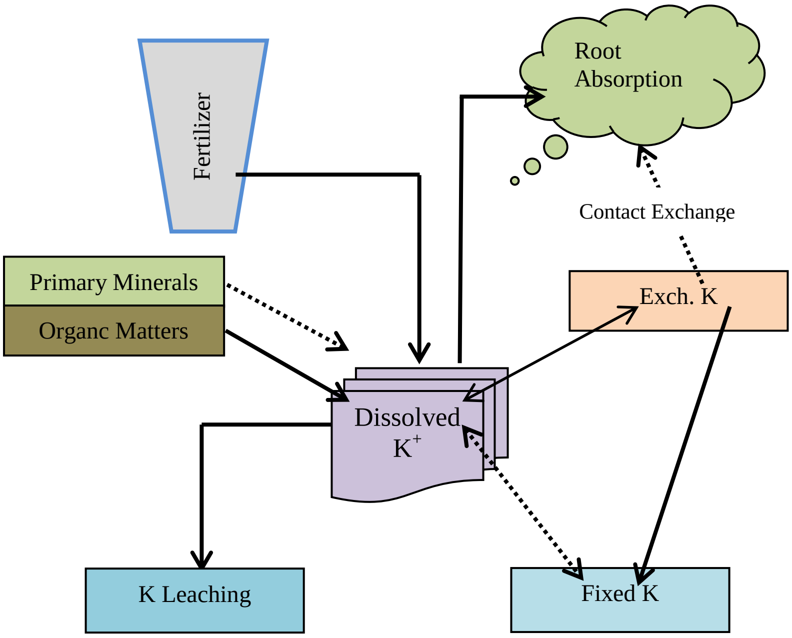


Fig. 7.2. The relationship between forms of K in the soil environment (After Salam, 2019).

7.2 The Release of Potassium from Organic Matters

In addition to those adsorbed in the surfaces of soil solids (organic and non-organic) and those contained in the primary minerals, the soil K is also contained in soil organic matters (**Table 7.1** and **Table 7.2**). This soil K is originated from the soil solution absorbed by plant roots and wandering in the plant tissues. This means that this plant nutrient is K^+ originally released into the soil solution by desorption and soil weathering. The decomposition of organic matters containing K may also contribute some amount of this K^+. However, the amount of K from organic matters is generally lower than that from soil minerals.

Different from that from the soil minerals, the K from soil organic matters is released through several enzymatic reactions catalyzed by various enzymes like phosphatases, proteases, and arylsulfatase which work on the decomposition of organic P, organic N, and organic S, respectively. In addition to releasing the related nutrient element i.e. $H_2PO_4^-$ and HPO_4^{2-}, NO_3^-, and SO_4^{2-}, these processes of course release several other plant nutrients including K^+. The higher the soil enzymatic activities and the higher the available organic matters may contribute higher K^+ into the soil solution. The soil enzymes are not only produced by plant roots but also by microorganisms and macroorganisms (earthworms), the populations and activities of which are stimulated by the presence of roots.

The rate of K release from organic matters is dependent on the soil enzymatic processes involved. As shown in **Table 7.3**, some important factors control the rates of soil enzymatic activities releasing K^+. First, the amount of substrates is the most important factor since soil enzymes work very specifically on particular substrates. Phosphatases work only on the decomposition of organic P, arylsulfatase only on organic S, and proteases only on organic N. The amount of substrates may control the rates of organic matter decomposition. Second, the activities of soil enzymes may determine the rates of organic matter decomposition. Effective roots and organisms may produce significant amount of enzymes that may cause the increase in organic matter decomposition. Third, as shown by the reactions in **Table 7.4**, all enzymatic reactions need water to progress. This means that the rates of organic matter decomposition and the release of K may increase in moist soils.

Table 7.4. The factors affecting the rates of K release from organic matters.

Nutrient Element	Biochemical Reactions	Main Product	Conntrolling Factors
P	**$RO—PO_3^{2-} + H_2O \rightarrow R—OH + HO\text{-}PO_3^{2-}$**	$H_2PO_4^-$ HPO_4^{2-}	[Organic P], [Phosphatase], Soil Water
S	**$R—OSO_3^- + H_2O \rightarrow R—OH + H^+ + SO_4^{2-}$**	SO_4^{2-}	[Organic S], [Arylsulfatase], Soil Water

The released K^+ may encounter several fates in the soil environment. The first possibility is dissolved in soil solution. The solution K^+ is vulnerable since it is relatively mobile. Therefore, the first fate is that this form of K is probably absorbed by roots and accumulated in plant tissues. The second possibility is that this soluble K is leached through the soil body by percolating water and is moved into subsoils. In a closed soil environment in the absence of root absorption and leaching, the solution K is probably adsorbed by the soil exchange sites and become adsorbed K or exchangeable K. In this case, the release of K from the soil organic matter decomposition can be measured by the soil exchangeable K.

7.3 The Effects of Soil pH on Soil Potassium Release

The rate of soil mineral weathering is controlled by its “equilibrium constant”. Taking the weathering of orthoclase shown in **Fig. 7.1** as an example, its equilibrium constant is expressed in **Eq. 7.1**. The value of K can be calculated with thermodynamic data of all species in Eq. 7.1.

$$K = \frac{[K^+]\,[Al^{3+}]\,[Si(OH)_4]}{[H^+]^4} \quad \text{....... Eq. 7.1}$$

The progress of orthoclase weathering can be predicted from the solubility product of all species involved in the reaction. If the case of the solubility product is lower than K, the weathering process will continue. This condition is mathematically expressed as follow:

If $K > \frac{[K^{+}]\,[Al^{3+}]\,[Si(OH)_4]}{[H^{+}]^4}$, the weathering process occurs and continues. On the other hand, if $K < \frac{[Na^{+}]\,[Al^{3+}]\,[Si(OH)_4]}{[H^{+}]^4}$, the weathering process does not occur.

Using this logic, the weathering process can be accelerated or inhibited. Considering the chemical weathering in Fig. 7.1, the weathering of orthoclase can be accelerated by:

1. increasing the soil moisture
2. lowering the soil pH
3. decreasing the concentration of K^+ in soil solution,
4. decreasing the concentration of Al^{3+} in soil solution, and/or
5. decreasing the concentration of $Si(OH)_4$ in soil solution.

On the other hand, if the weathering process is to be inhibited, the following actions can be taken::

1. decreasing the soil moisture,
2. increasing the soil pH,
3. increasing the concentration of K^+ in soil solution,
4. increasing the concentration of Al^{3+} in soil solution, and/or
5. increasing the concentration of $Si(OH)_4$ in soil solution.

Salam (2019) suggests that in general this logic is possibly used to manage the chemical weathering of minerals in the soil environment. Increasing the concentrations of reactants may probably increase the rate of chemical weathering in the soil environment; likewise, decreasing the concentrations of reaction products may probably increase the rate of the chemical weathering. For example, increasing the concentration of H^+ or decreasing the soil pH is the most interesting. As the reactant in most cases, H^+ may act as an attacking agent and therefore may accelerate the rate of chemical weathering. Some research results are summarized as those depicted in **Fig. 7.3**.

The weathering process on soil minerals is initiated by the substitution of Na, K, Ca, and Mg by H^+ ions in the mineral structure. In the process, hydrogen ions are consumed and then the structural cations are released into the soil solution. In the weathering of mica, H^+ ions from the soil solution may displace K^+ in the mica interlayers. Potassium ions are then released into the soil solution while H^+ ions enter the tetrahedral and octahedral positions displacing the cation positions. This acid dissolution is the main mechanism that weathers the silicate minerals. In an acid condition, 10 H^+ ions may weather 1 molecule of biotite producing 1.5 molecules of kaolinite and releasing various cations like K^+, Fe^{2+}, and Mg^{2+}. This reaction is mathematically expressed in **Eq. 7.2** (Stumm and Morgan, 1981).

$$\mathbf{K_2(Al_2Si_6)(Fe_3Mg_3)O_{20}(OH)_4 + 4\ Al(OH)_2(H_2O)_4 + 10\ H^+}$$
$$\mathbf{\rightarrow 1.5\ Al_4Si_4O_{10}(OH)_8 + 2\ K^+ + 3\ Fe^{2+} + 3\ Mg^{2+} + 2\ H_2O \quad ...... \quad Eq.\ 7.2}$$

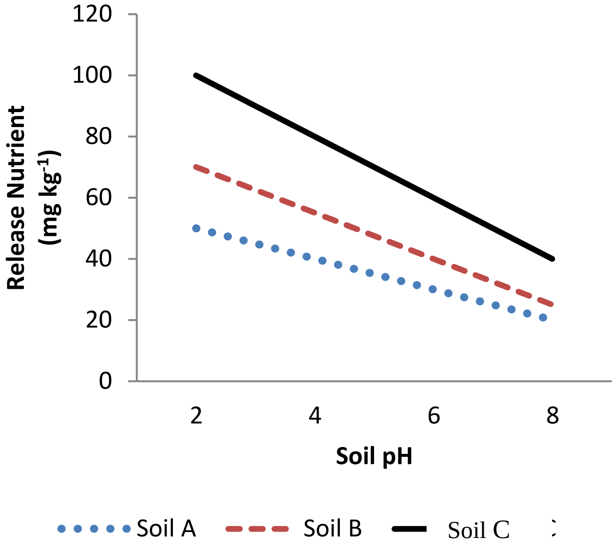


Fig. 7.3. Increasing the rate of nutrient release from soil minerals by increasing [H^+].

The work of H^+ ions is intensified by the presence of organic acids. Organic acids are unique, not just acids. They may weather the soil minerals due to its H ions that may act as attacking agents like those of inorganic acids. They also weather the soil minerals due to their low molecular weights and their functional groups like OH and COOH. Organic acids like citric acid and oxalic acid may form dissolved complexes with Mg^{2+} and K^+. This process may greatly enhance the soil mineral weathering because it may decrease the solution K^+.

Salam (2019) shows that the release of K from soils minerals of Oxisols from West Java Indonesia and Mollisols from Wisconsin the United States of America significantly increased with the decrease in soil pH (**Fig 7.4**). This pattern is also shown by several soils from West Java Indonesia and Wisconsin the United States of America used in a series of experiment by Salam (1989). This data show the effectiveness of H^+ as an attacking agent in soil chemical weathering.

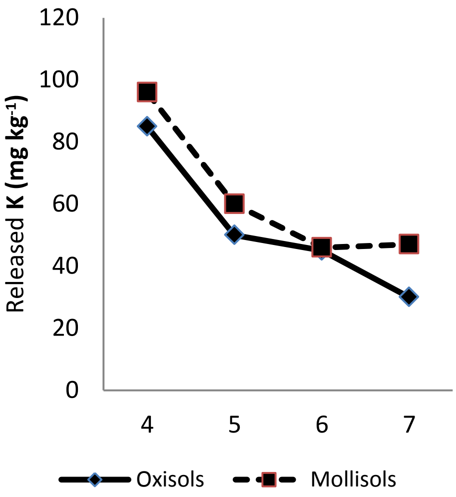


Fig. 7.4. The released K from soils under different pH.

7.4 The Effects of Weeds on Soil Potassium Release

To cope with problem of K deficiency in tropical regions, several break-throughs are being developed (Salam, 1989; Salam and Corey, 1993). The use of indigenous K by some methods is promising (Salam and Corey, 1993; Jalali and

Zarabi, 2006; Jalali, 2006; Farshadirad et al., 2012; Najafi-Ghiri and Jabari, 2013). Salam and Corey (1993) show that the soil potassium uptake by Sudan Grass was well-correlated with the soil potassium-supplying capacity. Absorbed K by Sudan grass was mostly from the dissolved and the exchangeable forms and partially from the nonexchangeable forms. Najafi-Ghiiri and Jabari (2013) show that clay fraction released more K than silt and sand fractions of calcareous soils. However, the use of indigenous mineral sources is rarely developed, particularly in tropical regions. Some are developed as organomineral fertilizers (Samuel & Ebenezer, 2014).

The use of plant nutrient elements from indigenous soil minerals needs a speeded weathering process to release non-exchangeable K, mainly by managing one or more soil environmental factors. The immediate soil property that significantly affects the weathering of soil minerals is the presence of H^+ ions (Johnston and Olsen, 1972; Manley and Evals, 1986; Salam, 1989; Najafi-Ghiri and Jabari, 2013; Salam, 2019). As shown previously the release of K in general increases with the increase in H^+ concentration (Salam, 1989; Calvaruso et al., 2010; Bray et al., 2015; Salam, 2019). Salam (1989; 2019) reports that some temperate soils from Wisconsin USA and tropical soils from West Java Indonesia consistently showed increasing amounts of released Ca, Mg, K, Zn, Si, and Al with decreasing pH ranging from 7 to 4. Previously, Johnston and Olsen (1972) shows that plant roots were able to extract P and other elements from apatite by dissolution process which is greatly affected by: (1) CO_2 released by roots and microorganisms, (2) chelating agents excreted by roots (Bray et al., 2015), (3) Ca adsorption and absorption by roots, and (4) acidity induced by acids excreted by roots. Manley and Evans (1986) shows that the effectiveness of organic acids to decompose soil minerals follows the order of citric > oxalic > salicylic > protocatechuic = gallic > *p*-hydroxybenzoic > vanilic = caffeic. Najafi-Ghiri and Jabari (2013) also show that acidic extractants released more K from soil minerals. The presence of releasing K bacteria may also increase the detachment of soil mineral K (Shang et al., 2015), probably through their acidifying properties. This means that there must be H^+ ion sources in the soil environment.

Based on the previous accounts, the weed rooting system is one of the H^+ ion and acidity sources for this purpose. Weeds may excrete some acids that may acidify the soil environment (Song and Huang, 1988; Walker et al., 2003; Badri and Vivanco, 2009; Calvaruso et al., 2010). In addition, weed roots may also release H^+ into the soil environment. The amount of acids and H^+ may increase with the extent of weed root masses. Badri and Vivanco (2009) also suggest that root exudates may stimulate the activities of soil microorganisms and organic matter decomposition, which may eventually lower the soil pH.

In addition to such exudates as H^+ ions and organic acids (Walker et al., 2003; Badri and Vicanco, 2009; Nihorimbere et al., 2011; Song et al., 2012; Huang et al., 2014), weed-roots may also produce enzymes that may alter the unavailable structurally bonded K in the organic residues into readily available inorganic K by which K is released (Duxbury and Tate III, 1981; Bolton et al., 1985; Reddy et al., 1987; Rejsek, 1991; Sakai and Tadano, 1993; Joner et al., 1995; Song et al., 2012; Salam, 2014; 2017). Some researchers report that the activities of enzymes are significantly higher in the rhizosphere than those in non-rhizosphere soils (Reddy et al., 1987; Joner et al., 1995; Bergstrom and Monreal, 1998; Fang et al., 2010). Different plants were shown to produce different activities of soil enzymes (Sakai and Tadano, 1993; Salam et al., 1997a; Bergstrom and Monreal, 1998; Wu et al., 2011). Salam et al. (1997a; 1997b) report that the activities of phosphatases in the root zone of *alang-alang* (*Imperata cylindrica*) were higher than those in the root zones of green kyllinga, pigweed, and amaranth. The excretion of enzymes was enhanced by root infection by mycorrhiza (Rejsex, 1991; Tarafdar and Marschner, 1994).

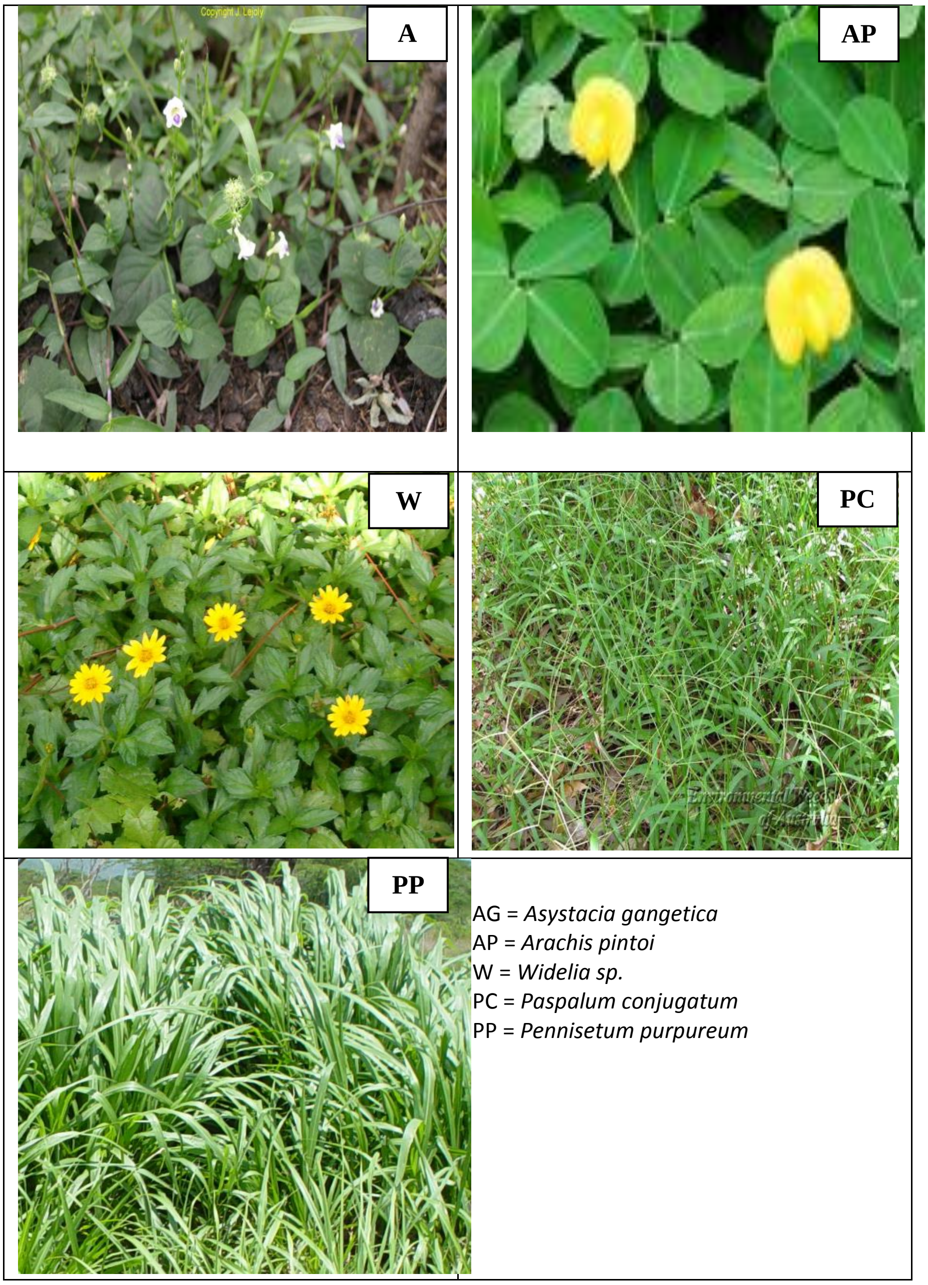
There are numerous weeds potential to employ in this mission (Salam et al., 1997a; 1997b; Sembodo et al., 2017). Sembodo et al. (2017) use several grass and broad-leaf weeds to improve the total soil organic matter and the related soil cation-exchange capacity (CEC) and report that *P. conjugatum, Crotalaria lappacea*, *Widelia sp.,* and *A. gangetica* were among those that significantly increased the soil organic matter content and soil CEC. They show that in the presence of these weeds the soil organic matter content significantly increased to about 200% from its initial value of 5.5 mg kg^{-1} and that of CEC increased to about 125% from its initial value of 4.45 $cmol_c$ kg^{-1}. Salam et al. (1997a) show that various weeds induced different values of soil pH; those in the root zones of pigweed (*Amaranthus spinosus L.*) and Amaranth (*Amaranthus tricolor* L.) were lower than that in the root zone of Green Kyllingia (*Cyperus kyllingia* L.) and were much lower than that in the root zone of in *alang-alang*. The changes in these soil-chemical properties may drive the release of more soil labile K. High organic matter contents and thus high soil CEC may adsorb the soluble K which may intensify the release of structural K in soil minerals (Jalali, 2006). This suggestion is in accordance with that reported by Wang and Huang (2001). The presence of weed rootings may also probably acidify the soil environment, firstly by the excretion of H^+, and secondly by the CO_2 evolution during weed root respiration.

To study the influence of several potential tropical weeds in accelerating the release of non-exchangeable K in tropical soils a plastic house experiment was conducted from January to June 2013 in the Faculty of Agriculture of the University of Lampung, Bandar Lampung, Indonesia. Soil samples were collected from Bandar Agung (-5,4117^o, 105,383^o) Jabung East Lampung and Serdang (-5,298^o, 105,687^o) Tanjung Bintang South Lampung Indonesia. From each location, a composite soil sample was taken from the depths of 0 – 30 cm and 30 – 60 cm. Soil samples were air-dried and sieved to pass a 2-mm sieve. Soil of Jabung was more fertile than that of Tanjung Bintang as shown by the higher soil pH, organic matter content, and exchangeable K.

Weeds including *Asystacia gangetica*, *Arachis pintoi*, *Widelia* sp., *Paspalum conjugatum*, and *Pennisetum purpureum* were collected from fields and initially planted and grown for several days in polybags to obtain the best weed seedlings. The visual properties of the weeds are depicted in **Fig. 7.5**. For the experiment, 10 seedlings of each weed were planted in the polybags each containing 5 kg oven-dry equivalent (24 hours 105 ^{o}C) air-dried soil samples which have been equilibrated for one week at the soil field moisture capacity or about 40%. The growing weeds were then let to grow for 2 months. During this experiment period, no other weeds were allowed to grow in the experimental unit.

As shown by the results of analysis of variance (Anova), the presence of weeds significantly affected the soil pH and exchangeable K (**Table 7.5**). Unlike those reported by Sembodo et al. (2015), the presence of weeds did not affect the soil organic C content (Table 7.5). Therefore, there must be a dynamic interrelationship between the changes in soil pH and the changes in the soil exchangeable K. However, this experiment cannot explain this phenomenon because the soil pH data indicate only the observation at the end of the experiment. However, it is obviously shown by the changes in the exchangeable K that K was released during the weed growing time (**Table 7.6**).

The data in **Table 7.6** clearly shows that weeds absorbed K from soils and depleted the soil exchangeable K during the growing time. The effectiveness of various weeds in absorbing K and causing the exchangeable K depletion is various. *Penisetum purpureum* is the most effective in depleting the soil exchangeable K. The order of their effectiveness in depleting the soil exchangeable K is *P. purpureum* > *P. conjugatum* > *Widelia sp.* > *A. gangetica* > *A. Pintoi*. However, the fact that the soil exchangeable K in soils under *A. pintoi* increased to about 114.0% in soil of Jabung and to about 145.0% in soil of Tanjung Bintang (**Table 7.6**), particularly in topsoils, suggests that the presence of weeds also stimulated the release of K from soil mineral structures through weathering processes.



AG = *Asystacia gangetica*
AP = *Arachis pintoi*
W = *Widelia sp.*
PC = *Paspalum conjugatum*
PP = *Pennisetum purpureum*

Fig. 7.5. Several weeds employed in the experiment.

Table 7.5. Variance analysis on the effect of weed roots on tropical soil properties.

Treatment Factors	Soil Properties		
	pH	Organic C	Exch. K
Main Plot:			
Weed Plant Roots (A)	**	ns	**
Sub-Plot			
Soil Type (B)	**	*	**
AB	**	ns	**
Sub Sub-Plot:			
Soil Layers (C)	ns	**	**
AC	**	ns	**
BC	**	ns	**
ABC	ns	ns	ns

ns = not significant, * significantly different,, ** very significantly different

The release was at least 14% of the initial exchangeable K in soil of Jabung and 45% of the initial exchangeable K in soil of Tanjung Bintang, assuming that the *A. pintoi* did not absorb K from the soil exchangeable K. The soil exchangeable K of these soils might have increased more than 14% and 45%, respectively, if weeds did not absorb soil K. This suggests that the weeds in fact stimulated the release of soil mineral structural K. The effectiveness of weeds in stimulating the release of soil K or in increasing the soil exchangeable K follows the order of: *A. Pintoi* > *A. gangetica* > *Widelia sp*. > *P. conjugatum* > *P. purpureum*.

The conceptual model depicted previously in **Fig. 1.10** may explain the weed-root induced release of soil mineral K. Weed roots may release the H^+ ions in exchange of the absorption of cations including K^+. The root respiration might have also released CO_2, that upon reaction with water molecules produced H^+ ion. The processes might have increased the concentration of H^+ ions, which then attacked the K position in the soil minerals. As reported, the released K^+ is intensified by the presence of more H^+ ions (Johnston and Olsen, 1972; Manley and Evals, 1986; Salam, 1989; Najafi-Ghiri and Jabari, 2013). Part of the released K was absorbed by weed roots and some other part was adsorbed by soil colloids increasing the soil exchangeable K. The increase in soil exchangeable K is obviously shown in soils under the influence of *A. pintoi* (**Table 7.6**). Other weeds might have, of course, increased the soil exchangeable K. However, the absorption of K by these weeds was more intensive than was *by A. pintoi*.

Table 7.6. The relative changes in soil exchangeable K as affected by weed roots.

Soils	**Layers**	**Weeds[1)]**				
		Ag	**Ap**	**W**	**Pc**	**Pp**
		% of initial contents[2)]				
Jabung	Topsoil	72.2	**114.0**	75.0	83.3	44.4
	Subsoil	65.5	93.1	58.6	69.0	38.0
Tanjung Bintang	Topsoil	88.9	**145.0**	66.7	55.6	33.3
	Subsoil	85.7	85.7	42.9	28.6	28.6
Average		78.1	110.0	60.8	59.1	36.1

1) Ag *Asystacia gangetica*, Ap *Arachis pintoi*, W *Widelia* sp., Pc *Paspalum conjugatum*, and Pp *Pennisetum purpureum*
2) Initial topsoil and subsoil exchangeable K were 0.36 and 0.29 $\text{cmol}_c\ \text{kg}^{-1}$, respectively, for soil of Jabung and 0.09 and 0.07 $\text{cmol}_c\ \text{kg}^{-1}$, respectively, for soil of Tanjung Bintang

The change in the soil exchangeable K (Δ Exch. K), assumed to be part of K that was absorbed by weeds, was found to be well-correlated with the weed shoot dry-weight with relatively high correlation coefficients, ranging from 0.58 to 0.89 (**Table 7.7**), and except in the subsoils of Tanjung Bintang, was also well-correlated with the weed root dry-weight also with relatively high correlation coefficients, ranging from 0.60 to 0.87 (**Table 7.8**). Δ Exch. K was calculated as follows:

Δ Exch. K = Final Exch. K (After Planting) – Initial Exch K (Before Planting) ……. Eq. 7.3

The correlation coefficients were in general higher in soil of Jabung which was more fertile than that in soil of Tanjung Bintang (**Table 7.7** and **Table 7.8**). These data suggest that the release of soil mineral K induced by weed roots was indeed related to weed absorption. This means that the released K was available for plant absorption. These phenomena are also shown by Anova that shows the influence of weeds on shoot and root dry-weights (**Table 7.9**).

Table 7.7. The relationships between shoot dry-weight and changes in the soil exchangeable K.

Soils	Layers	Weeds1)	Shoot Dry Weight	Δ Exch. K1)	Correlation Coefficient
			(g pot^{-1})	(cmol$_c$ kg^{-1})	(r)
Jabung	Topsoil	Ag	6.69	- 0.10	0.84
		Ap	4.13	+ 0.05	
		W	13.2	- 0.09	
		Pc	13.8	- 0.06	
		Pp	36.5	- 0.20	
	Subsoil	Ag	5.78	- 0.10	0.89
		Ap	3.59	- 0.02	
		W	9.55	- 0.12	
		Pc	9.30	- 0.09	
		Pp	32.5	- 0.20	
Tanjung Bintang	Topsoil	Ag	4.16	- 0.01	0.63
		Ap	2.47	+ 0.04	
		W	10.5	- 0.03	
		Pc	7.38	- 0.04	
		Pp	128	- 0.06	
	Subsoil	Ag	3.45	- 0.03	0.58
		Ap	1.85	- 0.03	
		W	8.67	- 0.04	
		Pc	4.97	- 0.05	
		Pp	126	- 0.05	

1) Ag *Asystacia gangetica*, Ap *Arachis pintoi*, W *Widelia* sp., Pc *Paspalum conjugatum*, and Pp *Pennisetum purpureum*

2) Δ Exch. K = Final Exch. K (After Planting) – Initial Exch. K (Before Planting)

Table 7.8. The relationships between root dry-weight and changes in the soil exchangeable K.

Soils	Layers	Weeds[1]	Root Dry Weight	Δ Exch. K[1]	Correlation Coefficient
			(g pot^{-1})	(cmol$_c$ kg^{-1})	(r)
Jabung	Topsoil	Ag	1.36	- 0.10	0.87
		Ap	2.15	+ 0.05	
		W	2.97	- 0.09	
		Pc	5.46	- 0.06	
		Pp	12.1	- 0.20	
	Subsoil	Ag	2.42	- 0.10	0.71
		Ap	4.40	- 0.02	
		W	2.72	- 0.12	
		Pc	3.46	- 0.09	
		Pp	13.3	- 0.20	
Tanjung Bintang	Topsoil	Ag	1.14	- 0.01	0.60
		Ap	1.31	+ 0.04	
		W	1.32	- 0.03	
		Pc	1.49	- 0.04	
		Pp	7.55	- 0.06	
	Subsoil	Ag	2.38	- 0.03	0.03
		Ap	1.34	- 0.03	
		W	2.17	- 0.04	
		Pc	1.69	- 0.05	
		Pp	2.01	- 0.05	

[1] Ag *Asystacia gangetica*, Ap *Arachis pintoi*, W *Widelia* sp., Pc *Paspalum conjugatum*, and Pp *Pennisetum purpureum*

[2] Δ Exch. K = Final Exch. K (After Planting) – Initial Exch. K (Before Planting)

The ability of weed roots to explore the soil mineral K is related to the values of root-to-shoot ratios (RSR) listed in **Table 7.10**. *A. pintoi*, that was shown to induce the highest Δ Exch. K (**Table 7.7** and **Table 7.8**), was found to have the highest RSR among the weeds employed in this research. The RSR of *A pintoi* in topsoil of Jabung was more than twice compared to those of *A. gangetica* and *Widelia sp.* and almost 1.5 times to those of *P. conjugatum* and *P. purpureum*. A similar pattern was observed in soil of Tanjung Bintang. The higher portion of *A. pintoi* biomass as roots might have enabled this weed to explore more soil minerals and induced the release of more soil mineral K. The RSR values of weeds are also shown to be higher in the subsoils than those in the topsoils since weed plant roots must work harder in less fertile condition.

Table 7.9. Variance analysis of the effects of weeds on dry-shoot and root weights.

Treatment Factors	Dry Weight	
	Shoots	Roots
Main Plot:		
Weed Roots (A)	**	**
Sub-Plot		
Soil Type (B)	**	**
AB	**	*
Sub Sub-Plot:		
Soil Layers (C)	**	**
AC	Ns	Ns
BC	Ns	*
ABC	ns	ns

ns = not significant, * significantly different, ** very significantly different

Table 7.10. The root-to-shoot ratio (RSR) of weeds grown in tropical topsoils and subsoils.

Soils	Layers	Weed Plants[1]				
		Ag	Ap	W	Pc	Pp
Jabung	Topsoil	0.203	0.521	0.225	0.395	0.342
	Subsoil	0.418	1.220	0.285	0.372	0.410
Tanjung Bintang	Topsoil	0.274	0.529	0.125	0.202	0.059
	Subsoil	0.690	0.725	0.250	0.340	0.016

[1] Ag *Asystacia gangetica*, Ap *Arachis pintoi*, W *Widelia* sp., Pc *Paspalum conjugatum*, and Pp *Pennisetum purpureum*

Table 7.11. The production of weed shoot per unit lost exchangeable K (S_K).

Soils	Layers	S_K of Weeds[1] (g dry-weight per cmol$_c$ kg^{-1})				
		Ag	Ap	W	Pc	Pp
Jabung	Topsoil	66.9	-82.6	147	230	183
	Subsoil	57.8	180	80.0	103	163
Tanjung Bintang	Topsoil	416	-62.0	351	185	2130
	Subsoil	115	62.0	217	99.0	2520

[1] Ag *Asystacia gangetica*, Ap *Arachis pintoi*, W *Widelia* sp., Pc *Paspalum conjugatum*, and Pp *Pennisetum purpureum*

[2] Σ_K = Shoot Dry-Weight/Δ Exch. K; Δ Exch. K = Final Exch. K (After Planting) – Initial Exch. K (Before Planting)

Hidayatullah (2019) reports that the RSR of *P. purpureum* was greater in soils contaminated by industrial waste containing high amount of Cu and Zn. The RSR of this grass significantly decreased with the levels of waste addition. This indicates that the root of this weed worked harder in contaminated soil and distributed more of its biomass into root and lower into shoot part (**Table 7.12**). However, this phenomenon was eliminated by liming, which is reported to increase the soil pH and lower the extractable Cu and Zn. The decrease in the extracted Cu and Zn help the root of the grass to live easier in the soils.

Table 7.12. The effect of heavy metal containing waste and lime on the RSR of *Penissetum purpureum* in soil of Sidosari South Lampung*.

Soil Treatment		**Root**	**Shoot**	**RSR**
Waste	**Lime**			
Mg ha^{-1}		**g polybag^{-1}**		
0	0	1.90	10.0	0.19
	5	3.57	13.7	0.26
15	0	4.02	18.3	0.22
	5	2.66	16.6	0.16
60	0	4.49	12.8	0.35
	5	2.75	13.1	0.21

*Hidayatullah (2019)

The effectiveness of *A. pintoi* in inducing the release of K is also shown by the values of Σk, that indicates the production of weed shoot per unit lost exchangeable K calculated by **Eq. 7.4**.

$$\Sigma_K = \text{Shoot Dry-Weight}/\Delta\ \text{Exch. K} \quad \ldots\ldots. \quad \text{Eq. 7.4}$$

where Σ_K is expressed in g dry-weight per cmol$_c$ kg^{-1}. The S_K of *A. pintoi* in topsoils is highest among the five weeds both in soil of Jabung and in soil of Tanjung Bintang (**Table 7.11**). Minus values indicate that there was no exchangeable K used but there was an increase instead. The increase was obviously originated from the release of soil mineral structural K.

However, the effectiveness of *Arachis pintoi* is not consistent. Lestari (2018) studied the effect of *Arachis pintoi* in several fertile and infertile soils of Lampung as compared to that of *Penissetum purpureum* as shown in **Table 7.13**. Soil samples were taken from 9 sites in Lampung. After drying and sieving to 2 mm, soil samples were planted with these weed species for 4 weeks after which the soils were analized for the pH 7.00 N NH_4OAc extracted K.

Table 13. The pH 7.0 *N* NH_4OAc extracted K from several soils of Lampung planted with two different species of weeds*.

Soil Samples	**Available K (mg kg^{-1})**		
	Control (No Weed)	***A. Pintoi***	***P. purpureum***
Gedongmeneng	2.18 A (a)	2.20 A (a)	2.21 B (a)
Sidosari	1.97 B (a)	1.91 E (b)	1.91 C (b)
Tanjung Bintang	1.97 B (a)	1.87 F (b)	1.80 D (c)
Sekampung Udik	2.20 A (a)	2.20 A (a)	2.25 A (a)
Gisting	2.19 A (a)	2.14 B (a)	1.92 C (b)
Hulu Sungkai	2.01 B (a)	2.01 C (a)	1.95 C (b)
Kotabumi	2.02 B (a)	1.99 CD (ab)	1.94 C (b)
Abung Selatan	2.01 B (a)	1.95 DE (b)	1.96 C (b)
Liwa	2.19 A (a)	2.21 A (a)	2.18 B (a)
Rataaan	2.08	2.05	2.01
LSD 5%	0.05		

*Lestari (2018)

Key Questions

1. How can weed roots increase the soil soluble and exchangeable K? Explain the sources of K and how these sources release K!
2. How do the soil minerals weather? Explain an example that includes the effect of soil pH on accelerating the process!
3. Explain the release of K from organic K sources! How do soil enzymes participate in this process?
4. What is the effect of Root-To-Shoot ratio on nutrient release from soil minerals? How does the mass distribution between root and shoot in marginal soils? What happen in fertile soils?
5. Explain all K forms in the soil system and their relationships with the plant root absorption!
6. Explain the supplies of K from soils! How do the supplies relate to each chemical form of K in the soil system?
7. Explain the nutrient element sources in the soil system and the mechanisms of releases of their nutrient elements!
8. What are the important factors that control the release of nutrient elements in soils? Explain!
9. Explain the relationship between the release of K from soil minerals versus soil pH, water, and leaching! Describe it with graphs!
10. Explain the effects of soil water and H^+ in the weathering of orthoclase! What conclusion you can make from this reaction?
11. Explain the availability of soil K!
12. Explain the relatonship between the availability of K and their chemical forms in the soil system!
13. How is the release of K from organic sources in the soil system? Explain!
14. What are the important factors controlling the release of K from organic matters? How does each of these factors accelerate the process?
15. Explain the fates of the released K from organic matter decomposition in the soil-water system!
16. Explain the effect of soil pH on the rates of soil mineral weathering! How does each factor accelerate the process?
17. Explain how to increase the weathering of orthoclase in the soil system!
18. Explain the effects of organic acids on the soil K?
19. Explain the effect of K releasing bacteria! How can you manage the bacteria to enhance the soil mineral weathering!
20. How does *A pintoi* stimulate more K release in the soil system? Explain it with some soil chemical reaction!
21. Explain the role of RSR in K release in the soil system!

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22. How does the RSR of weeds affect the K release in infertile or contaminated soils? Explain!
23. What are the effects of heavy-metal containing waste on the RSR of weeds? What happen if lime or organic matter is added into the contaminated soils?

Chapter 8

Effects of Tropical Weeds on Heavy Metals

Heavy metals are of two categories: plant nutrient heavy metals that includes those needed by plants like Fe, Mn, Cu, Zn, and Mo and non-plant nutrient heavy metals like Pb, Cd, Hg etc that are not needed by plants. Both categories show similar chemical characteristics and similar behaviors in the soil environment. Both categories are absorbed by plant roots and toxic at high concentrations.

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Heavy metals are trace elements and their natural concentrations in the soil environment are relatively low. Enhanced concentrations above the natural or the allowable levels may jeopardize the living things. They may accumulate in living tissues of the living things and may cause serious health problems. Several disasters occurred in the 1950s among which was in Minamata Bay Japan caused by an extremely high level Hg called Minamata Disease. Around the same time also occurred Itai-Itai Disease by Cd contamination of irrigation water used for paddy fields. The enhancement of soil heavy metals also occurred in several locations in Indonesia among which are in Jakarta Bay, Lampung Bay, etc., caused by unwise disposal of industrial and mine waste into the environment. The problem of heavy metals may become a great concern since industrialization may intensify the environmental pollution by heavy metals.

Heavy metals in the soil environment are also affected by the presence of weeds since the concentrations of heavy metals are influenced by the changes in soil pH, organic acids, soil organic C, and organic matter contents. These soil properties are previously discussed to be affected by the presence of weed roots. The concentrations of soil heavy metals are in general enhanced by the decrease in soil pH that decreases in the ambience of weeds roots. The increase in soil organic C and organic matter contents may increase the soil CEC that may decrease the concentrations of heavy metals in soil solution caused by heavy metal adsorption. On the contrary, the increase in organic acid complexing agents may solubilize heavy metals and hence may cause them to stay dissolved in soil solution.

Montiel-Rozas et al. (2016) suggest that the bioavailabilities of heavy metals can be modified by different root exudates. Among them, low molecular weight organic acids (LMWOAs) play an important role in this process. The release of LMWOAs like oxalic acids was proven to be an important mechanism against heavy metal stress, which is unique to each species and modifiable by means of organic amendment addition. Therefore, the changes in the land cover may also cause the changes in heavy metal solubility and concentrations since different vegetation covers may cause different magnitude of changes in soil pH, soil organic acids, soil organic C and organic matter contents, and soil CEC.

8.1 The Chemistry of Heavy Metals in Soils

Heavy metals presence in soils may have different forms that may include free ions, complexes and chelates, exchangeable, secondary minerals (precipitates), primary minerals, and organics which are mostly in equilibrium among each other. The existing equilibria between these various forms of heavy metals in the soil environment are shown in **Fig. 8.1**. Free ionic form of heavy metals in the soil-water is the central of heavy metal dynamics due to several reasons: (a) the availabilities of heavy metal elements to plant root absorption and heavy metal toxicities are related to this form (Allen et al., 1980; Checkai et al., 1987a; 1987b; Hernandez-Soriano et al., 2012), (b) the rates of heavy metal movement and leaching in the soil system are related to this form, (c) all chemical mechanisms controlling the concentrations of heavy metals (compelexation-decomplexation, chelation-dechelation, precipitation-dissolution, and adsoption-desorption processes) in the soil environment are also related to this form (Bowman and O'Connors, 1982; Sanders, 1982; Salam and Helmke, 1998; Hernandez-Soriano et al., 2012).

Free ion of heavy metals is in a direct relationship with their absorption by plant roots. The free ionic form is also in chemical equilibria with the processes of chelation-dechelation, complexation-decomplexation and precipitation-dissolution, as well as adsorption-desorption processes. The status of free ionic forms of heavy metals is also greatly affected by the emission of heavy metals from industrial wastes, fertilizers, and pesticides. Numerous reports shows that these materials contribute great amounts of heavy metals in the soil environment (Lagerwerff, 1982; Kardoz et al., 1986; Leung, 1988; Hegstrom and West, 1989; Alloway, 1990b; Davies, 1990; Kiekens, 1990; Rivai, 1990; Dowdy et al., 1991; Boon and Soltanpour, 1992; Jing and Logan, 1992; Wang et al., 1992; Herrero and Martin, 1993; Sweet et al., 1993; Cabrera et al., 1994; Nicholson et al., 1994; Tsoumbaris and Tsoukali-Papadopoulou, 1994; Schuhmacher et al., 1994; Bilski and Alva, 1995; Flegal and Smith, 1995; Vile et al., 1995; Gimeno-Garcia et al., 1996; Salam et al., 1996; Yeh et al., 1996; Salam et al., 1997a; Juracek and Ziegler, 2006; Biasioli et al., 2007; Benke et al., 2008; Berenguer et al., 2008; Lin et al., 2008; Hobara et al., 2009; Benn et al., 2010; Cakmak et al., 2010; Kien et al., 2010; Wang et al., 2010; and Tu et al., 2012). Similarly, the status of free ionic of heavy metals in soil water is also affected by absorption by plant roots and/or leaching by percolating water, which may cause the decrease in heavy metal free ionic form concentration in the soil water.

Fig. 8.1 clearly shows that the heavy metals in complexes, chelates, adsorbed sites, and/or precipitates will buffer the concentrations of free ionic heavy metals based on the equilibration principles (Lindsay, 1979). This suggests that the related equilibrium constants are of great importance. Whenever the concentration of free ionic heavy metals in soil water is lowered by some mechanisms such as plant root absorption or leaching, the heavy metals in complexes, chelates, adsorbed sites, or precipitates will be released to compensate the respective equilibrium constants through equilibrium processes. On the other hand, if the concentrations of free ionic heavy metals in soil water are high enough due to external addition such as waste and fertilizer applications, parts of the free ionic heavy metals in soil solution will be complexed, chelated, adsorbed, or precipitated, depending on the pertaining conditions to reach new equilibrium values.

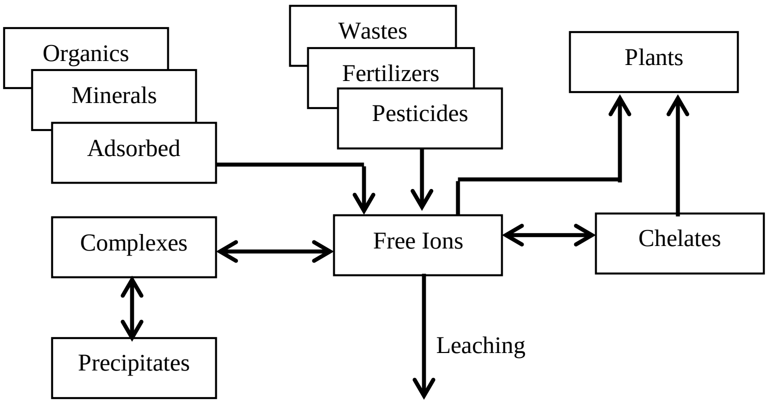

Fig. 8.1. The relationships between forms of heavy metals in the soil environment (Adapted from Salam, 1997a; Salam, 2017).

Cavallaro and McBride (1980) reports that the free ionic Cu^{2+} concentration in the soil system was greatly pH-dependent, but the concentration was below the levels needed for the precipitation processes to occur. Abd-elfattah and Wada (1981) also suggest that Zn^{2+}, Pb^{2+}, Cu^{2+}, Co^{2+}, and Cd^{2+} at concentrations 10^{-7} to 10^{-2} M in 10^{-3} to 10^{-2} M $CaCl_2$ were not precipitated as hydroxides but were adsorbed by cation-exchange sites. Salam and Helmke (1998) also report that the logarithmic of Cu^{2+} concentration was linearly related to the soil pH and was controlled by adsorption-desorption process (**Fig. 8.2**). The importance of each chemical processes in controlling the concentrations of heavy metals in soil water is debatable, but are in general depending on the heavy metal cation concentration and soil pH.

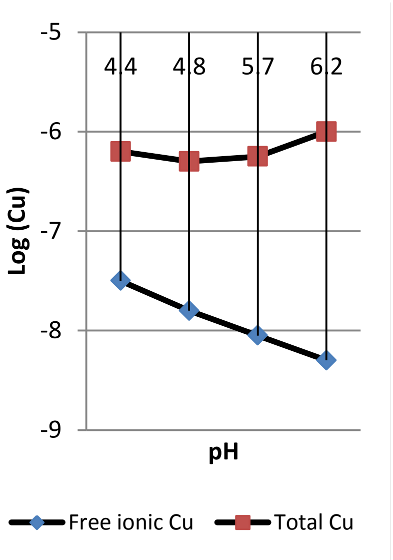

Fig 8.2. The relationship between logaritmic (Cu^{2+}) and total dissolved Cu (Cu_T) with soil pH (Adapted from Salam and Helmke, 1998).

Salam (2017) shows the possibility of hydroxide precipitation at lower pH may occur when the concentration of heavy metal cation is higher (**Fig. 8.3)**. **Fig. 8.3** shows that at high concentrations, heavy metal cations precipitate at lower pH (A) and not at low concentrations (B). A good example is probably exemplified by Fe^{2+} that may precipitates at lower pH when the concentration of $[Fe^{2+}]$ is higher. The calculation is shown in **Table 8.1**. At $[Fe^{2+}] = 10^{-6}$ M the precipitation of $Fe(OH)_2$ occurs at pH = 10.15 while at $[Fe^{2+}] = 10^{-3}$ M or 1,000 times higher, the $Fe(OH)_2$ precipitation occurs at pH = 8.65, about 1.85 unit pH lower. At $[Fe^{3+}]$ 1,000,000 times higher or $[Fe^{3+}] = 1$ M, the precipitation may occur at even lower pH i.e. pH = 7.15.

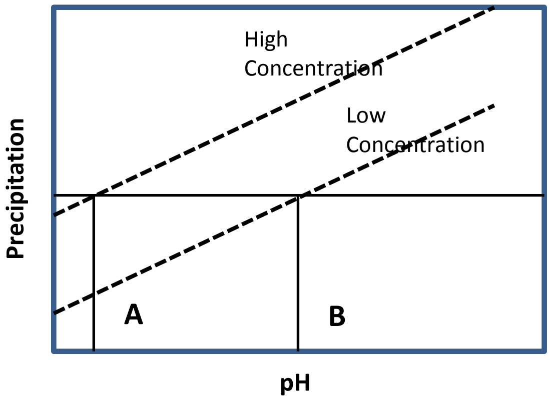

Fig. 8.3. The precipitation of heavy metal cation as a function of pH (Salam, 2017).

Table 8.1. The precipitation of $Fe(OH)_2$ at different concentration of Fe^{2+}*.

$[Fe^{2+}]$ M	pH	Calculation
10^0	7.15	$K = [Fe^{2+}][OH^-]^2$
10^{-3}	8.65	$K = 10^{-13.7}$
10^{-6}	10.15	$[OH]^2 = K/[Fe^{2+}]$ pH + pOH = 14

*Salam (2017)

However, in general soil workers agree that all mechanisms greatly depend on soil pH (Ma and Lindsay, 1990; Workman and Lindsay, 1990; Salam and Helmke, 1998; and Hernandez-Soriano et al., 2012). Complexation, chelation, precipitation, or adsorption processes increase with the increase in soil pH. The soil adsorption capacities increase with the increase in soil pH due to H^+ ionization from various soil functional groups, both organic and inorganic and, thereby, the holding capacity of soil solids towards heavy metal cations also increases. By this process, the concentrations of heavy metals in soil water decrease with the increase in soil pH (Workman and Lindsay, 1990; El-Falaky et al., 1991; Salam and Helmke, 1998). Some other soil workers also believe that the heavy metal precipitation is important at high soil pH. The precipitation of heavy metals may increase at high pH with high concentrations of heavy metals, particularly if the concentrations of the precipitating agents like carbonate and sulphate ions in soil water are high (Singh and Sekhon, 1977; Brummer et al., 1983).

Some soil properties may affect the magnitude of the respective forms of heavy metals in the soil environment. Soil pH is repeatedly reported to be the most important factor (Salam and Helmke, 1998; Salam, 2017; Salam, 2019). As discussed previously the increase in soil pH may lower the concentrations of free ions and total dissolved heavy metals in soil solution (**Fig. 8.2**). At high concentration of heavy metals, parts of the heavy metals are precipitated forming secondary minerals due to the increase in the concentration of OH^- as shown in **Fig. 8.2**. At low concentration, heavy metal adsorption may dominate due to increased CEC as a result of adsorbed H neutralization by OH^- ions, shown in **Fig. 8.4** and **Fig. 8.5**. The increase in the soil enzymatic activities may also indirectly enhance the heavy metal adsorption. The acceleration of organic matter decomposition by soil enzymes may cause the emergence of high amounts of soil organic matters negative sites as a result of organic functional group dissociation like phenolics, hidroxyls, and carboxylics (**Fig. 8.6** and **Fig. 8.7**).

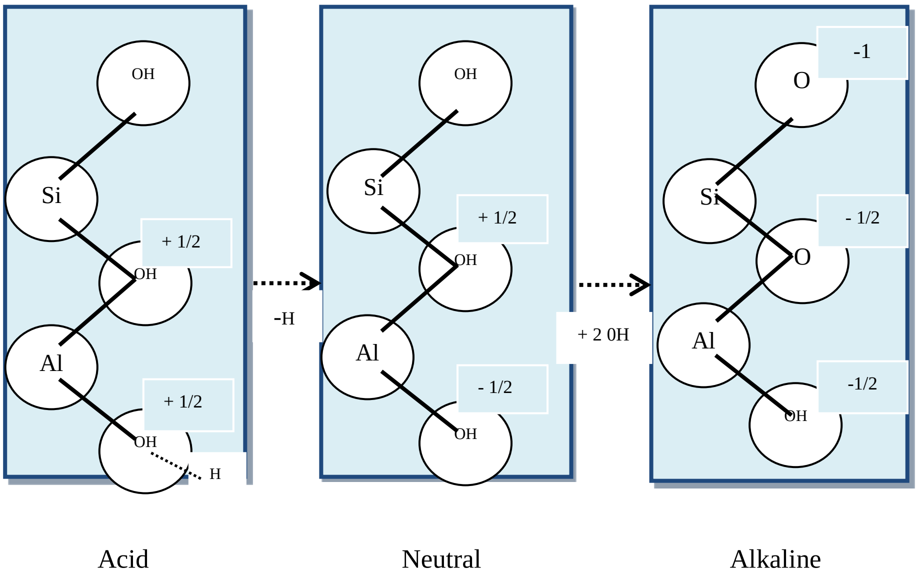

Fig. 8.4. The development of negative charges of 1:1 silicate clay minerals (Bohn et al., 1985; Salam, 2017).

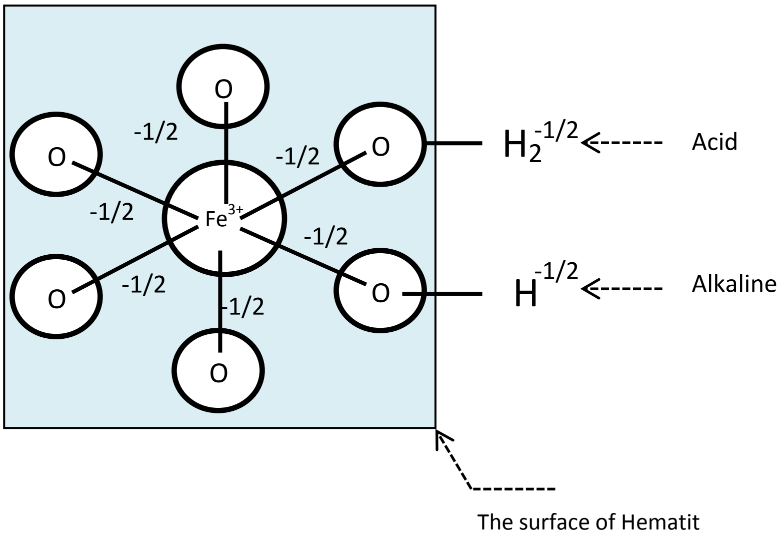

Fig. 8.5. The development of negative charges of oxides of Hematite (Fe_2O_3) (Bohn et al., 1985; Salam, 2017).

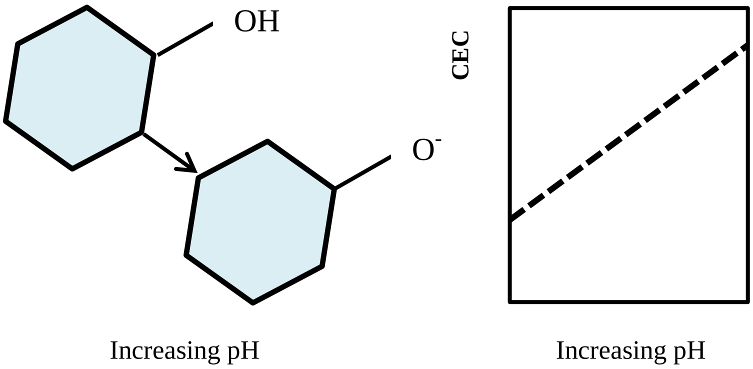

Fig. 8.6. The development of negative charges of organic matters origin with phenolic functional groups (Salam, 2017).

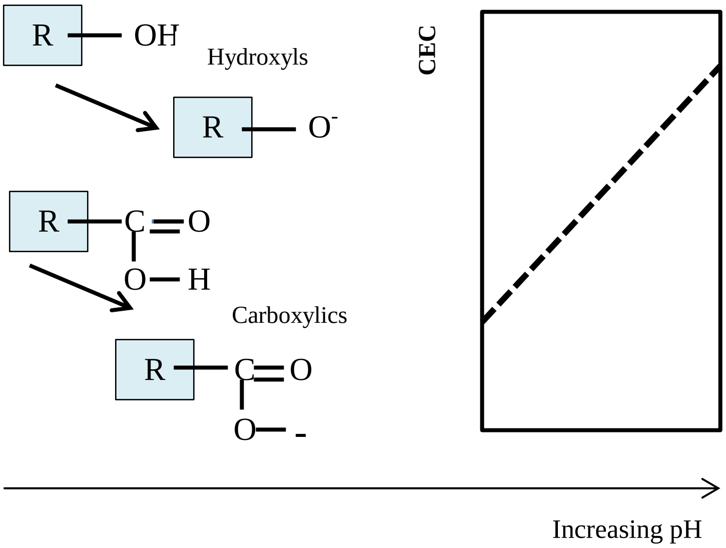

Fig. 8.7. The development of negative charges of organic matter origin with hydroxylic and carboxylic functional groups (Salam, 2017).

The decrease in soil pH may reverse the process. The decrease in soil pH may dissolve the heavy metal precipitates, decrease the soil CEC and release the adsorbed heavy metal cations. Likewise, the presence of organic acids may dissolve heavy metal precipitates, desorb the adsorbed heavy metals, and solubilize the heavy metals to stay in soil solution in the forms of metal complexes or metal chelates. Therefore, any natural or anthropogenic agents and processes that may change the soil pH, the concentration of organic acids, and the activities of soil enzymes may change the chemical processes and the concentration of heavy metal in soil solution.

8.2 Effects of Weed Management

As discussed previously, weeds influence various soil properties which directly or indirectly affect the magnitude of the respective forms of heavy metal in the soil environment. The magnitude of the effects on heavy metals depends greatly on the magnitude of weed root effects on the related soil properties. The presence of effective weeds may greatly affect the heavy metal forms in the soil environment. For example, the presence of *alang-alang* may cause the concentration of dissolved heavy metals to be lower than do the presence of other weeds since the rhizosphere of *alang-alang* show higher pH than other weeds (Salam et al., 1997a).

However, due to the fact that generally the rhizosphere of weeds show lower pH due to the excretion of H^+, organic acids , and the evolution of respired CO_2 that may increase the soil solution H^+, the concentration of free ions and dissolved heavy metals in the soil solution should be higher than in the control soil without weeds. Hydrogen ions may increase the release of heavy metals from precipitates and primary minerals. The presence of organic compexing agents may also solubilize heavy metal precipitates and heavy metal complexes. This process may intensify the dissolution of heavy metal precipitates (secondary minerals) and primary minerals. The decrease in soil pH and the increase in the concentration of complexing agents are a good combination that may accelerate the weathering of soil minerals and increase the concentrations of heavy metals in soil solution as free ions, complex ions, and chelates.

The presence of various enzymes excreted by weed roots may also accelerate the decomposition of various organic matters containing heavy metals. In addition to increasing the concentrations of dissolved heavy metals, this process may also enhance the organic matter surfaces with adsorption sites expressed as CEC. The increase in soil CEC may directly decrease the concentrations of free ions and indirectly decrease the concentration of complexes and chelates. Therefore, the organic matter decomposition catalyzed by enzymes may enhance not only the concentrations of free ions but also the concentration of exchangeable heavy metal cations.

Salam et al. (1997a) and Sriyani and Salam (1998) planted amaranth (*Amaranthus tricolor*) and some tropical weeds including pigweed (*Amaranthus spinosus*), green kyllinga (*Cyperus kyllingia*), and *alang-alang* (*Imperata cylindrical*) in Oxisols from Gedongmeneng, Bandar Lampung, Indonesia. Soil was sampled after a four-week growth and is analyzed for the soil availabilities of heavy metal micronutrients using DTPA methods (Baker and Amacher, 1982) and soil pH using pH-electrode. The results are listed in **Table 8.2**.

Table 8.2 clearly shows that the soil pH under *alang-alang* was the highest. Compared to the initial soil pH of 5.25, it is understood that the presence of *alang alang* neutralized the rhizosphere soil pH, meaning that *alang-alang* roots excreted more OH^- and HCO_3^- ions than H^+ ions. In a lesser magnitude, *C. kyllingia* also excreted more OH^- and HCO_3^-. On the other hand, *A. tricolor* and *A. spinosus* excreted more H^+ and hence showed lower pH that the initial pH. The neutralization of H^+ by *alang-alang* roots is suspected as the reason for lower availabilities of Fe, Cu, and Pb in the rhizosphere of *alang-alang* compared to those in the root-zones of other weeds and amaranth because the availabilities of heavy metal cations in general decreased with the increase in soil pH. This phenomenon is consistent with that reported by Heradilla (1997) that the absorption of Cu and Pb by *alang-alang* was lower than those by the other weeds.

Table 8.2. The effect of amaranth and some tropical weeds on the soil pH and heavy metal availabilities*.

Soil Properties	*Imperata cylindica* (*Alang-alang*)	*Amaranthus tricolor* (Amaranth)	*Amaranthus spinosus* (Pigweed)	*Cyperus kyllingia* (Green Kyllinga)
pH (H_2O 1:2)	6.25	5.03	5.01	5.64
Fe (mg kg^{-1})	22.5	80.6	15.2	47.3
Mn (mg kg^{-1})	14.9	187	1.77	2.13
Zn (mg kg^{-1})	8.45	7.68	4.05	11.1
Cu (mg kg^{-1})	0.44	1.00	0.69	1.23
Pb (mg kg^{-1})	0.19	1.13	0.79	0.50

*Adapted from Salam et al. (1997a) and Sriyani and Salam (1998)

8.3 Effects of Forest Conversion

Land-use conversion has long been suspected to change soil properties including the soil chemical, soil physical, and soil biological properties important for agriculture. As discussed previously, data showed that land-use conversion from the primary forest to secondary forest, coffee plantation, and cultivated lands lowered some soil chemical properties like soil CEC, soil organic C, organic matter, and total N, soil enzymatic properties (urease, arylsulfatase, β–glucosidase, and alkaline and acid phosphatases) (Salam et al., 1998b). The dominant vegetation and soil life are also shown to change by land-use conversion (Salam, 2014).

The availabilities of heavy metal plant nutrients were also the important soil chemical properties that changed by land-use conversion. This change is logical based of their relationship with other soil chemical properties like soil pH, CEC , and organic matter content (Parfiit et al., 1995; Rodella et al., 1995; Alloway, 1990; McGrath et al., 1988). The changes in microclimate as affected by land clearing, particularly the soil temperatures and the soil moisture content, may accelerate the decomposition of organic matters and the weathering of soil minerals, that may release various micronutrients that may be weakly adsorbed by soil solids or leached by percolating water through the soil pore channels. Intensive tillage in agricultural soils may also intensify the process of decomposition (Klein and Koths, 1980) causing the decrease in heavy metal micronutrient availability in soils.

The changes in vegetation, soil microorganisms, soil erosivity, soil organic matter content, and fertilization practices may also change the availabilities of heavy metal micronutrients (Klein and Koths, 1980; Herrero and Martin, 1993; He and Singh, 1994; Gimeno-Garicia et al., 1996; McLaughlin et al., 1996; Salam, 1996). Salam et al. (1998b) report that the organic matter content and CEC of topsoils and subsoils decreased by land conversion from primary forest to secondary forest, coffee plantation, and intensive cultivated land. This suggests that the land conversion may also decrease the availabilities of heavy metal micronutrients.

Salam (1999) report that in general the availabilities of Cu and Zn were higher in topsoil and subsoils of the primary and the secondary forest compared to those in the coffee plantation and cultivated land (**Fig. 8.8** and **Fig. 8.9**). The relative concentrations of these heavy metal micronutrients compared to those in the primary forest are listed in **Table 8.3**. The changes in the soil available Cu in each location were linearly correlated with Organic C content, Total N contents, and CEC with correlation coefficients ranging from 0.682-0.976, 830, 0,752-0.860, and 0.723-0.861, respectively. The availability of Zn was also well-correlated with these three soil properties with correlation coefficients ranging from 0.710 – 0.907, 0.767 – 0.883, and 0.754 – 0956, respectively.

The above data show that forest conversion lowered the availabilities of heavy metal micronutrients due to several reasons. Forest clearing changed the soil microclimate, particularly related to the soil moisture content and temperature that might have accelerated the soil mineral weathering and organic matter decomposition due to the increased microorganism population and activities. Intensive soil tillage might have also accelerated this process and decreased the soil organic matter content, that might have finally changed the availabilities of heavy metal micronutrients. Soil erosion and leaching after land clearing might have also accelerated the losses of these metals. Conversely, fertilization in coffee plantation and cultivated land might have slightly increased the availabilities of Cu and Zn due to the fertilizer contaminants. The phenomenon is shown by the slight increase in the availabilities of Cu and Zn in the land system of Bukit Ringgis and Sekincau.

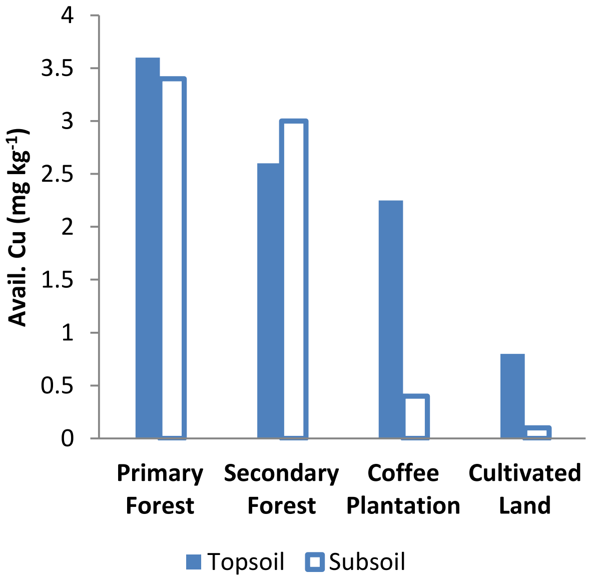

Fig. 8.8. The changes in soil available Cu in different land-use systems of Tri Mulya, West Lampung, Indonesia ((Redrawn from Salam, 1999).).

Based on the fact that the primary forest was located higher that the secondary forest, coffee plantation, and cultivated land, it is predicted that in the beginning, the fertility of the coffee plantation and cultivated land was initially higher than the primary and secondary forests. The land-use conversion drastically decreased the availabilities of Cu and Zn in coffee plantation and cultivated land.

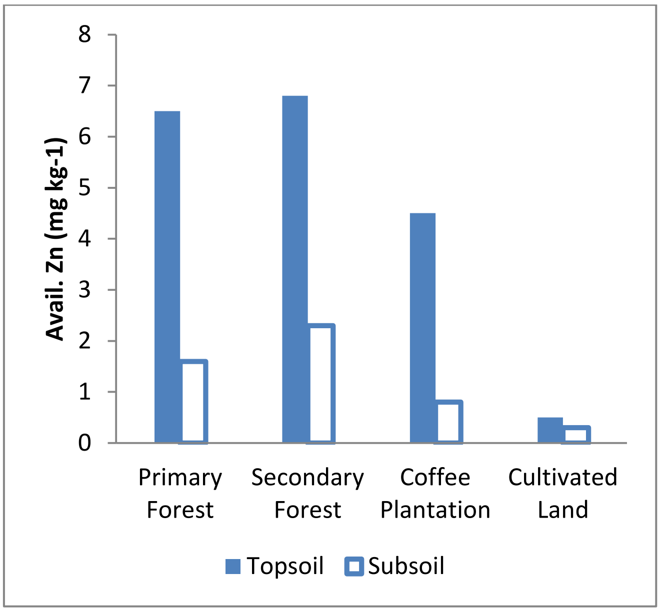

Fig. 8.9. The changes in soil available Zn in different land-use systems of Tri Mulya, West Lampung, Indonesia (Redrawn from Salam, 1999).

As those of Cu and Zn, the availability of Fe in general was higher in the primary forest and secondary forest compared to those in coffee plantation and cultivated land, both in topsoil and subsoil (**Table 8.3**, **Fig. 8.10**). This data shows that land-use conversion also decreased the availability of Fe. This change was also caused by the increased soil mineral weathering and organic matter decomposition combined with the intensive Fe leaching and erosion. These changes are also well-correlated with Organic C (r = 0.772 – 0.831), with Total N (r = 0.673 – 0.835), and soil CEC (r = 0.560 – 0.940). The Organic C, Total N, and soil CEC are previously reported to decrease by land-use conversion from the primary forest to secondary forest, coffee plantation, and cultivated land.

Table 8.3. The effect of land-use conversion on the relative availabilities of heavy metal nutrients in West Lampung (compared to the primary forest)*.

	Location	Secondary Forest		Coffee Plantation		Cultivated Land	
		Topsoil	Subsoil	Topsoil	Subsoil	Topsoil	Subsoil
Cu	Bukit Ringgis	0.19	0.46	0.53	0.09	0.60	0.22
	Sekincau	0.22	-	0.33	-	0.37	-
	Tri Mulya	0.71	0.87	0.63	0.13	0.23	0.01
Zn	Bukit Ringgis	0.12	0.45	0.23	0.15	0.26	0.35
	Sekincau	0.19	0.69	0.37	0.87	0.54	1.15
	Tri Mulya	1.11	1.20	0.71	0.44	0.08	0.07
Fe	Bukit Ringgis	1.29	5.92	0.39	0.16	0.57	0.58
	Sekincau	0.02	0,54	0.04	0.27	0.06	0.68
	Tri Mulya	0.36	0.57	0,57	0.82	0.39	0.19
Mn	Bukit Ringgis	0.54	2.20	2.64	1.49	0.87	1.94
	Sekincau	0.36	0.87	0.36	0.18	0.40	1.73
	Tri Mulya	1.33	1.46	0.71	0.33	0.55	0.06

***After Salam (1999)**

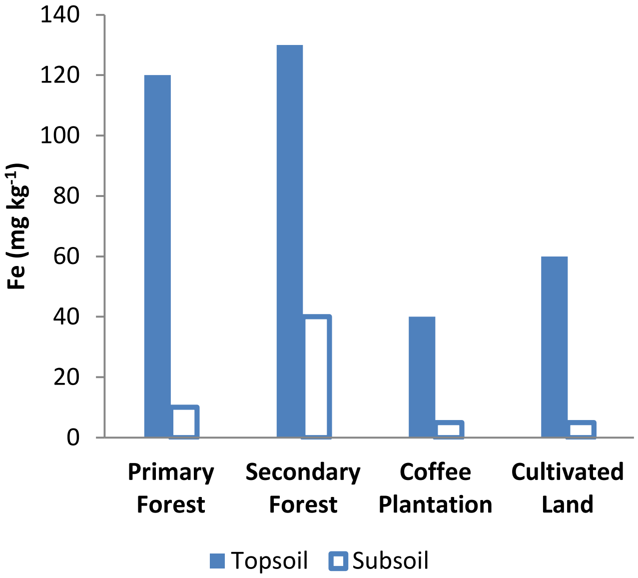

Fig. 8.10. The changes in soil available Fe in different land-use systems of Bukit Ringgis, West Lampung, Indonesia (Redrawn from Salam, 1999).

The change in the availability of Mn in Tri Mulya is similar to those of Cu, Zn, and Fe; higher in the primary forest and the secondary forest than those in the coffee plantation and cultivated land both in topsoil and subsoil (**Fig. 8.11**). The change are also well-correlated with Organic C (r = 0.725), with Total N (r = 0.748), and soil CEC (r = 0.627). In Bukit Ringgis and Tri Mulya, the availability of Mn was higher in the coffee plantation and/or the cultivated land. It is probable that in these locations the released Mn was immobilized stronger on the soil solids and hence more difficult to leach.

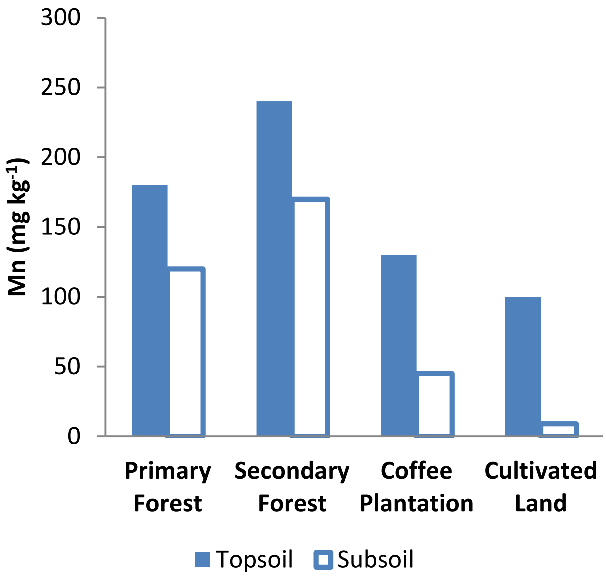

Fig. 8.11. The changes in soil available Mn in different land-use systems of Tri Mulya, West Lampung, Indonesia (Redrawn from Salam, 1999).

In general, the effects of land-use conversion from forest to coffee plantation and cultivated land shows similar pattern on the availability of heavy metal micronutrient including Cu, Zn, Fe, and Mn. Their availabilities are higher in the forests that those in the coffee plantation and the cultivated land. The availabilities are well-correlated with the changes in several soil properties like organic C, organic matter content, Total N, and soil CEC, which also decreased with land-use conversion from forest to coffee plantation and cultivated land.

Key Questions

1. Explain the two catagories of heavy metals in the soil environment and also their properties and functions to plants!
2. What are the relations of micronutrient metal elements and their effects on plants? What are the effects of their excesses and scarce concentrations on plants and other living things?
3. What is the relation of non-micronutrient metal elements and their effects on plants? What are the effects of their excesses and scarce concentrations on plant and other living things?
4. What is heavy metal contamination and pollution in soils? What are their effects on the living things?
5. How do weeds affect the concentrations and availabilities of micronutrient and non-micronutrient heavy metals in the soil environment? Explain the chemical reactions involved in responding to the phenomenon of soil pollution by heavy metals!
6. Explain the various forms of heavy metals in the soil water system and their relationships!
7. Explain the availabilities of each form of heavy metals to plants!
8. Explain the chemical dynamics of heavy metal in the soil system!!
9. Explain the various chemical reactions involved among all chemical forms of heavy metals in the soil system!
10. Explain the effects of pH on the concentrations of various forms of heavy metals in the soil system!
11. Explain the effects of CEC on the concentrations of various forms of heavy metals in the soil system!
12. Explain the effects of lime and organic matter on the concentrations of various forms of heavy metals in the soil system!
13. Explain the effects of various soil enzymes on the concentrations of various forms of heavy metals in the soil system!
14. Explain the effects of pH on the concentration of various forms of heavy metals in the soil system!
15. Explain the effects of weeds on soil pH and the concentration of various forms of heavy metals in the soil system!

16. Explain the effects of land-use conversion on soil chemical and biological properties! Give some examples!
17. Explain the effects of land-use conversion on heavy metals in the soil system! Give examples!

Chapter 9.
Closing Remarks

Weeds are very unique vegetation. In addition to the fact that they are very expansive and competitive, the also significantly affect the soil environment. Weeds are reported to significantly affect the soil chemical, soil biochemical, and the soil physical properties. Therefore, weeds may affect the soil fertility and the growth of crop plants.

Weeds roots excrete H^+ and organic acids that provide two of the very important chemical species in the soil environment i.e. H^+ ions and organic complexing agents. Hydrogen ions may eventually lower the soil pH. The evolution of CO_2 from hydrocarbon oxidation in weed roots and microorganism associated with weed roots may intensify the soil ambient acidification due to the formation of H^+ as a result of the reaction between CO_2 and water molecules. The decrease in soil pH may release some nutrient elements contained in the structure of the primary and secondary minerals. The complexing agents may complex parts of the nutrient elements and cause the nutrient elements to stay dissolved in the soil solution and, by mass action, may also increase the release of plant nutrient elements from soil minerals.

Weed roots and microorganism and macrorganims associated with them also excrete soil enzymes. These biocatalysts are very important in the cycles of some nutrient elements like C, P, N, and S. The presence of soil enzymes may speed up the transformation of organic nutrient elements, which are not available to root absorption, into inorganic nutrient elements, that are readily available to plant roots. The presence of soil enzymes may accelerate the supplies of nutrients to plant roots from organic sources.

In addition to their effects on the soil chemical and the soil biological properties mentioned above, the presence of weeds is also very important to improve the soil physical properties. The increase in organic C through weed residues may increase the soil organic C and the soil moisture content and maintain the soil temperature. The increase in soil CEC may also maintain the soil moisture content. The increase in the soil organic C is not affected only by weed organic residues. The excretions of weeds roots may also increase the soil organic matter. In general, the presence of weeds may improve the soil fertility.

10.1 The Chemistry of Soils under Weed Management

The effects of weeds are significant on the soil chemical properties and also on the soil biological and the soil physical properties. The soil chemical properties affected by weeds may include the soil pH, the soil complexing agents, the soil enzymatic properties, the concentration of CO_2, the soil organic matter, organic C and total N, the soil CEC, the availability of various nutrient elements, the soil exchangeable bases, etc. The soil biological properties affected may include the population and activity of soil microorganisms, the evolution of CO_2, the population of mesoorganisms like earthworms, etc. The soil physical properties affected may include the soil moisture content and the soil temperature.

The soil pH in the rhizosphere of weeds decreases due to several reasons. The first is the excretion of H^+ ions by weed roots. The second is the excretion of organic acids by weed roots. The combined excretion of H^+ and organic acids by weed roots may cause a significant decrease in soil pH. Third is the reaction of CO_2 evolved by weed roots and the associated organisms that may produce high amount of H^+. These three reasons may eventually lower the soil pH in the ambient soil mass.

The evolution of CO_2 occurs by at least two important mechanisms. In obtaining energy for growth and nutrient element absorption, weed roots may oxidize hydrocarbon. In the presence of O_2 in the soil air, hydrocarbon (CHO) in the weed roots is oxidized producing CO_2, H_2O, and energy. The energy is used among which to obtain some of the plant nutrient elements in the soil environment. Similar to plant roots, both microorganism and mesorganism like earthworms also oxidize hydrocarbon for their food to obtain energy. Energy is immediately used. The CO_2 released in the respiration by weed roots and macro- and microorganisms may enter the soil solution. Upon reaction with water molecules, CO_2 may form H_2CO_3, which is unstable and quickly dissociate producing H^+ following **Eq. 9.1**.

$$\mathbf{CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-} \quad \text{.......} \quad \textbf{Eq. 9.1}$$

The reaction of these two compounds (respiration) may form H^+ and HCO_3^- (bicarbonate). The production of H^+ may lower the soil pH and affect several other important soil properties.

The increase in soil enzymatic activities by weed roots, microorganisms and mesoorganisms may accelerate the decomposition of organic residues in the soil environment. In addition to accelerating the cycles of several nutrient elements, these processes may enhance the availabilities of some nutrient elements. The concentrations of several nutrient anions and cations such as HPO_4^{2-}, $H_2PO_4^-$, SO_4^{2-}, NO_3^-, K^+, Ca^{2+}, etc increase. The decomposition of weed residues may also increase organic C and organic matters, and also the soil CEC. The presence of more organic acid complexing agents may cause some elements like some micronutrient metal element to stay dissolved in soil water and be available to plant roots.

The increase in organic matter contents may increase the soil water contents which in turn may accelerate the soil mineral weathering and organic matter decomposition. The increase in soil water may also increase the population and activities of microorganisms and mesoorganisms that produce soil enzymes and organic acids excreted into the soil environment. Therefore, the presence of weed roots in general may increase the soil fertility.

10.2 The Availabilities of Plant Nutrients under Weed Management

The availabilities of macro and micronutrients in soils under weeds may increase significantly. The increase is caused by several mechanisms. The most important sources of nutrients in soil minerals and organic matters may speed up the release of nutrient elements through soil mineral weathering and organic matter decomposition by the decrease in soil pH and the increase in soil enzymatic activities. The supplies of nutrient elements may stay high as long as the soil pH relatively low and the soil enzymatic activities relatively high. The presence of organic acids which may act as organic complexing agents may maintain the availability of these elements

The increase in soil C and organic matter maintains sufficient soil moisture content which may make the dissolved nutrient elements to be available to plants. In addition, the increase in soil CEC may maintain nutrient reserves available to plants. Higher CEC also makes the mineral weathering continues and maintain the availability of nutrient elements from soil mineral sources. The increase in soil moisture content also maintain higher microbial and earthworm population and activities, and production of enzymes. Higher organic matter decomposition also releases nutrient elements from organic sources. Earthworms also produce faces that contain nutrient elements.

10.3 The Use of Effective Weeds

It is obvious that weed roots may increase the fertility of soils by improving the soil chemical, physical, and biological properties. Therefore, it is probable that weeds are used in the management of soils for crop plants. However, it is important to first select effective weeds to conduct this mission. A little number of weeds are reported to employ in this mission even though further researches must be conducted. Research must not only focus on the effectiveness of weeds in enhancing the soil fertility but also on how the effective weeds are applied in crop production. Such alternatives as to employ weeds in the same time during plant growth or to employ weeds before planting the main crops are one of the choices. The most important is how to get the benefit of increased soil fertility by the presence of weeds.

Key Questions

1. How does the soil acidification occur by weed rooting system? What substances and reactions involved in this process? Explain!
2. How does the oxidation reaction in the weed roots producing CO_2 occur and acidify the soils? Explain!
3. What are the effects of root excretion of H^+ and organic acids? What soil properties are affected by the these substances? Explain!
4. One way of weeds to extract soil nutrients is by excreting enzymes through their roots. Explain the mechanism!
5. What are the functions of enzymes? Explain it with examples! What is the relationship of this reaction with the soil organic and inorganic sources of soil nutrients?
6. Explain the role of soil enzymes in the nutrient cycles including the C-, N-, S-, and P cycles!
7. Explain the effect of weeds on soil physical properties with some examples! Explain the particular effect of weeds on soil moisture content!
8. Explain the effect of weeds on soil chemical properties with some examples! Explain the particular effect of weeds on soil K!
9. Explain the effect of weeds on soil biological properties with some examples! Explain the particular effect of weeds on soil bacterial and fungal population and activities!
10. Explain the effect of weeds on soil pH with some chemical reactions!
11. Explain the effect of weeds on the availabilities of some plant nutrients! Explain the particular effect of weeds on soil total N!
12. Explain the effect of weeds on soil cation exchange capacity (CEC)! What soil properties directly affect this? Does weed roots affect these soil properties?
13. Explain the effects of weeds on soil organic C and organic matter content!
14. Explain the effects of weeds on soil heavy metal availabilities! What soil properties directly affect this? Do weed roots affect these soil properties? Explain! Explain the particular effect of weed on soil Pb!
15. Can the presence of weeds affect the soil mineral weathering? Explain what soil properties may accelerate this reaction and how! How do weeds affect the changes in these soil properties? Explain!
16. How do weeds accelerate the soil organic matter decomposition? What soil properties affect this reaction? How do weeds affect the changes in these soil properties? Explain!
17. The increase in soil CEC may increase the soil mineral weathering dan organic matter decomposition. How do weeds involve in this acceleration? What chemical reactions involved in this process?

References

Abd-elfattah, A. and K. Wada. 1981. Adsorption of lead, copper, zinc, cobalt, and cadmium by soils that differ in cation-exchange materials. J. Soil Sci., 32:271-283.

Abella, S.R and S.C. Engel. 2013. Influences of wildfires on organic carbon, total nitrogen, and other properties of desert soils. Soil Sci. Soc. Am. J., 77(5):1806-1817.

Acosta-Martinez, V., L. Cruz, D. Sotomayor-Ramirez, and L. Perez-Alagria. 2007. Enzyme activities as affected by soil properties and land use in a tropical watershed. Appl. Soil Ecol., 35:35-45.

Acosta-Martinez, V., D. Acosta-Mercado, D. Sotomayor-Ramirez, and L. Cruz-Rodriguez. 2008. Microbial communities and enzymatic activities under different management in semiarid soils. Appl. Soil. Ecol., 38:249-260.

Adkins, S. 1997. Introduction to Weed Science. Pp. 23-38. *In* M. Julien and G. White (Eds.). Biological Control of Weeds: Theory and Practical Application. ACIAR Monograph Series, Canberra, Australia.

Alexander, M. 1977. Introduction to Soil Microbiology. 2nd ed. John Willey & Sons, Inc., New York.

Allen, H.E., R.H. Hall, and T.D. Brisbin. 1980. Metal speciation. Effects on aquatic toxicity. Environ Sci. Technol., 14:441-443.

Alloway, B.J. 1990a. Soil processes and behaviors of metals. pp. 7-28. *In* B.J. Alloway (Ed). Heavy Metals in Soils. Blackie, London.

Alloway, B.J. 1990b. The origins of heavy metals in soils. pp. 29-39. *In* B.J. Alloway (Ed). Heavy Metals in Soils. Blackie, London.

Badri, D.V. and J.M. Vivanco. 2009. Regulation and function of root exudates. Plant Cell Envrion., 32(6):660-681.

Baker, D.E. and M.C. Amacher. 1982. Nickel, copper, zinc, and cadmium. pp. 323-336. *In* A.L. Page, R.H. Miller, and D.R. Keeney (Eds.). Methods of Soil Analysis Part 2: Chemical and Microbiological Properties. 2nd Ed. SSSA, Inc., Madison.

Barber, S.A. 1981. Soil chemistry and availability of plant nutrients. pp. 1-12. *In* R.H. Dowdy, J.A. Ryan, V.V. Volk, and D.E. Baker (Eds.). Chemistry in the Soil Environment. ASA Spec. Publ. No. 40. ASA, CSSA, & SSSA, Inc., Madison.

Barber, S.A. 1984. Liming materials and practices. pp. 171-209. *In* F. Adams (Ed.). Soil Acidity and Liming. ASA, CSSA, & SSSA Inc., Madison.

Bartlett, R.R. 1981. Oxidation-reduction status of aerobic soils. pp. 77-102. *In* R.H. Dowdy, J.A. Ryan, V.V. Volk, and D.E. Baker (Eds.). Chemistry in the Soil Environment. ASA Spec. Publ. No. 40. ASA, SSSA, Inc., Madison.

Baruah, M. and P.R. Mishra. 1984. Dehydrogenase and urease activity in rice-field soils. Soil Biol. Biochem., 16:423-424.

Baumert, V.L., N.A. Vasilyeva, A.A. Vladimirov, I.C. Meier, I. Kogel-Knabner, and C.W. Mueller. 2018. Root exudates induce soil macroaggregation facilitated by fungi in subsoil. Front. Environ. Sci., 27: https://doi.org/10.3389/fenvs.2018.00140.

Beckie, H.J., L.F. Friesen, K. . Nawolsky, and I.A. Morrison. 1990. A rapid bioassay to detect trifluralin-resistant green foxtail (*Setaria viridis*). Weed Technol., 4(3): 505 – 508.

Benke, M.B., S.P. Indraratne, X. Hao, C. Chang, and T.B. Goh. 2008. Trace element changes in soil after long-term cattle manure applications. J. Environ. Qual., 37:798-807.

Benn, T., B. Cavanagh, K. Hristovski, J.D. Posner, and P. Westerhoff. 2010. The release of nanosilver from consumer products used in the home. J. Environ. Qual., 39:1875-1882.

Berenguer, S. Cela, F. Santeveri, J. Boixadera, and J. Loveras. 2008. Copper and zinc soil accumulation and plant concentration in irrigated maize fertilized with liquid swine manure. Agron J., 100:1056-1061.

Bergstrom, D.W. and C.M. Monreal. 1998. Increased soil enzyme activities under two row crops. Soil Sci. Soc.Am. J., 62:1295-1301.

Bergstrom, D.W., C.M. Monreal, and D.J. King. 1998. Sensitivity of soil enzyme activities to conservation practices. Soil Sci. Soc. Am. J., 62:1286-1295.

Biasioli, M., H. Greman, T. Kralj, F. Madrid, E. Diaz-Barrientos, and F. Ajmone-Marsan. 2007. Potentially toxic elements contamination in urban soils. J. Environ. Qual., 36:70-79.

Bilski, J.J. and A.K. Alva. 1995. Transport of heavy metals and cations in a fly ash amended soil. Bull. Environ. Contam. Toxicol., 55:501-509.

Bohn, H.L., B.L. McNeal, and G.A. O'Connor. 1985. Soil Chemistry. 2nd ed. John Wiley & Sons, Inc., New York.

Bolton Jr., H., L.F. Elliott, and R.I. Papendick. 1985. Soil microbial biomass and soil enzyme activities: effect of fertilization and cropping practices. Soil Biol. Biochem., 17:297-302.

Bolton, M.P. 1989. Biology and ecology of prickly acacia. Report of Richmond Prickly Acacia Field Day, 19 September 1989. Brisbane, Australia: Queensland Department of Lands. pp. 21-25.

Bonmati, M., B. Ceccanti, and P. Nannipieri. 1991. Spatial variability of phosphatase, urease, protease, organic carbon, dan total nitrogen in soil. Soil Biol. Biochem., 23:391-396.

Boon, D.Y. and P.N. Soltanpour. 1992. Lead, cadmium, and zinc contamination of Aspen garden soils and vegetation. J. Environ. Qual., 21:82-86.

Boulman, O.T., D. Curtin, C.A. Campbell, V.O. Bjederbeck, and H. Ukrainetz. 1995. Soil acidification from long-term use of anhydrous ammonia and urea. Soil Sci. Soc. Am. J., 59:1488-1494.

Bowman, R.S. and G.A. O'Connor. 1982. Control of nickel and strontium sorption by free metal ion activity. Soil Sci. Soc. Am. J., 46:933-936.

Bray, A.W., E.H. Oelkers, S. Benneville, D. Wolf-Boenisch, N.J. Potts, G. Fones, and L.G. Benning. 2015. The effect of pH, grain size, and organic ligands on biotite weathering rates. Geochimica et cosmochimica Acta, 164: 127-145.

Bridges, D.C. 1999. General overview of weeds in crop systems. pp.547-567. *In* J. R. Ruberson (Ed.). Handbook of Pest Management. Marcel Dekker, Inc., New York.

Broadbent, F.E., T. Nakashima, and G.Y. Chang. 1985. Performance of some urease inhibitors in field trials with corn. Soil Sci. Soc. Am. J., 49:348-351.

Brummer, G., K.G. Tiller, U. Herms, and P.M. Clayton. 1983. Adsorption-desorption and/or precipitation-dissolution processes of Zn in soils. Geoderma, 31:337-354.

Brzostek, E.R., A. Greco, J.E. Drake, and A.C. Finzi. 2013. Root carbon inputs to the rhizosphere stimulate extracellular enzyme activity and increase nitrogen availability in temperate forest soils. Biogeochem., 115:65-76

Cabrera, C., E. Ortega, C. Gallego, M.L. Lorenzo, C. Asesnsio, and M.C. Lopez. 1994. Lead concentration in farmlands in Southern Spain: Influence of the use of sewage sludge as fertilizer. Bull. Environ. Contam. Toxicol., 53:32-38.

Cabugao, K.G., C.M. Timm, A.A. Carrell, J. Childs, T-Y.S. Lu, D.A. Pelletier, D.J. Weston, and R.J. Norby. 2017. Root and rhizosphere bacterial phosphatase activity varies with tree species and soil phosphorus availability in Puerto Rico tropical forest. Front. Plant Sci., https://doi.org/10.3389/fpls.2017.01834.

Cai, G.X., J.R. Freney, W.A. Muirhead, J.R. Simpson, D.L. Chen, and A.C.F. Trevitt. 1989. The evaluation of urease inhibitors to improve the efficiency of urea as a N-source for flooded rice. Soil Biol. Biochem., 21(1):137-145.

Cakmak, D., E. Saljnikov, V. Mrvic, M. Jakovljevic, Z. Marjanovic, B. Sikiric, and S. Maksimovic. 2010. Soil properties and trace element contents following 40 years of phosphate fertilization. J. Environ. Qual., 39:541-547.

Calvaruso, C., M.-P. Turpault, E. Leclerc, J. Ranger, J. Garbaye, S. Uroz, and P. Frey-Klett. 2010. Influence of forest trees on the distribution of mineral weathering-associated bacterial communities of the *Scleroderma citrinum* Mycorrhizosphere. Applied Environ. Microbiol. 76, 4780-4787.

Cavallaro, N. and M.B. McBride. 1980. Activities of Cu^{2+} and Cd^{2+} in soil solutions as affected by pH. Soil Sci. Soc. Am. J., 44:729-732.

Chan, K.Y. 1997. Consequences of changes in particulate organic carbon in Vertisols under pasture and cropping. Soil Sci. Soc. Am. J., 61:1376-1382.

Chekai, R.T., L.L. Hendrickson, R.B. Corey, and P.A. Helmke. 1987a. A method for controlling the activities of free metal, hydrogen, and phosphate ions in hydroponic solutions using ion exchange and chelating resins. Plant Soil, 99:321-334.

Chekai, R.T., R.B. Corey, and P.A. Helmke. 1987b. Effect of ionic and complexed metal concentrations on plant uptake of cadmium and micronutrient metals from solution. Plant Soil, 99:335-345.

Corey, R.B. 1964. Soil Analysis. College of Agriculture and Life Sciences, University of Wisconsin, Madison.

CropLife Asia. 2007. CropLife Asia Annual Report. 26 p.

Davies, B.E. 1990. Lead. pp. 177-196. *In* B.J. Alloway (Ed.). Heavy Metals in Soils. John Wiley and Sons, Inc., New York.

Deng, S.P. and M.A. Tabatabai. 1996. Effect of tillage and residue management on enzyme activities in soils: 1. Amidohydrolases. Biol. Fert. Soils, 22:202-207.

Dharmakeerti, R.S. and M.W. Thenabadu. 1996. Urease activity in soils: a review. J. Natn. Sci. Coun., 24(3):159-195.

Dowdy, R.H., J.J. Latterell, T.D. Hinesly, R.B. Groesman, and D.L. Sulivan. 1991. Trace metal movement in an Aeric Ochraqualf following 14 years of annual sludge applications. J. Environ. Qual., 20:119-123.

Duxbury, J.M. and R.L. Tate III. 1981. The effect of soil depth and crop cover on enzymatic activities in pahokee muck. Soil Sci. Soc.Am. J., 45:322-328.

Ekenler, M. and M.A. Tabatabai. 2003. Responses of phosphatases and arylsulfatase in soils to liming and tillage systems. J. Plant Nutr. Soil Sci., 166: 281–290.

El-Falaky, A.A., S.A. Aboulroos, and W.L. Lindsay. 1991. Measurement of cadmium activities in slightly acidic to alkaline soils. Soil Sci. Soc. Am. J., 55:974-979.

Ellis, B.G. and B.D. Knezek. 1982. Adsorption reactions of micronutrients in soils. pp. 57-78. *In* J.J. Mortvedt, P.M. Giordano, and W.L. Lindsay (Eds.). Micronutrients in Agriculture. SSSA, Inc., Madison.

Fan, X.H. and Y.C. Li. 2010. Nitrogen release from slow-release fertilizers as affected by soil type and temperature. Soil Sci. Soc. Am. J., 74:1635-1641.

Fang, S., J. Liu, D. Liu, and B. Xie. 2010. Enzymatic activity and nutrient availability in the rhizosphere of poplar plantations treated with fresh grass mulch. Soil Sci. Plant Nutr., 56:483-491.

Farshadirad, A., E. Dordipour, and F. Khormali. 2012. Kinetics of non-exchangeable potassium release from soil and its components in some soils of Golestan Province. J. Water Soil Sci., 16:273-285.

Fernandez-Calvino, D., M. Arias-Estevez, M. Diaz-Ravina, and E. Baath. 2012. Assessing the effects of Cu and pH on microorganisms in highly acidic vineyard soils. Europ. J. Soil Sci., 63:571-578.

Flegal, A.R. and D.R. Smith. 1995. Measurement of environmental lead contamination and human exposure. Environ. Contam. Toxicol., 143:1-45.

Frankenberger, W.T., Jr. and J.B. Johanson. 1982. Effect of pH on enzyme stability in soils. Soil Biol. Biochem., 14:433-437.

Frankenberger, W.T., Jr. and W.A. Dick. 1983. Relationship between enzyme activities and microbial growth and activity indices in soils. Soil Sci. Soc. Am. J., 47:945-951.

Garbuio, F.J., D.L. Jones, L.R.F. Alleoni, D.V. Murphy, and E.F Caires. 2011. Carbon and nitrogen dynamics in an Oxisol as affected by liming and crop residues under No-Till. Soil Sci. Soc. Am. J., 75:1723-1730.

Garcia-Morote, F.A., F.R. Lopez-Serrano, M. Andres, E. Martinez-Garcia, M. Lucas-Borja, T. Dadi, D. Candel, and C. Wic. 2012. Effects of woodland maturity, vegetation cover and season on enzymatic and microbial activity in thermophilic Spanish Juniper woodlands (*Jiniperus thurifera* L.) of southern Spain. Europ. J. Soil Sci., 63:579-591.

Garrels, R.M. and C.L. Christ. 1965. Solutions, Minerals, and Equilibria. Freeman, Cooper & Co., San Fransisco.

Ge, Y.Y., Q-L. Wang, L. Wang, W-X. Liu, X-Y. Liu, and Y-J. Huang. 2017. Response of soil enzymes and microbial communities to root extracts of the alien *Alternanthera philoxeroides.* Arch. Agron. Soil Sci. 64:708-717

Geiger, G., H. Brandl, G. Furrer, and R. Schulin. 1998. The effect of copper on the activity of cellulase and β-glucosidase in the presence of montmorillonite or Al-montmorillonite. Soil Biol. Biochem., 30(12):1537-1544.

Gianfreda, L., M.A. Rao, and A. Violante. 1992. Adsorption, activity, and kinetic properties of urease on montmorillonite, aluminum hydroxide and $Al(OH)_x$-montmorillonite complexes. Soil Biol. Biochem., 24(1):51-58.

Gianfreda, L. 2015. Enzymes of importance to rhizosphere processes. J. Soil Sci Plant Nutr. 15(2): Temuco jun. 2015 Epub 30-Abr-2015.

Gimeno-Garcia, E., V. Andreu, and R. Boluda. 1996. Heavy metals incidence in the application of inorganic fertilizers and pesticides to rice farming soils. Environ. Pollut., 92:19-25.

Gopalakrishnan, S., T. Watanabe, S.J. Pearse, O. Ito, Z.A.K.M. Hossain, and G.V. Subbaraq. 2009. Biological nitrification inhibition by *Brachiaria humidicola* roots varies with soil type and inhibits nitrifying bacteria, but not other major soil microorganisms. Soil Sci. Plant Nutr., 55:725-733.

Handayani, I.P. and P. Prawito. 1998. Dinamika mineralisasi karbon dan nitrogen pada lahan alang-alang (*Imperata cylindrica*). J. Tanah Trop., 7:93-102. (In Indonesian).

Handayani, I.P. 2001. Comparison of soil quality in cultivated fields and grassland. J. Tanah Trop., 12:135-143.

Harisson, A.F. 1983. Relationship between intensity of phosphatase activity and physico-chemical properties in woodland soils. Soil Biol. Biochem., 15:93-99.

Harpstead, M.I., F.D.Hole, and W.F. Bennet. 1988. Soil Science Simplified. 2nd ed. Iowa State Unv. Press, Ames.

Harrison Jr., H. F. and J. K. Peterson. 1994. Sweet potato periderm compound inhibit yellow nutsedge (*Cyperus esculentus*) growth. Weed Technol. 8(1): 168 – 171.

Hayano, K. 1973. A method for the determination of β–glucosidase activity in soils. Soil Sci. Plant Nutr., 19:103-108.

He, Q.B. and B.R. Singh. 1994. Crop uptake of cadmium from phosphorus fertilizer: II. Relationship with extractable soil cadmium. Water Air Soil Pollut., 74:267-280.

Hegstrom, L.J. and S.D. West. 1989. Heavy metal accumulation in small mammals following sewage sludge application to forests. J. Environ. Qual., 18:345-349.

Hejda, M., P. Pysek, and V. Jarosik. 2009. Impact of invasive plants on the species richness, diversity and composition of invaded communities. J. Ecol., 97: 393 – 403.

Hellmann, B., L. Zelles, A. Palojarvi, and Q. Bai. 1997. Emission of climate-relevant trace gases and succession of microbial communities during open-wind row composting. Appl. Environ. Microb., 63(3):1011-1018.

Hendrickson, L.L. and M-J. O'Connor. 1987. Urease inhibition by decomposition products of phenylphosphorodiamidate. Soil Biol. Biochem., 19(5):595-597.

Hendrickson, L.L. and E.A. Doughlass. 1993. Metabolism of the urease inhibitor N-(n-Butyl) Thyophosphoric Triamide (NBPT) in soils. Soil Biol. Biochem., 25(11):1613-1618.

Heradilla, M. 1997. Pertumbuhan dan Serapan Timbal oleh Tanaman Bayam (*Amaranthus tricolor* L.) dan Beberapa Jenis Tanah Tropika di Tanah yang Tercemari oleh Timbal. Script. Faculty of Agriculture University of Lampung Bandar Lampung. (In Indonesian).

Hernandez-Soriano, M.C., F. Degryse, E. Lombi, and E. Smolders. 2012. Manganese toxicity in barley is controlled by solution manganese and soil manganese speciation. Soil Sci. Soc. Am. J., 76:399-407.

Herrero, T.C. and L.F.L. Martin. 1993. Evaluation of cadmium level in fertilized soils. Bull. Environ. Contam. Toxicol., 50:61-68.

Hidayatullah, M.A. 2019. Pertumbuhan dan Serapan Cu dan Zn oleh Rumput Gajah (*Penissetum purpureum)* pada Tanah 21 Tahun Setelah Tercemar Limbah Industri Berlogam Berat dan Dikapur. B.S. Thesis. Faculty of Agriculture University of Lampung. Bandar Lampung. (In Indonesian).

Hillel, D. 1980. Fundamentals of Soil Physics. Academic Press, San Fransisco.

Ho, I. 1979. Acid phosphatase activity in forest soil. Forest Sci., 25(4):567-568.

Hobara, S., N. Mizuno, Y. Amano, H. Yokota, and H. Taniyama. 2009. Mercury distribution in tephra soil layers in Hokaido, Japan, with reference to 34,000-year stratification. Soil Sci. Plant Nutr., 55:582-589.

Holcomb, J.C., D.M. Sullivan, D.A. Horneck, and G.H. Clough. 2011. Effect of irrigation rate on ammonia volatilization. Soil Sci. Soc. Am. J., 75:2341-2347.

Holm, L.G., D.L. Plucknett, and J.V. Pancho. 1977. The World's Worst Weeds: Distribution and Biology. Univ. of Hawaii Press, Honolulu, USA.

Huang, X.F., J.M. Chaparro, K.F. Reardon, R. Zhang, Q. Shen, and J. Vivanco. 2014. Rhizosphere interactions: root exudates, microbes, and microbial communities. Botany, 92:267-275.

Jalali, M. 2006. Kinetics of non-exchangeable-potassium release and availabilities in some calcareous soils in Western Iran. Geoderma, 135, 63-71.

Jalali, M. and M. Zarabi. 2006. Kinetics of non-exchangeable-potassium release and plant response in some calcareous soils. J. Plant Nutr. Soil Sci., 169:196-204.

Jha, D.K., G.D. Sharma, and R.R. Mishra. 1992. Soil microbial population numbers and enzyme activities in relation to altitude and forest degradation. Soil Biol. Biochem., 24:761-767.

Jing, J. and T.J. Logan. 1992. Effects of sewage sludge cadmium concentration on chemical extractability and plant uptake. J. Environ. Qual., 21:73-81.

Johnston, W.B. and R.A. Olson. 1972.. Dissolution of fluorapatite by plant roots. Soil Sci., 111:29-36.

Joner, E.J., J. Magid, T.S. Gahoonia, and I. Jakobsen. 1995. P depletion and activity of phosphatases in the rhizospheres of mycorrhizal and non-mycorrhizal cucumber (*Cucumis sativus* [L.]). Soil Biol. Biochem., 27:1145-1151.

Joner, E.J. and I. Jakobsen. 1995. Growth and extracellular phosphatase activity of arbuscular mycorrhizal hyphae as influenced by soil organic matter. Soil Biol. Biochem., 27:1153-1159.

Julien, M. and G. White. 1997. Biological Control of Weeds: Theory and Practical Application. ACIAR Monograph Series No. 49. 192 p.

Juracek, K.E. and A.C. Ziegler. 2006. The legacy of leaded gasoline in bottom sediment of small rural reservoirs. J. Environ. Qual., 35:2092-2102.

Kamprath, E.J. 1984. Crop responses to lime on soils in the tropics. pp. 349-368. *In* F. Adams (Ed.). Soil Acidity and Liming. 2nd ed. SSSA, Inc., Madison.

Kardos, L.T., C.E. Scarsbrook, and V.V. Volk. 1986. Recycling elements in wastes through soil-plant systems. pp. 303-324. *In* L.F. Elliott and F.J. Stevenson (Eds). Soils for Management of Organic Wastes and Waste Water. SSSA Inc., Madison.

Kiekens, L. 1990. Zinc. pp. 261-279. *In* B.J. Alloway (Ed). Heavy Metals in Soils. Blackie, London.

Kien, C.N., N.V. Noi, L.T. Son, H.M. Ngoc, S. Tanaka, T. Nishina, and K. Iwasaki. 2010. Heavy metal contamination of agricultural soils around a chromite mine in Vietnam. Soil Sci. Plant Nutr., 56:344-356.

Klein, T.M. and J.S. Koths. 1980. Urease, protease, and acid phosphatase in soil continuously cropped to corn by conventional or no-tillage methods. Soil Biol. Biochem., 12:293-294.

Kliewer, B.A. and J.W. Gillian. 1995. Water table management effects on denitrification and nitrous oxide evolution. Soil Sci. Soc. Am. J., 59:1694-1701.

Kogan, M. and P. Jepson. 2007. Ecology, sustainable development and IPM: the human factor. pp. 361-389. *In* M. Kogan and P. Jepson (Eds.). Perspectives in Ecological Theory and Integrated Pest Management. Cambridge Univ. Press, New York.

Komisi Pestisida Indonesia. 2008. Pestisida untuk Pertanian dan Kehutanan. Koperasi Ditjen BSP, Jakarta. 490 hlm. (In Indonesian).

Kotroczo, Z.K., Z. Veres, I. Fekete, Z. Krakomperger, J.A. Toth, K. Lajtha, and B. Tothmeresz. 2014. Soil enzyme activity in response to long-term organic matter manipulation. Soil Biol. Bochem., 70: 237-243.

Kumar, V. and R.J. Wagenet. 1984. Urease activity and kinetics of urea transformation in soils. Soil Sci., 137:263-269.

Lagerwerff, J.V. 1982. Lead, mercury, and cadmium as environmental contaminants. pp. 593-636. *In* J.J. Mortvedt, P.M. Giordano, and W.L. Lindsay (Eds.). Micronutrients in Agriculture. SSSA Inc., Madison.

Lestari, N. 2018. Pengaruh Kacang Pintoi (*Arachis pintoi*) dan Rumput Gajah (*Penissetum purpureum)* terhadap K-Tersedia, C-Organik, dan pH Beberapa Jenis Tanah di Lampung. B.S. Thesis. Faculty of Agriculture University of Lampung. Bandar Lampung. (In Indonesian).

Leung, H.W. 1988. Environmental sampling of lead near a battery reprocessing factory. Bull. Environ. Contam. Toxicol., 41:427-433.

Lin, C., I. Negev, G. Eshel, and A. Banin. 2008. *In situ* accumulation of copper, chromium, nickel, and zinc in soils used for long-term waste water reclamation. J. Environ. Qual., 37:1477-1487.

Lindsay, W.L. 1979. Chemical Equilibria in Soils. John Wiley & Sons, Inc., New York.

Liu, M., D.E. Kissel, P.F. Vendrell, and M.L. Cabrera. 2004. Soil lime requirement by direct titration with calcium hydroxide. Soil Sci. Soc. Am. J., 68:1228-1233.

Luo, Y-Q., X-Y. Zhao, O. Andren, Y-C. Zhu, and W-D. Huang. 2014. Artificial root exudates and soil organic carbon mineralization in a degraded sandy grassland in northern China. J. Arid Land, 6(4):423-431.

Ma, Q.Y. and W.L. Lindsay. 1990. Divalent zinc activity in arid-zone soils obtained by chelation. Soil Sci. Soc. Am. J., 54:719-722.

Malcolm, R.E. 1983. Assessment of phosphatase activities in soils. Soil Biol. Biochem., 15:403-408.

Manley, E.P. and L.J. Evans. 1986. Dissolution of feldspars by low-molecular-weight aliphatic and aromatic acids. Soil Sci., 141:106-112.

Margalef, O., J. Dardans, M. Fernandez-Martinez, R. Molowny-Horas, I.A. Janssens, P. Ciais, D. Goll, A. Richter, M. Obersteiner, D. Arsensio, and J. Penuelas. 2017. Global patterns of phosphatase activity in natural soils. Sci Rep., 7:1337.

Martens, D.A., J.B. Johansen, and W.T. Frankenberger, Jr. 1992. Production and persistence of soil enzymes with repeated addition of organic residues. Soil Sci., 153:53-61.

McFadyen, R. and B. Wilson. 1997. A history of biological control of weeds. pp 17-22. *In* M. Julien dan G. White (Eds.). Biological Control of Weeds: Theory and Practical Application. ACIAR Monograph Series, Canberra, Australia.

McGrath, S.P., J.R. Sanders, and M.H. Shalaby. 1988. The effects of soil organic matter levels on soil solution concentrations and extractabilities of manganese, zinc, and copper. Geoderma, 42:177-188.

McLaughlin, M.J., K.G. Tiller, R. Naidu, and D.P. Stevens. 1996. Review: the behavior and environmental impact of contaminants in fertilizers. Aust. J. Soil Res., 34:1-54.

Montiel-Rozas, M.M., E. Madejon, and P. Madejon.. 2016. Effect of heavy metals and organic matter on root exudates (low molecular weight organic acids) of herbaceous species: An assessment in sand and soil conditions under different levels of contamination. Environ. Pollut., 216:273-281.

Moyo, C.C., D.E. Kissel, and M.L. Cabrera. 1989. Temperature effects on soil urease activity. Soil Biol. Biochem., 21:935-938.

Najafi-Ghiri, M. and H.R. Jabari. 2013. Effect of soil minerals on potassium release from soil fractions by different extractants. J. Arid Land Res. Manag., 27:111-127.

Nakas, J.P., W.D. Gould, and D.A. Klein. 1987. Origin and expression of phospatase activity in a semi-arid grassland soil. Soil Biol. Biochem., 19(1):13-18.

Nannipieri, P., B.Ceccanti, S. Cervelli, and E. Matarese. 1980. Extraction of phosphatase, urease, protease, organic carbon, and nitrogen from soil. Soil Sci. Soc. Am. J., 44:1011-1016.

Naseby, D.C. and J.M. Lynch. 1997. Rhizosphere soil enzymes as indicators of pertubations caused by enzyme substrate addition and innoculation of a genetically modified strain of *Pseudomonas fluorescens* on wheat seed. Soil Biol. Biochem., 29(9-10):1353-1362.

Nasution, U. 1986. Origin and range of enzymes in soils. pp.51-80. *In* R.G. Burns (Ed.). Soil Enzymes. Academic Press, London, New York, San Fransisco.

Navas, M.L. 1991. Using plant population biology in weed research: a strategy to improve weed management. Weed Res., 31: 171-179.

Nicholson, F.A., K.C. Jones, and A.E. Johnston. 1994. Effect of phosphate fertilizers and atmospheric deposition on long-term changes in the cadmium content of soil and crops. Environ. Sci. Technol., 28:2170-2175.

Nihorimbere, V., M. Ongena, M. Smargiassi, and P. Thonart. 2011. Beneficial effect of the rizhospehere microbial community for plant growth and health. Biotechnologie, Agronomie, Societe et Environnement, 15:327-337.

Oki, Y., T. Adachi, and M. Senge. 1999. Sustainable management of hilly areas by plant cover. Proc. Int. Symp. 'Can Biological Production Harmonize with Environment?' – Reports from Research Sites in Asia – Asian National Environmental Science Center, The University of Tokyo, Oct 19-20, 1999, Tokyo. pp.215-218.

Ontia, N. 2018. Pengaruh Gulma *Arachis pintoi* dan *Penissetum purpureum* terhadap pH, C-Organik, dan K-Tersedia tanah 20 tahun setelah tercemar logam berat dan dikapur. B.S. Thesis. Faculty of Agricuture University of Lampung. Bandar Lampung. (In Indonesian).

Osunkoya, O.O., F.E. Othman, and R.S. Kahar. 2005. Growth and competition between seedlings of an invasive plantation tree, *Acacia mangium*, and those of a native Borneo heath-forest species, *Melastoma beccarianum*. Ecol. Res, 20: 205 – 214.

Parfitt, R.L., D.J. Giltrap, and J.S. Whitton. 1995. Contribution of organic matter and clay minerals to the cation exchange capacity of soils. Commun. Soil Sci. Plant Anal., 26:1343-1355.

Park, S.C., T.C. Smith, and M.S. Bisesi. 1992. Activities of phosphomonoesterase and phosphodiesterase from *Lumbriscus terrestris*. Soil Biol. Biochem., 24:873-876.

Peterson, J.K. and H.F. Harrison, Jr. 1995. Sweet potato allelopathic substance inhibits growth of purple nutsedge (*Cyperus rotundus*). Weed Technol., 9(2): 277 –280.

Pujiyanto, Sudarsono, A. Rachim, S. Sabiham, A. Sastiono, and J.B. Baon. 2003. Pengaruh bahan organik dan jenis tanaman penutup tanah terhadap bentuk bahan organik tanah, distribusi agregat, dan pertumbuhan kakao (*Theobroma cacao* L.). J. Tanah Trop., 17:75-87. (In Indonesian).

Radosevich, S., J. Holt, and C. Ghersa. 1997. Weed Ecology. Implications for Management. John Wiley & Sons, Inc., New York.

Reddy, G.B., A. Faza, and R. Bennet, Jr. 1987. Activity of enzymes in rhizosphere and non-rhizosphere soils amended with sludge. Soil Biol. Biochem., 19 203-205.

Reddy, G.B., R.A. Reinert, and G. Eason. 1991. Enzymatic changes in the rhizosphere of loblolly pine exposed to ozone and acid rain. Soil Biol. Biochem., 23:1115-1119.

Rejsek, K. 1991. Acid phosphomonoesterase activity of ectomycorrhyzal roots in Norway spruce pure stands exposed to pollution. Soil Biol. Biochem., 23 667-671.

Rivai, I.F., H. Koyama, and S. Susuki. 1990. Cadmium content in rice and its daily intake in various countries. Bull Environ. Contam. Toxicol., 44:910-916.

Robert, M. and J. Berthelin. 1986. Role of biological and biochemical factors in soil mineral weathering. pp. 453-495. *In* P.M. Huang and M. Schnitzer (Eds.). Interactions of Soil Minerals with Natural Organics and Microbes. SSSA Special Publ. No. 17. SSSA, Inc., Madison.

Rodella, A.A., K.R. Fischer, and J.C. Alcarde. 1995. Cation exchange capacity of an acid soil as influenced by different sources of organic matter. Commun. Soil Plant Anal., 26:2961-2967.

Rojo, M.J., S.G. Carcedo, and M.P. Mateos. 1990. Distribution and characterization of phosphatase and organic phosphorus in soil fraction. Soil Biol. Biochem., 22:169-174.

Ross, D.J. and A. Cairns. 1982. Effects of earthworms and ryegrass on respiratory and enzyme activities of soil. Soil Biol. Biochem., 14:583-587.

Ross, M. A. and C. A. Lembi. 2008. Applied Weed Science: Including Ecology & Management of Invasive Plants (3rd ed.). Prentice Hall, USA. 339 p.

Rumpel, C., A. Crème, P.T. Ngo, G. Velasquez, M.L. Mora, and A. Chabbi. 2015. The impact of grassland management on biogeochemical cycles involving carbon, nitrogen and phosphorus. J. Soil Sci. Plant Nutr., 15(2):Temuco jun.2015 Epub 30-Abr-2015.

Saa, A., M.C. Trasar-Cepeda, F. Gil-Sotres, and T. Carballas. 1993. Changes in soil phosphorus and acid phosphatase activity immediately following forest fires. Soil Biol. Biochem., 25(9):1223-1230.

Sakai, H. and T. Tadano. 1993. Characteristics of response of acid phosphatase secreted by the roots of several crops to various conditions in the growth media. Soil Sci. Plant Nutr. 39:437-444.

Salam, A.K. 1989. The relative rates of plant nutrient release through weathering of soil minerals. M.S. Thesis. University of Wisconsin-Madison. Madison, USA.

Salam, A.K. and R.B. Corey. 1993. The soil potassium supplying-capacities measured by resin methods. Indon. J. Tropic. Agric., 4(2), 47-52.

Salam, A.K. 1996. Aktivitas enzim fosfatase pada lahan kopi berlereng dengan beberapa teknik pengendalian gulma. Pros. Konf. HIGI (1996):77-84. (In Indonesian).

Salam, A.K., N. Sriyani, M. Heradilla, and A. Septiana. 1997a. Alang-alang (*Imperata cylindrica* [L.] Beauv.) mengubah sifat kimia dan biokimia tanah tercemar timah hitam. pp. 1026-1029. Proc. III Seminar Nas. Biology XV. Bandar Lampung. (In Indonesian).

Salam, A.K., N. Sriyani, M. Heradilla, and A. Septiana. 1997b. Aktivitas fosfatase di daerah perakaran beberapa gulma tropika yang tercemar timah hitam. Agrivita, 20:12-16. (In Indonesian).

Salam, A.K., A. Iswati, S. Yusnaini, and A. Niswati. 1997c. Status kesuburan tanah dalam pertanaman singkong (*Manihot esculenta* Crantz) di Gunung Batin Lampung Utara: 1. Tingkat ketersediaan unsur hara. J. Agrotrop., 2(1):35-41. (In Indonesian).

Salam, A.K., S. Yusnaini, and A. Niswati. 1997d. Status kesuburan tanah dalam pertanaman singkong (*Manihot esculenta* Crantz) di Gunung Batin Lampung Utara: 2. Aktivitas enzim tanah. J. Agrotrop., 2(1):42-47. (In Indonesian).

Salam, A.K., N. Sriyani, M. Heradilla, and A. Septiana. 1997e. Alang-alang (*Imperata cylindrica* [L.] Beauv.) mengubah sifat kimia dan biokimia tanah tercemar timah hitam. Pros III Seminar Nasional Biologi XV, Bandar Lampung (1997):1026-1029. (In Indonesian).

Salam, A.K. and P.A. Helmke. 1998. The pH dependence of free ionic activities and total dissolved concentrations of copper and cadmium in soil solution. Geoderma, 83:181-291.

Salam, A.K., S. Djuniwati, and Sarno. 1998a. Lowering heavy metal solubilities in tropical soils by lime and cassava-leaf compost additions. Proc. Environ. Technol. Manag. Sem.: D2-11.

Salam, A.K., A. Katayama, and M. Kimura. 1998b. Activities of some soil enzymes in different land use systems after deforestation in hilly areas of West Lampung, South Sumatra, Indonesia. Soil Sci. Plant Nutr., 44(1):93-103.

Salam, A.K., Y. Desvia, R. Subiyantoro, H. Susanto, and M. Utomo. 1998c. Perubahan aktivitas enzim fosfatase dan β–glukosidase akibat sistem olah tanah jangka panjang. pp. 417-422. *In* Z. Irfan, Z. Lamid, D. Jahya, Irawati, and Ardi (Eds.). Pros. Sem. Nas. Budidaya Pertanian Olah Tanah Konservasi. Himpunan Ilmu Gulma Indonesia. Padang. (In Indonesian).

Salam, A.K., J. Susilo, and N. Sriyani. 1998d. Lead availability and absorption by green kyllinga, corn, and amaranth in Gedongmeneng soil treated with a lead-containing electronics industrial waste and lime. J. Agrotrop., 3(2):19-23.

Salam, A.K., S. Yusnaini, and Rachmalia. 1998e. Perubahan aktivitas fosfatase selama 16 minggu dalam tanah Ultisol Tanjungan Lampung Selatan akibat perlakuan bahan organik. Pros. Sem. Nas. Peranan Mikrobiologi dalam Agroindustri untuk Menunjang Ketahanan Pangan Nasional (1998):332-339. (In Indonesian).

Salam, A.K. 1999. Perubahan ketersediaan unsur hara mikro kelompok logam berat akibat alih fungsi lahan di Lampung Barat. Lingk. Pembangunan, 10(3):176-183. (In Indonesian).

Salam, A.K., Y. Desvia, E. Sutanto, T. Syam, S.G. Nugroho, and M. Kimura. 1999a. Activities of soil enzymes in different land-use systems in middle terrace areas of Lampung Province, South Sumatra, Indonesia. Soil Sci. Plant Nutr., 45(1):89-99.

Salam, A.K., E. Sutanto, Y. Desvia, A. Niswati, Dermiyati, and M. Kimura. 1999b. Activities of soil enzymes in fields continuously cultivated with cassava, sugarcane, and pineapple in middle terrace areas of Lampung Province, South Sumatra, Indonesia. Soil Sci. Plant Nutr., 45 (4):803-809.

Salam, A.K., Afandi, N. Sriyani, and M. Kimura. 2001. Soil enzymatic activities in a hilly coffee plantation in Lampung Province, South Sumatra, Indonesia, under plant cover management. Soil Sci. Plant Nutr., 47(4): 695-702.

Salam, A.K. 2014. Enzymes in Tropical Soils. Global Madani Press. Bandar Lampung. 210p.

Salam, A.K. 2017. Management of Heavy Metals in Tropical Soil Environment. Global Madani Press. Bandar Lampung. 257p.

Salam, A.K., N. Sriyani, S.K. Dewi, and F. Santoso. 2019. Weed-root induced release of potassium in tropical soils. (In review).

Salam, A.K. 2019. Ilmu Tanah Fundamental. 2nd Ed. Bandar Lampung: Global Madani Press. (In Indonesian).

Samuel, A.L. and A.O. Ebenezer. 2014. Mineralization rates of soil forms of nitrogen, phosphorus, and potassium as affected by organomineral fertilizer in sandy loam. Adv. Agric., Article ID 149209, 5 p.

Sanders, J.R. 1982. The effect of pH upon the copper and cupric ion concentrations in soil solution. J. Soil Sci., 33:679-689.

Santelmann, P.W. 1987. Herbicide bioassay. pp. 79-87. *In* B. Truelove (Ed.). Research Method in Weed Science. Southern Weed Science Society of America.

Sarapatka, B., L. Dudova, and M. Krskova. 2004. Effect of pH and phosphate supply on acid phosphatase activity in cereal roots. Biologia, 59(1):127-131.

Satchell, J.E. and K. Martin. 1984. Phosphatase activity in earthworm faeces. Soil Biol. Biochem., 16:191-194.

Satchell, J.E., K. Martin, and R. Krisnamoorthy. 1984. Stimulation of microbial phosphatase production by earthworm activity. Soil Biol. Biochem., 16:195.

Schroder, J.L., H. Zhang, K. Girma, W.R. Raun, C.J. Penn, and M.E. Payton. 2011. Soil acidification from long-term use of nitrogen fertilizers on winter wheat. Soil Sci. Soc. Am. J., 75:957-964.

Schuhmacher, M., J.L. Domingo, J.M. Llobet, and J. Corbella. 1994. Cadmium, chromium, copper, and zinc in rice and ricefield soil from Southern Catalonia, Spain. Bull. Environ. Contam. Toxicol., 53:54-60.

Sembodo, D. R. J. 2010. Gulma dan Pengelolaannya. Graha Ilmu, Yogyakarta. (In Indonesian).

Sembodo, D. R. J., N. Sriyani, and Afandi. 2012. Kajian pemanfaatan gulma *in situ* sebagai sumber bahan organik yang berpotensi untuk memperbaiki kualitas lahan kritis. J. Gulma Tumbuhan Invasif Trop. 3(1): 21-27. (In Indonesian).

Sembodo, D.R.J., N. Sriyani, Afandi, and M. Senge. 2017. Utilization of *in situ* weeds as organic materials to improve quality of critical land. (*In review)*..

Shang, H.L., Y.L. Bi, S.P. Peng, and W.W. Xie. 2015. Mechanism of potassium release from different silicate minerals by releasing K bacteria in Northwest Arid Land, China. *Acta* Mineralogica Sinica 35, 337-343.

Singer, M.J. and D. Munns. 1987. Soils An Introduction. MacMillan Publ. Co., New York.

Singh, B. and G.S. Sekhon. 1977. Adsorption, desorption, and solubility relationship of lead and cadmium in some alkaline soils. J. Soil Sci., 28;271-275.

Siregar, C. A. and S. Tjitrosoedirdjo. 1999. *Acacia nilotica* invasion in Baluran National Park East Java Indonesia. pp. 101-109. *In* S. Tjitrosoedirdjo and I. C. Stuckle (Eds.). Integrated Weed Management in Managed and Natural Ecosystem, Biotrop Special Publication No. 61.

Song, F., X. Han, X. Zhu, and S.J. Herbert. 2012. Response to water stress of soil enzymes and root exudates from drought and non-drought tolerant corn hybrids at different growth stages. Can. J. Soil Sci., 92: 501–507.

Song, S.K. and P.M. Huang. 1988. Dynamic of potassium release from potassium-bearing minerals as influenced by oxalic and citric acids. Soil Sci. Soc. Am. J., 52:383-390.

Speir, T.W., R. Lee, E.A. Pansier, and A. Cairns. 1980. A comparison of sulphatase, urease, and protease activities in planted and in fallow soils. Soil Biol. Biochem., 12:281-291.

Sriyani, N. 1993. Studies of *Imperata cylindrica* Vegetative Reproduction System and The Effects of Glyphosate Absorption, Translocation, and Exudation on The Reduction and Pattern of Rhizome Bud Sprouting. Ph.D. Disertation. University of Wisconsin-Madison, Madison, Wisconsin.

Sriyani, N. 1999. Sulphosate, paraquat, and combination of paraquat and diuron herbicides for land preparation in no-tillage upland rice (*Oryza sativa*). Proc. 17th Asian-Pacific Weed Science Society (APWSS) Conference, Bangkok-Thailand, 22-27 November 1999. pp. 282-287.

Sriyani, N. 2003. Penggunaan teknik bioassay untuk deteksi residu herbisida pascatumbuh glifosat dan paraquat dalam tanah dan air. J. Agrotrop., 8(2):40-45. (In Indonesian).

Sriyani, N. 2004. Penggunaan teknik bioassay untuk mendeteksi herbisida 2,4-D dalam tanah dan air. J. Agrotropika, 9(1):8.12. (In Indonesian).

Sriyani, N. 2008. Keakuratan metode bioassay delam mendeteksi herbisida pratumbuh ametrin dan diuron dalaml tanah dan air. J. Agrista. Edisi Khusus Dies Natalis Fakultas Pertanian Universitas Syiah Kuala:186-192. (In Indonesian).

Sriyani, N. 2009a. Herbisida: Ketepatan dan Keamanan Aplikasinya. *Dalam* Penyuluhan dalam Rangka Pemberdayaan Masyarakat Pubian Lampung Tengah dalam Bidang Pertanian dan Peternakan (A. K. Salam, M.A.S. Arif, S. Yusnaini, Erwanto, N. Sriyani, dan Alimuddin). Laporan Pengabdian Kepada Masyarakat, Universitas Lampung. (In Indonesian).

Sriyani, N. 2009b.. Cara Aman Aplikasi Herbisida. *Dalam* Penyuluhan Ketepatan dan Keamanan Penggunaan Herbisida pada Budidaya Berbagai Varietas Jagung Hibrida di Natar, Lampung Selatan (N. Sriyani, D.R.J. Sembodo, dan F. Yelli). Laporan Pengabdian Kepada Masyarakat, Universitas Lampung. (In Indonesian).

Sriyani, N. 2010. Pengelolaan Gulma dan Herbisida untuk Meningkatkan Produktivitas Lahan Pertanian Secara Berkelanjutan. Pidato Ilmiah Pengukuhan Guru Besar Bidang Pengelolaan Gulma dan Herbisida, Fakultas Pertanian, Universitas Lampung. 14 Oktober 2010. Penerbit Universitas Lampung. (In Indonesian).

Sriyani, N., A.T. Lubis, D.R.J. Sembodo, D. Mawardi, H. Suprapto, H. Susanto, H. Pujisiswanto, T. Adachi, and Y. Oki. 2013. Upland Weed Flora of Southern Sumatra, An Illustrated Weed Identification Book. Global Madani Press. Bandar Lampung.

Studdert, G.A., H.E. Echevernia, and E.M. Casanovas. 1997. Crop-pasture rotation for sustaining the quality and productivity of a Typic Argiudoll. Soil Sci. Soc. Am. J., 61:1466-1472.

Stumm, W. and J.J. Morgan. 1981. Aquatic Chemistry, An Introduction Emphasizing Chemical Equilibria in Natural Waters. 2nd ed. John Wiley & Sons, New York.

Supriatin, S. Yusnaini, and A.K. Salam. 2007. Aktivitas fosfatase dalam kotoran cacing tanah pada lahan kopi dengan beberapa sistem pengelolaan vegetasi penutup tanah. J. Tanah Trop., 12(2):111-120. (In Indonesian).

Sweet, C.W., S.J. Vermete, and S. Landsberger. 1993. Source of toxic trace elements in urban air in Illinois. Environ. Sci. Technol., 27:2502-2510.

Tabatabai, M.A. 1982. Soil enzymes. pp. 903-947. *In* A.L. Page, R.H. Miller, and D.R. Keeney (Eds.). Methods of Soil Analysis Part 2: Chemical and Microbiological Properties. 2nd ed. SSSA, Inc., Madison.

Tabor, P. 1949. Cogongrass, *Imperata cylindrica* in the Southeastern United States. Agron. J. 41: 270.

Tate III, R.L. 1984. Function of protease and phosphatase activities in subsidence of pahokee muck. Soil Sci., 138:271-278.

Tate III, R.L. 1987. Soil Organic Matter Biological and Ecological Effects. John Wiley & Sons, Inc., New York.

Tate III, R.L., R.W. Parmelee, J.G. Ehrenfeld, and L. O'Rielly. 1991. Enzymatic and microbial interactions in response to pitch pine root growth. Soil Sci. Soc. Am. J., 55:998-1004.

Thomas, G.W. and W.L. Hargrove. 1984. The chemistry of soil acidity. pp. 3-56. *In* F. Adams (Ed.). Soil Acidity and Liming. ASA, CSSA, and SSSA Inc., Madison.

Tisdale, S.L, W.L. Nelson, and J.D. Beaton. 1985. Soil Fertility and Fertilizers. 4th ed. Macmilan Publ. Co., New York.

Tjitrosoedirdjo, S.S., I. Mawardi, and S. Tjitrosoedirdjo. 2016. 75 Important Invasive Plant Species. SEAMEO BIOTROP, Bogor.

Trasar-Cepeda, M.C. and F. Gil-Sotres. 1987. Phosphatase activity in acid high organic matter soils in Galicia (NW Spain). Soil Biol. Biochem., 19:281-287.

Trasar-Cepeda, M.C. and F. Gil-Sotres. 1988. Kinetics of acid phosphatase activity in various soils of Galicia (NW Spain). Soil Biol. Biochem., 20:275-280.

Trasar-Cepeda, M.C., T. Carballas, F. Gil-Sotres, and E. De Blass. 1991. Liming and the phosphatase activity and mineralization of phosphorus in an andic soil. Soil Biol. Biochem., 23:209-215.

Tsoumbaris, P. and H. Tsoukali-Papadopoulou. 1994. Heavy metal in common foodstuff: quantitative analysis. Bull. Environ. Contam. Toxicol., 53:61-66.

Tu, C.L., T.B. He, C.Q. Liu, and X.H. Lu. 2012. Effects of land use and parent materials on trace elements accumulation in topsoil. J. Environ. Qual., 42(1):103-110.

Vile, M.A., M.J.V. Novak, E. Brizova, R.K. Wieder, and W.R. Schell. 1995. Historical rates of atmospheric Pb deposition using ^{210}Pb dates peat cores: corroboration, computation, and interpretation. Water Air Soil Pollut., 70:89-106.

Vinotha, S.P., K. Parthasarathi, and L.S. Ranganathan. 2000. Enhanced phosphatase activity in earthworm casts is more of microbial origin. Current Sci., 79:1158-1159.

Walker, T.S., H.P. Bais, E. Grotewold, and J.M. Vivanco. 2013. Root exudation and rhizosphere biology. Am. Soc. Plant Biol., 32, 44-51.

Wang, J.D., C.S. Jang, Y.H. Hwang, and Z.S. Chen. 1992. Lead contamination around a kindergarten near a battery recycling plant. Bull. Environ. Toxicol., 49:23-30.

Wang, F.L. and P.P. Huang. 2001. Effect of organic matter on the rate of potassium adsorption. *Can. J. Soil Sci.,* 81:325-330.

Wang, Z., L. Chai, Z. Yang, Y. Wang, and H. Wang. 2010. Identifying sources and assessing potential risk of heavy metals in soils from direct exposure to children in a mine-impacted city, Changsha, China. J. Environ. Qual., 39:1616-1623.

Workman, S.M. and W.L. Lindsay. 1990. Estimating divalent cadmium activities measured in arid-zone soils using competitive chelation. Soil Sci. Soc. Am. J., 54:987-993.

Wu, Y., L. Lu, B. Wang, X. Lin, J. Zhu, Z. Cai, X. Yan, and Z. Jia. 2011. Long-term field fertilization significantly alters community structure of ammonia-oxidizing bacteria rather than archaea in a paddy soil. Soil Sci. Soc. Am. J., 75:1431-1439.

Yang, J., R.W. Blanchar, R.D. Hammer, and A.L. Thomson. 1996. Soybean growth and rhizosphere pH as influenced by A Horizon thickness. Soil Sci. Soc. Am. J., 60:1901-1907.

Yeh, C.-Y., H.-Y. Chiou, R.-Y. Chen, K.-H. Yeh, W.-L. Jeng, and B.-C. Han. 1996. Monitoring lead pollution near a storage battery recycling plant in Taiwan Republic of China. Arch. Environ. Contam. Toxicol., 30:227-234.

Yusnaini, S., A.K. Salam, and M. Nonaka. 2007. Activities of soil enzymes in corn field enriched with manure. J. ISSAAS, 13(1):18-25.

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Zhao, X. and L. Zhou. 1991. Effect of the urease inhibitor, hydroquinone on soil enzyme activities. Soil Biol. Biochem., 23(11):1089-1091.

Ziska, L. H. 2003. Rising carbon dioxide: implication for weed-crop competition. pp. 615-634. *In* T.W. Mew, D.S. Brar, S. Peng, D. Dawe, and B. Hardy (Eds.). Rice Science: Innovations and Impacts for Livelihood. Proc. Int. Rice Research Conference, 16-19 September 2002, Beijing, China. IRRI, Manila, Filipina. pp. 615-634.

Glossary

Acidification To make a reaction medium to have a lower pH. For example, soil acidification is to make the soil pH lower by using S powder or naturally by root excretion of organic acids or by producing CO_2 during root respiration.

Adsorption A chemical process by which an ion is attached to a solid with an opposite charge. For example, the adsorption of cations by the negative charges of soil organic matters.

Alkalization To make a medium to have a higher pH. For example, soil alkalization is to make the soil pH higher by a liming material such as calcite or dolomite. In general it is referred to as liming.

Allelopathy Biochemicals produced by particular plant roots that are poisonous to other plants.

Arylsulfatase An organic substance produced by microorganisms, earthworms, or plant roots acting as a biocatalyst functioning to accelerate the detachment of S from organic S to form inorganic SO_4^{2-} available for plant root absorption.

Availability The easiness of soil nutrient elements of various forms in soils to be absorbed by plant roots.

Base Saturation The quantity of base cations (Ca, Mg, K, and Na) adsorbed on the soil exchange sites expressed as percent of base over the soil cation exchange capacity (CEC).

Bioassay A method to measure response of a particular living organism to determine the existence or concentration of a chemical in a substrate (Satelmann, 1987).

Biocatalyst A catalyst produced by living things that accelerate the decomposition of organic matters and transform the organic forms into the inorganic forms of nutrients available to plant roots.

Biological Invasion The entry of a progressive foreign plant species into a particular habitat that is new to the species.

Biological Weed Control The method to control weed population by employing natural enemies of weeds.

Carbon Cycle or C-Cycle The chain of all the processes of C transformation from CO_2 in the atmosphere to CH_2O (sugars, proteins, and fats) as structural and functional substances in plant tissues and microorganisms, and then their ultimate decomposition back to form inorganic C as CO_2 available to plants.

Catalyst A substance that may accelerate the rate of a reaction to a magnitude of several orders without itself participates in the reaction. Examples of catalysts are phosphatases and ureases.

Cation Exchange The exchange of adsorbed cations on the soil exchange-sites with other cations in soil solution controlled by the coulombic law $F = q_1q_2/r^2$ where F is the attraction force between the soil exchange-sites and cations, q_1 is the amount of soil exchange-site charges, q_2 the cation charge, and r the distance of cations from the soil exchange-sites.

Cation Exchange Capacity The maximum quantity of all free ionic metals that can be adsorbed by the surfaces of a quantity of soil solids, expressed in $cmol_c\ kg^{-1}$.

Chelation A chemical process by which a cation is hold by multidentate organic agent forming a soluble complex.

Chelate A chemical species of any element formed between any cation with organic multi-functional groups. One example of chelates is Fe-EDTA in which a divalent cation Fe^{2+} is associated with organic multi-ligand EDTA.

Chemical Weed Control The method to control weeds by using organic or inorganic lethal chemical substances.

Coffee Plantation Land-use system for commercial coffee plants

Complexation The association of one elemental species with another elemental species with different charges such as $Cu(OH)^+$, $Pb(H_2PO_4)^+$, or $Al(OH)_4^-$.

Complex Ion An ionic species formed by the association on one elemental species with another elemental species with different charges such as $Cu(OH)^+$, $Pb(H_2PO_4)^+$, or $Al(OH)_4^-$.

Cultivated Land Land-use system for intensively planted crops like paddy, corn, and/or vegetables.

Culture Technique Weed Control Weed control conducted by availing an optimum growing environment for the crop plants, which is not suitable for weeds so that the growth of weeds is inhibited (Sriyani, 2010).

Decomplexation A chemical process in which a complex ion release its cations driven by low concentration of the participating species. For example, $Zn(OH)^+$ becomes Zn^{2+} and OH^-.

Decomposition A chemical process by which the organic and structurally bound elements not available to plants are detached to be inorganic elements available to plants. For example, the decomposition of organic P to form inorganic P (orthophosphates) available for plant root absorption.

Deforestation The transformation of forest from the primary forest to secondary forest, plantation, and intensively cultivated lands or other uses by human being.

Desorption A chemical process by which an attached ion onto a charged solid is detached. For example, the detachment of exchangeable Ca on soil solids to form Ca^{2+} in soil solution.

Dissolution A chemical process in which precipitate or mineral dissolve forming all the related species at concentrations lower than those needed to compensate the related solubility constant.

Drying An action of draining water from paddy field.

Electron Acceptor A chemical compound that may be reduced after receiving electron(s) from an electron donor encountering oxidation in a redox reaction.

Electron Donor A chemical compound donating electron(s) after encountering oxidation in a redox reaction.

Environmental Weeds Weeds existing in non-agricultural lands which may negatively affect plant biodiversity.

Equilibrium Constants the constant values indicating the relationship between the activities of products relative to the activities of reactants of the related steady state chemical reactions.

Exchangeable Cation The adsorbed cations on the soil exchange-sites exchangeable with other cations in soil water.

Exchangeable K The adsorbed K on the soil exchange-sites exchangeable with other cations in soil water.

Excretion The release of organic and inorganic substances including organic acids, enzymes, H^+, and OH^- by plant roots.

Free Ion A charged elemental species does not associate with any other elemental species such as Pb^{2+}, Fe^{3+}, Cl^-, NO_3^-, or $H_2PO_4^-$.

Flooding The submerging of paddy field with irrigation water.

Heavy Metals A group of trace elemental metals with relatively high density of more than 5 g cm^3.

Integrated Weed Control The control of weeds by wisely considering all methods of weed control depending on the existing and magnitude of weed problem in the field.

Leaching The vertical movement of chemical substances in soils through percolating water in the soil pore channels.

Liming The chemical treatment of soil using a particular lime material to enhance the soil pH and improve its chemical properties (See **Alkalization**).

Mechanical-Physical Weed Control The method to destroy or to eliminate the physics of weeds by physical pressure with the objective to kill or inhibit the growth and propagation of weeds (Sriyani, 2010).

Mixed Plantation Land-use system with multi-vegetation planted on it.

Monoculture Plantation Land-use system with one kind vegetation planted on it.

Natural Enemy A particular animal species which is naturally the predator of a particular animal or plant species.

Nitrogen Cycle or N-Cycle is the chain of all the processes of N transformation from N_2 in the atmosphere to NH_4^+ and NO_3^-, and then their absorption by plant roots and transformation to be structural and functional substances in plant tissues and microorganisms, and then their ultimate decomposition back to form inorganic N (NH_4^+ and NO_3^-) available to plants.

Optimum pH A pH value at which the activity of a particular soil enzyme is highest.

Oxidation The chemical process in which the oxidation number of an element in one substance increases due to the loss of one or more electrons released and accepted by any other substance called electron acceptor.

Percolation is the gravitational movement of water in soil through pore channels.

Phosphorus Cycle or P-Cycle The chain of transformation from Organic P to inorganic P by decomposition process and absorption of inorganic P through its re-synthesis in plants to produce new organic matters and back to the decomposition of organic matters to produce inorganic P

Phosphatase An organic substance produced by microorganisms, earthworms, or plant roots acting as a biocatalyst functioning to accelerate the detachment of P from organic P to form inorganic orthophosphates ($H_2PO_4^-$ and HPO_4^{2-}) available for plan root absorption.

Physical-Mechanical Weed Control The method to destroy or to eliminate the physics of weeds by physical pressure with the objective to kill or inhibit the growth and propagation of weeds (Sriyani, 2010).

Precipitate A chemical compound resulted by precipitation process that occurs at saturated concentrations of all the related species controlled by the reaction solubility constant.

Precipitation A chemical process resulting in a precipitate that occurs at saturated concentrations of all the related species controlled by the reaction solubility constant.

Preventive Weed Control The method to limit weed investation and to depress their growth and spreading so that any other weed control method is not necessary or at least minimized (Sriyani, 2010).

Primary Forest Land-use system with natural and undisturbed vegetation growing on it.

Protease The soil enzyme functioning as a biocatalyst participating in the acceleration of protein decomposition.

Redox Reaction A pair reactions containing a simultaneous oxidation and reduction reactions in which electrons are transferred from the oxidized substances to the reduced substances.

Reduction A chemical process in which the oxidation number of an element in one substance decreases due to the acceptance of one or more electrons released by any other substances called electron donors.

Reductor Any substance that may release one or more electrons and causes any other substance to accept the electron and be reduced.

Respiration The oxidation of hydrocarbon as an electron donor and O_2 as the electron acceptor producing energy, water molecules, and carbondioxide molecules

Root-To-Shoot Ratio An expression of root dry-weight over shoot dry-weight.

Secondary Forest Land-use of forest relatively disturbed by human activities covered by regrown or replanted vegetation.

Soil The toppest part of earth crust consisting topsoil (Horizon A), subsoil (Horizon B), and parent materials (Horizon C) being weathered affected by soil parent materials, climate, topography, living things, and time.

Soil Enzyme A catalyst that accelerates the transformation of elements in organic matters not available for plant root absorption to inorganic elements easily absorbed by plant roots.

Soil Minerals Naturally formed inorganic crystallic compounds mostly composed of Si, Al, and O with small amounts of other complementary elements.

Soil Reaction (pH) A mathematical expression of the magnitude of H^+ concentration in soil solution expressed as minus logarithmic concentration of H^+ in soil solution.

Succession The process of ecosystem recovery through a series of vegetation composition changes after a major natural or anthropogenic disturbance.

Sulfur Cycle or S-Cycle The chain of all the processes of S transformation from SO_4^{2-} in soil solution absorbed by plant roots and its transformation to be structural and functional substances like proteins in plant tissues and microorganisms, and then their ultimate decomposition back to form inorganic SO_4^{2-} available to plants.

Urease An organic substance produced by microorganisms, earthworms, or plant roots acting as a biocatalyst functioning to accelerate the detachment of N from Urea to form NH_3.

Urease Inhibitor An organic or inorganic compound that may inhibit the work of Urease so that the hydrolysis of urea and, hence, the production of NH_3 is limited.

Water Content The amount of water contained in soils expressed as percent weight.

Weathering A physical or chemical or biological destruction of soil mineral structure resulting in a new, more simple, and more stable minerals. In chemical weathering, some inorganic elements are freed and are available to plants. For example, during the chemical weathering of feldspars in the presence of H^+ ions and H_2O molecule, K^+ ions are freed to be available for plants.

Weed A fast growing, competitive, destructive, and unwanted plant that disturb human activities.

Weed Control The method to eliminate or decrease the population and propagation of weeds in a particular land.

Weed Dominance The superiority of a particular weed over others expressed in percent composition per square meter.

Weed Management Maximum utilization of all environmental aspects to make sure that the negative effects of weeds on crop plants are minimum.

Subject Index

Biography of The Author

Abdul Kadir Salam was born in Bandung, West Java, Indonesia, on the first of November 1960. He finished elementary school (1972), junior high school (1976), and senior high school (1980) in Cirebon West Java, Indonesia. He got his bachelor's degree in Soil Science from Bogor Agricultural University in Bogor, Indonesia (1984). He earned his master's and Ph.D.'s degrees from the University of Wisconsin-Madison, the United States of America in 1989 and 1993, respectively, in the fields of Soil Chemistry-Fertility and Water Chemistry. He participated in a *Postdoctoral Program* in the field of Soil Biochemistry (Soil Enzymes) in *Nagoya University*, Japan, in 1995 – 1996.

As a faculty staff since 1984 in the Faculty of Agriculture the University of Lampung, he taught several courses for bachelor's, master's program, and doctor's: Basic Chemistry, Fundamentals of Soil Science, Soil Chemistry, Soil Fertility, Fertilizers and Fertilizing, Soil and Plant Analysis, Research Methodology, Scientific Writing Techniques, and Environmental Chemistry and Pollution. He also conducted research projects on various soil problems, particularly related to nutrient and non-nutrient elements (heavy metals) and soil enzyme management funded by the University of Lampung, the Ministry of Culture and Education, Japan Society for the Promotion of Science, Indonesia Toray Science Foundation, and the Ministry of Research and Technology. He published more than 75 technical papers in national and international journals. He was also a trainer in several research methodology trainings and scientific paper trainings.

In addition to writing *The Chemistry and Fertility of Soils under Tropical Weeds* (2019), he also published *Ilmu Tanah Fundamental* or *Fundamental of Soil Science* (2012) and its revised edition (2019), *Enzymes in Tropical Soils* (2014), *Management of Heavy Metals in Tropical Soil Environment* (2017) – A summary of his research results for the last 30 years (1987–2017), and currently *Manajemen Hara Tanaman or Management of Plant Nutrients* to be published in 2020. He also published *Melatih Guru Muda Menyusun Karya Tulis* or *Training Young Teachers to Compose Articles* as The Editor (2014) and *Sepuluh Tahun Sekolah Global Madani* or *Ten Years of School of Global Madani* (2020) as one of the Editor.

In the University of Lampung, he had been assigned to the following posts: Chair of the Laboratory of Soil Chemistry and Fertility (1985-1986, 1997-1999), Chair of the Soil Science Department (1998-2001), Expert Staff of the Vice Rector of Academic Affairs (1999-2004), The Director of the Sub-Project Management Unit Technological and Professional Skills Development Project TPSDP (2001-2008), and the Director of the Graduate School (2006–2011). He was also the Executive Director of Al-Kautsar Education Foundation Lampung (2002-2010), that managed pre-elementary school, elementary school, junior high school, and senior high school. Since 2010 he was assigned as the Director of Education Foundation of Global Madani Lampung that managed elementary school, junior high school, and senior high school with enriched curriculum, and the University of Al-Madani (College of Economics and Business since 2018).

Nanik Sriyani is a professor of Weed and Herbicide Management in Faculty of Agriculture, University of Lampung. She was born in Magelang, a beautiful town in Central Java, Indonesia, on the first of January 1962. She finished elementary school (1973), junior high school (1976), and senior high school (1980) in Magelang, Central Java, Indonesia. She got her bachelor's degree in Agronomy from Bogor Agricultural University in Bogor, Indonesia (1984). She earned her master's and Ph.D.'s degrees from the University of Wisconsin-Madison, the United States of America in 1989 and 1993, respectively, in the field of Plant Physiology and Weed Science.

As a faculty staff since 1986 in the Faculty of Agriculture the University of Lampung, she teaches several courses for bachelor's and master's programs: Weed Science and Management, Herbicide in the Environment, Herbicide Physiology, Management of Weeds and Herbicides, Basic Plant Physiology, Crop Physiology, Basic Plant Protection, Research Methodology, and Environmental Chemistry and Pollution. She has also conducted research projects on various weed and herbicide control and management, funded by various resources: the University of Lampung, the Ministry of Culture and Education, Japan Society for the Promotion of Science, Indonesia Toray Science Foundation, the Ministry of Research and Technology and Higher Education, and various private companies such as Gunung Madu Plantation, Great Giant Food Company, Syngenta Indonesia, Monsanto Indonesia, DuPont Indonesia, etc.

From 1997, she has been appointed by Ministry of Agriculture as an independent researcher to test herbicides before their releases. Right now she is a member of Indonesian Pesticide Committee, since 2017. From her intensive research results, she published more than 70 scientific papers in national and international journals. Her latest book is *The Chemistry and Fertility of Soils under Tropical Weeds* (2019), as a coauthor to Professor Abdul Kadir Salam. Her other books are Weed of Southern Sumatra: Identification Book (2013) and *Pengendalian Gulma Terpadu* or Integrated Weed Management (2017). She also published *Melatih Guru Muda Menyusun Karya Tulis* or *Training Young Teachers to Compose Articles* as one of the contributor (2014).

In the University of Lampung, she had been assigned to the following posts: Chair of the Laboratory of Weed Science and Chair of Weed Science Peer Group (1996 until now), Expert Staff of the Vice Rector of Collaboration Affairs (2000-2004), Expert Staff of the Vice Rector of Academic Affairs (2005-2007). Since 2010 she has been assigned as the Director of Academic and Students Affairs of Education Foundation of Global Madani Lampung that manage elementary, junior high, and senior high schools. In 2018 she was also appointed as the Director of the University of Al-Madani (College of Economics and Business).

THE CHEMISTRY AND FERTILITY OF SOILS UNDER TROPICAL WEEDS

ABDUL KADIR SALAM AND NANIK SRIYANI

A great deal of researches reveals that the presence of weeds modifies the chemistry and fertility of soil environment. The chemistry and fertility of soils affected by weeds may include soil reaction and other soil properties affected by the changes in soil pH like soil cation exchange capacity, the soil enzymatic activities such as those of phosphatases, ureases, arylsulfatases, and β-glucosidases, the soil exchangeable potassium, the soil organic carbon, phosphorus, nitrogen, and sulfur contents, and the heavy metal solubility. This book deals with these kinds of soil chemical and fertility properties under various tropical weeds mostly investigated in the Province of Lampung Indonesia.

This book is organized into nine chapters. Chapter 1 (Introduction) briefly focuses on the interrelationship between the chemistry of soils and the existence of plants and weeds in the soil environment. Chapter 2 (The Soil – Weed Interrelationships) describes more specifically the interrelationship between the chemistry of soils and the growth of weeds while Chapter 3 (The Important Facts about Tropical Weeds) briefly describes the important weeds of the tropics: their concepts, their effects, invasion and dominance, and their control and management. Chapters 4 - 9 deal with the effects of weed presence on the chemistry and fertility of soils that include soil pH and soil enzymatic activities (Chapter 4: Effects of Forest Conversion, Chapter 5: Effects of Tropical Weeds on Soil pH and Enzymatic Activities), soil contents of carbon, phosphorus, and sulfur(Chapter 6: Effects of Tropical Weeds on Soil Carbon, Nitrogen, Phosphorus, and Sulfur), soil exchangeable potassium (Chapter 7: Effects of Tropical Weeds on Soil Potassium), and heavy metals (Chapter 8: Effects of Tropical Weeds on Heavy Metals). Chapter 9 (Closing Remarks) highlights some important conclusions related to the effect of weed existence on the chemistry and fertility of soils.

Abdul Kadir Salam is a Professor of Soil Science in the Faculty of Agriculture, the University of Lampung, Indonesia (since 2001); earned her bachelor’s degree (1984) from Bogor Agricultural University, Indonesia, Master’s degree (1989) and Doctor of Phillosophy (1993) from the University of Wisconsin-Madison USA, and participated in Posdoctoral Program (1995-1996) in Nagoya University, Nagoya, Japan.

Nanik Sriyani is a Professor of Weed Science in the Faculty of Agriculture, the University of Lampung, Indonesia (since 2010); earned his bachelor’s degree (1984) from Bogor Agricultural University, Indonesia, Master’s degree (1989) and Doctor of Phillosophy (1993) from the University of Wisconsin-Madison USA, and the Chair of Weed Science Society of Indonesia (2018-2020).

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