COMMUNAUTÉ FRANÇAISE DE BELGIQUE

UNIVERSITÉ DE LIÈGE – GEMBLOUX AGRO-BIO TECH

Towards a regional soil reference system for fertility assessment and monitoring in the highlands of Mindanao, Philippines

Guadalupe M. DEJARME-CALALANG

Dissertation originale présentée en vue de l'obtention du grade de Docteur en Sciences Agronomiques et Ingénierie Biologique

Promoteurs: Laurent Bock
Gilles Colinet

Année civile 2015

To RODOLFO, my husband

and my sons, JANSSEN and JAMES CONRAD,

this work is dedicated.

Acknowledgment

I am truly grateful to all, who in one way or another have supported me in this challenging work.

To the Cooperation of Universities for Development (CUD) for the scholarship grant,

To Xavier University, Philippines, for the study leave grant and research support through its Faculty Development Program.

To Prof Laurent Bock, my PhD Promoteur, to whom I deeply acknowledge, for unselfishly imparting to me his knowledge in Soil Science through his utmost guidance in the over-all PhD research, and his incessant encouragement that get me through in this intellectually and physically demanding work,

To Prof Gilles Colinet, Co-Promoteur for assisting me in the data gathering, who painstakingly had checked the pot experiment part of the manuscript, and for his guidance on the statistical analyses,

To the five MSc students who worked with me in this CUD project and shared to me their gathered information, Lola Richelle, Fanny Lebrun, Sophie Barbieux, Sophie Van Daele of Universite de Liege-Gembloux Agro Bio Tech (ULg-GxABT), and Simon Maurissen of Universite Libre de Brussels,

To the members of the PhD Committee; Prof Aurore Degre of ULg-GxABT and Prof Vincent Hallet of Universite de Namur for their assistance in the data gathering, Prof Philippe Lebailly and Prof Guy Mergeai of ULg-GxABT, Prof Joseph Dufey and Prof Sophie Opfergelt of Universite Catholique de Louvain for their valuable comments and suggestions to improve the study and PhD manuscript, and to Dr. Valerie Genot, for the NIRS analysis of the soil samples,

I sincerely am thankful to the two farming communities, Miarayon and Bendum for the friendship and safety during the field work,

I deeply acknowledge the help of Barangay Captain Robert Sulatan and Lanie Sulatan who assisted me in organizing the fieldwork in Miarayon, for without them, it would be difficult for me to infiltrate the area, to Sr Jessica Gemino and the Missionary Sisters of the Sacro Costato, Mateo Sanchez SJ and Miriam Layucan of the St Therese of the Child Jesus Parish, Noel and Nenet Hanginan for accommodating us during the field work, the farmers and their families who collaborated with me in the work, Corsino Buling and family, Roel Buling and family, Dodong and Zelda Flores, Jermie Angel, Virginio Sulod, the late Florito Bagas and his family, Nerio Salino, Ranilo Lajero and family, Hermilito Angel, Jerson Angel, Myrna and Zeke Sanghid, Sergio Hinganan, Roberto Memper, Eugenio Lagayon, Adogar Member, Felix de la Cerna, Mariano and Virginia Sulatan, Lucio Laguilay, the late Enerio Hinganan and his sons, to those who had provided the muscles during the augering and pit digging, Bernardo Sulatan, Jake Memper, Patrino Inta, Jick and Jig Sulatan, Albert Memper, Johnny and Jay Sulatan and Hernan Palma.

To the Bendum Community; the farmers who collaborated with me in the Bendum work, Julie Menaling, Nestor Menaling, Hipolito and Joy Buaya, Myrna Berdisula, Julie Gallamaso, Man Dagnayan, Norberto Navas, Berto Banahan, Dole Deloso, Danny Bono, Genara Hewe, to those who assisted us in pit digging and soil sampling Anecito Santer, Rufino Sagula, Jessie Berdisula, Nilo Almahan, Jason Menaling and to the pupils of Apo Palamguwan Cultural Education Center who always had accompanied us to the field.

To the Soil Science Unit Staff of ULg-GxABT, to Raphael Tarantino for all his assistance given, from administrative organizations to computer concerns, Amandine Lienard for constantly checking with me my ECTS requirements, to Beatrice Lagrange and Malorie Renneson for the logistical support and to Francoise Toussant for the plant and soil analyses.

To the Environmental Science for Social Change (ESSC); Andres Ignacio and to the very supportive ESSC staff Arnel Santander, Eric “Popoy” Bruno, Cherie Domer, Freida Tabuena, Leanne Fernandez, Ceasar Aguinaldo, Ariel Amor, Jenifer Ogaña, Eddie Campos, Aili Gatuslao, Joan Jamisolamin and Robelito Buntas.

To Xavier University colleagues: to Dr Lina Kwong, Mark Alexis Sabines and Alexis Maristaza of the Agricultural Engineering Department, to Glenda Orlanes and Reynaldo Antonio Mante of the College of Agriculture-Assistant Dean’s Office, Bern Geveso and Virgie Bulang of the Office of the President for the various assistance, to Lorna Picar and Richel Malon of the Central Purchasing Unit for facilitating the purchase of the Isuzu Fuego and spare parts, to Ramil Pajo and Noemi Dacudao of the Physical Plant Office, for the conversion of a space into a Soil Laboratory, to Jofferdale Gallamaso for the laboratory design, to Franciso Umaran for setting-up the internet connection in the laboratory and its maintenance, and to Madame Elisabeth Enerio of the Office of International Cooperation and Networking, for her assistance in my difficulties of the French language.

To Hernando Pacana and the Manresa Experimental Research Station workforce of Xavier University, Aldwin Palanas, Allan Ranis, Boeding Mingoc, Nestor Diango, Samuel Libot and Arnold Casil for facilitating the work, from the construction of the pot experiment shed, the driving services provided during field work, the maintenance of the soil laboratory and of the field work vehicle, to the Manresa Security Unit for the safety provided during the numerous overnight-stays in the Soil Laboratory because of the PhD manuscript preparation.

I truly appreciate Prof Françoise Orban and her family for they are my family in Belgium. I am grateful for the welcoming and generosity of Madame Jennifer Bock and her family, from the weekend dinners, the transport facilitated from and to Brussels airport, to the provisions of home effects for my apartment, to Madame Françoise Descamp, Monsieur Thierry Henckaerts and Madame Alix Raway for always providing me a place in Maison Nord Sud, my home in Gembloux.

To the Jesuit fathers; Jose Ramon T Villarin SJ and Peter W Walpole SJ, for whom through them I was able to find the PhD grant, and to Roberto C Yap SJ for continuing the support until the end of my PhD study.

Thank you.

Guadalupe M. Dejarme-Calalang

Abstract

This PhD research work is a contribution to the umbrella research project in Mindanao, Philippines entitled "*Establishing strategic partnership in research to strengthen local governance in land and water management for greater human security in Mindanao (EPaM)*" which was supported by the Cooperation of Universities for Development - Inter University Program (CUD-PIC) of Belgium with the long term objective to capacitate local entities in managing land and water resources in their jurisdiction.

As part of the CUD-PIC project, the research has two objectives: (1) the establishment of a Soil Reference System (SRS) to respond to the needs of soil information for scientific bases in land use planning and agricultural development at the local level, and (2) the use of this established SRS as a pertinent tool for agricultural extension services to local farmers on soil management and crop production.

The specific study locations were Miarayon, Talakag and Bendum, Malaybalay City of the Bukidnon Province.

The study had four sub components: (i) the geomorphopedological identification of potentialities and constraints, (ii) the soil fertility assessment with predominant crop yields to initiate a SRS as bases for monitoring in the future, (iii) the soil fertility assessment and calibrating using a test plant in a pot experiment, and (iv) the information integration of the SRS for highland areas in Mindanao, Bukidnon.

Miarayon and Bendum soils are both derived from volcanic parent materials, but their development differs by duration and rock origin. Bendum soils are derived from ultramafic rocks in the periods of Upper Cretaceous and Paleogene and Oligocene Lower Miocene while Miarayon soils originated from pyroclastic rocks of the Pliocene-Quaternary period. Dominance of total elements in soils of both areas is due to either natural causes or anthropogenic activities. The dominance of Mg in Bendum rocks is effectively due to its ultramafic parent rock materials while in Miarayon the prevalence of Ca is due to the application of chicken dung in which chicken feed formulas have Ca additives. Moreover Miarayon soils have in general higher organic matter content and more available nutrients

than Bendum soils. The encroachment of cultivation on the steep slopes in both areas indicates the high demand of lands for production in the highlands.

Crops in Miarayon which are intended for the market are short term, such as vegetables, with a growing season of three to four months. Bendum crops that are for the market are perennial ones such as rubber and coffee and therefore are long term crops, and abaca which are for fiber materials. Food crop in Miarayon is corn while in Bendum is corn and sweet potato. Crop yields are indicators of soil fertility and crop management in a given prevailing climate. In Miarayon soils, there is a good relationship between the yields of potato and TOC, TN, Ca and Mg. There is also a good relationship between yields of corn and Ca and Mg. The robustness of relationships is shown in spite of few observations.

A pot experiment was carried out to test the response of a plant to different soil types. Results on plant nutrient analyses had shown the transfer of elements, from parent rock materials, to soil formation and until the nutrient absorption by the test plant. Results had corroborated the findings in literature researches about which nutrients are prevalently assimilated by test plants.

The methodology used in this SRS shall serve as template for instruction and research on soils in Mindanao. The integrated information is good input for extension work on soil management and crop production at local level. To achieve a good data density, the Near Infrared Reflectance Spectroscopy (NIRS) is a promising technology in soil analysis. Findings in this research work had led to the following recommendations: (i) disseminate the developed SRS methodology and framework and replicate the work in other highland areas in Mindanao, Philippines, (ii) Disseminate the established SRS in the region, (iii) study the sustainability of highland agricultural production, (iv) make follow-up studies on soil nutrient dynamics, (v) study the hydropedology of highland areas, (vi) establish soil conservation programs, and (vii) conduct environmental toxicology studies in highland vegetable areas.

Résumé

Cette recherche doctorale a été réalisée dans le cadre du Projet d'Initiative Ciblé (PIC) intitulé « Establishing strategic partnership in research to strengthen local governance in land and water management for greater human security in Mindanao (EPaM project) » qui a été conduit aux Philippines grâce à un financement de la Coopération Universitaire belge au Développement (CUD). Ceci avec l'objectif à long terme d'améliorer les capacités locales dans la gestion des ressources en terres et en eau dans leur juridiction.

Dans ce cadre, notre contribution visait (1) à l'établissement d'un système de référence sur les sols (SRS) pour répondre aux besoins d'information sur les sols comme bases scientifiques en planification dans l'usage des terres et le développement agricole au niveau local, et (2) à l'application d'un tel système dans les conseils personnalisés à l'agriculteur en matière de gestion des sols et de production agricole. Les sites d'études, situés en Province de Bukidnon, sont le village de Miarayon dans le district de Talakag et celui de Bendum dans le district de Malaybalay City.

Plus spécifiquement, l'étude a comporté quatre volets, à savoir : (i) l'identification géomorphopédologique des potentialités et des contraintes, (ii) l'évaluation de la fertilité des sols en pleins champs eu égard aux rendements des cultures dominantes et ce, pour initier le système de référence sur les sols et un suivi dans l'avenir, (iii) l'évaluation de la fertilité des sols en milieu contrôlé (pots) eu égard à une plante de référence, et (iv) l'intégration de l'information en ce système de référence sur les sols pour les Hautes terres de Mindanao, Bukidnon.

Les sols de Miarayon et de Bendum sont dérivés de matériaux parentaux d'origine volcanique, mais leur développement diffère par l'âge et la nature même des roches. Les sols de Bendum sont dérivés de roches ultramafiques d'entre le Crétacé supérieur et le Miocène inférieur tandis que ceux de Miarayon sont dérivés de roches du Pliocène et du Quaternaire. La dominance de magnésium dans les roches de Bendum est précisément due à ce caractère ultramafique. Les sols de Miarayon ont par contre des teneurs plus élevées en matière organique et advantage d'éléments disponibles que ceux de Bendum. Les fortes teneurs en éléments totaux dans les sols des deux sites est soit due à des causes naturelles soit aux activités anthropiques. La prévalence de calcium à Miarayon est due à l'application de fientes

de volaille car les formules alimentaires sont riches en cet élément. La progression des cultures sur les sols de fortes pentes indiquent que, dans les deux sites, la demande en sols pour la production agricole est importante dans les Hautes terres.

Les cultures à Miarayon qui sont destinées au marché telles que les légumes sont de court terme avec une période de croissance de trois à quatre mois. Les cultures de Bendum qui sont destinées au marché telles que le caoutchouc et le café sont pérennes ; il en est de même de l'abaca qui est cultivé pour ses fibres. Les cultures vivrières sont le maïs à Miarayon et le maïs et des plantes racines à Bendum. Les rendements des cultures sont indicateurs de la fertilité des sols et de la gestion de ces cultures dans un contexte climatique donné. Dans les sols de Miarayon, il y aune bonne corrélation entre les rendements en pommes de terre et la teneur en carbone organique total, en azote total, en calcium et magnésium ainsi qu'avec le rapport C/N. Il y a aussi une bonne corrélation entre le rendement en maïs, le calcium et le magnésium. La robustesse des corrélations est montrée malgré le relativement faible nombre d'observations.

Une expérimentation en pots a été conduite pour tester la réponse d'une plante test à différents types de sol. Les résultats des analyses de plante ont montré le transfert des éléments, du matériau parental, au sol et jusqu'à l'absorption par la plante test. Ces résultats ont corroboré les données de la littérature quant à la prévalence des nutriments.

La méthodologie utilisée dans ce système d'information sur les sols servira de canevas pour l'éducation et la recherche sur les sols à Mindanao. L'intégration de l'information constitue une bonne base pour la vulgarisation en matière de gestion des sols et de production agricole au niveau local. Pour obtenir une bonne densité de données, la spectroscopie dans le proche infrarouge constitue une technologie prometteuse en analyse de sol.

Les résultats de ce travail de recherche conduisent aux recommendations suivantes : (i) disséminer la méthodologie et le canevas du système d'information sur les sols ainsi développé et reproduire le travail dans d'autres sites des Hautes terres à Mindanao, Philippines, (ii) disséminer dans la région le système établi, (iii) étudier la soutenabilité de la production agricole dans les Hautes terres, (iv) opérer des études de suivi sur la dynamique des éléments, (v) étudier les caractéristiques hydropédologiques des Hautes terres, (vi) établir des programmes de conservation des sols, et (vii) conduire des études de toxicologie environnementale sur les légumes produits dans ces Hautes terres.

CONTENTS

Chapter III Geomorphopedology, potentialities and constraints identification of the Bukidnon highland soils, Northern Mindanao, Philippines 37

Chapter V Soil fertility assessment and monitoring through pot experiment for Bukidnon agricultural highland soils, Northern Mindanao, Philippines 133

Chapter VI The SRS for Bukidnon highlands, Northern Mindanao, Philippines: Soil information integration and the prospects of soil analysis in the region 158

Chapter VII Conclusions and recommendations 178

LIST OF TABLES

LIST OF FIGURES

Chapter I

Introduction

1. Chapter overview

Land, as agriculture's key resource, is at humankind's disposal. Its inherent capability to support crop production is less understood and therefore its carrying capacity is less valued. The desire for economic affluence has led people to overexploit this finite resource and the repercussions of its unsustainable use have bounced back to the societies' economy and environment. Soil is the heart of the land and if this heritage is destroyed, it is difficult to restore. Soil degradation and declining land productivity are among the realities that undermine the food security of a nation's vulnerable sector. Choices in using the land have to be carefully planned according to its inherent capabilities to support a particular development. Planning and management should be substantiated with scientifically based information to come up with objective decisions in using the land resource.

The Food and Agriculture of the United Nations has named the year 2015 as the International Year of Soils (FAO-UN, 2015) to acknowledge the importance of this non-renewable and natural resource which is the basis for healthy food production, the foundation of vegetation, and the earth's biodiversity support. This further recognizes the role of soils in humans' combating and adapting to climate change, strengthening the society's resilience to natural calamities and for the food security and a sustainable future. The goal of the celebration is to heighten the consciousness of society on the importance of sustainable soil management as the foundation of food, fuel and fiber production, environmental balance and to better adjust to the earth's changing climate. This occasion highlights the urgency for stakeholders to synergize their efforts to support in protecting this indispensable but vulnerable natural resource. This PhD research project, even how small this is compared to the global initiatives in sustainable soil use and management, is a contribution from Mindanao, Philippines towards the aim of the International Year of Soils 2015. For great things start from small beginnings, local stakeholders can think globally while acting locally.

The Cooperation of Universities for Development–Inter University Program (CUD–PIC) of Belgium had granted support to a project in the Philippines entitled: *“Establishing strategic partnership in research to strengthen local governance in land and water management for greater human security in Mindanao (EPaM)”*. The partnership was composed of three Universities in Wallonia, Belgium; the Universite de Liege - Gembloux Agro Bio-Tech (ULg-GxABT), Universite de Namur (UN) and Universite Catholique de Louvain (UCL) and an institute and two Universities in Mindanao, Philippines namely: Environmental Science for Social Change (ESSC), Xavier University (XU) and Ateneo de Davao University (ADDU). The EPaM project had two PhD research subject areas. The first research subject was the “*Development of a generic protocol for an integrated soils and water Land Information System (LandIS) applied to land use planning in Mindanao, Philippines*”. The second was the *“In-depth analysis of factors mitigating the effects of disaster events: vulnerability to flood and migration in Mindanao*. The first subject was the premise of this PhD work which had sought to build a regional Soil Reference System (SRS) for fertility assessment and monitoring to provide scientific bases for decisions in agricultural land use planning of highland areas in Mindanao, Philippines.

This introductory chapter presents the importance of land and soils in Philippine agriculture, the opportunities they offer and the constraints they are facing and imparts the significance of the PhD research work. This chapter further presents the questions that this PhD research wishes to answer. Brief descriptions of each part of this dissertation are discussed in the last section of this chapter.

2. Land, a vital resource for Philippine agriculture

The Philippines with a population of 98.39M, has a total land area of 30M ha in which agriculture presently occupies 40.58% (World Bank Group, 2014). The Philippine economy is deeply rooted in agriculture. In the history of the nation's agriculture, the Filipino farmers had raised food crops for self-sufficiency and for export to the international markets. The country’s agricultural enterprise had gained prominence in the outside world during the Spanish regime because of its production of tobacco (*Nicotiana tabacum*, Linn.), abaca (*Musa textilis*, Nee), coffee (*Coffea spp.*)

and spices for export (Merino, 1952). Like other tropical countries in the world, the Philippine agricultural lands are economically, socially and environmentally pressured. Marginal areas and the highlands are the frontiers of Philippine agriculture and these are encroached for food production expansion.

In the last century, the demand for land to be devoted for food production had increased to cope up with the Philippines' growing population. The country's population density in 1910 was sporadically spread (28 person-km^{-2}) to a densely inhabited (273 person-km^{-2}) in 2003 (Kastner and Nonhebel, 2010). In a ten-year period, that is from 2000 (205 person-km^{-2}) to 2010 (308 person-km^{-2}) this had increased by 20.7% (NSO, 2012). Because of improvements in agricultural technology, the average capita food supply had been improved in the last century and the amount of land required to feed a person declined (Kastner and Nonhebel, 2010). In the last 50 years, the size of arable lands had increased by 10.18% only but the nominal allocation in hectare per person had decreased from 0.18 person-ha^{-1} in 1961 to 0.06 person-ha^{-1}in 2011 (World Bank Group, 2014). However, the land size requirement reduction is overtaken by the increase in population which make the overall land requirement for food much higher than before.

Many of the Philippine soils are derived from volcanic parent materials. Volcanic ash-derived soils are known to be the most productive and can support intensive agriculture (Poudel and West, 1999; Raymundo and Vicente, 1985). To conserve this natural but vulnerable inheritance, the LandIS should be developed to come up with an SRS and the obtained facts should effectively be disseminated to the stakeholders. To aid in coming up with operational decisions for the sustainable use of agricultural soil resources, information on the SRS shall encompass the present status of its soil morphology, potentiality and constraints, fertility and productivity.

3. Socio-economic and agroecosystem issues in the Philippine highlands

Poverty in the Philippine rural areas is a phenomenon which remains to be a challenge for countryside development. The poorest are in the agriculture and fishing sectors (Asian Development Bank, 2009) although these industries had absorbed the most number in the rural workforce. Highland regions are supposed to be the frontiers of Philippine agriculture. However, because of the escalating demand for food production areas, these marginal lands are impinged. The inequity in land ownership had driven the landless farmers to go up to the highlands and open the forest and cultivate the soil for the family's subsistence. Farmers too work as paid laborers in agricultural plantations to support their families.

In Bukidnon, the Philippine government’s move to fast track the development in agriculture and timber industry had paved the way for migrants to settle and cultivate the soil (Lao, 1992) thereby creating changes in the socio-economic and cultural climate in the Province. The indigenous population who were unable to adapt and integrate themselves in the new socio-economic mainstream was pushed up farther to the highlands where they do swidden farming. This was during the postwar period until the 1970s, when heavy in-migration in Bukidnon had occurred and the new settlers typically homesteaders had cleared rain forests (Bouis and Haddad, 1990). Swidden (Figure I-1a) is a term of Scandinavian origin which means “land cleared by burning” and for centuries has been one of the most important land use systems in the tropics, including Southeast Asia (Mertz *et al*., 2009). This land use system is practiced in many parts of the Philippines but there are no reliable estimates of its areal extent (Schmidt-Vogt *et al.*, 2009). Swidden areas are later on converted into permanent crop fields (Figure I-1b) and because of population expansion in the highlands and for economic reasons

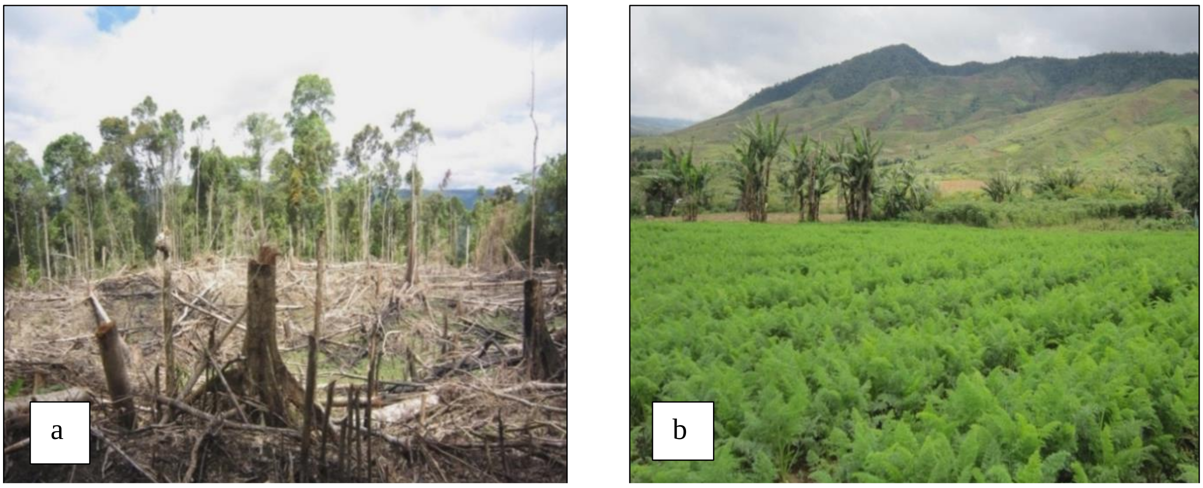


Figure I-1. Highland cultivation areas in the Philippines: (a) a newly opened plot in the Upper Pulangui River catchment and (b) permanent intensively cultivated plot in Upper Cagayan de Oro River catchment (Photos: G. Calalang).

these are cultivated intensively.

In recent decades the country's stabilization of the lowlands intensification has begun and industrialization has failed to absorb excess labor which resulted to the major migration of subsistence farmers to the highlands (Cramb, 2005). The exodus of migrants to the highlands that created population pressure and with pervasive poverty, has led to the deforestation of areas including sloping lands for crop production (Asio *et al.,* 2009). Cultivation techniques employed in farming are not appropriate for sloping lands. Lantican *et al.* (2003) had mentioned that in the Manupali watershed of Bukidnon highlands, crop production in sloping lands has resulted to high soil erosion rates and degradation of soil resources not only in the upstream location but also in the downstream. In the upper slopes of Manupali watershed, soil erosion on commercial vegetable farms was reported to be largely responsible for crop productivity decline (Poudel *et al*., 2000).

4. The LandIS for land use planning in agricultural development

Highland areas in the Philippines which are supposed to be the frontiers of the country's agriculture are under pressure because of current socio-economic, political and environmental situations. The inequitable land distribution, the rising demand of land to grow food and industries' raw materials, and the declining soil productivity are among the socio-economic factors that cause the intensive use of highland areas. Land utilization competitions are on agricultural, industrial, infrastructure development and tourism as well. The decisions in using the resource lie in the hands of authorized entities. Because the nature of land is less understood, environmental impacts when its use is changed are unforeseen. Such consequences can include soil compaction, water logging, increased runoff, soil erosion, pollution and other untoward outcomes of poorly informed decisions in changing the use of the land.

Concepcion (2000) pointed out that the absence of a national land use policy is among the issues of concern for sustainable agriculture in the Philippines which had resulted to indiscriminate conversion of agricultural lands and inadequate monitoring of land conversions, outdated land use plans and non-delineated forests. To sustainably use these land resources and address the food security demands of the populace, adequate and quality land and soil resources information are crucial. The Presidential Decree (PD) 1586, the Philippine Environmental Impact Statement System, classifies a primary agricultural land as Environmentally Critical Area (ECA) (DENR, 2003). Any development project in ECAs requires Initial Environmental Examination (IEE) to identify its potential impacts and justify the purpose of this undertaking. An Environmental Impact Assessment (EIA) follows if the proposed project has predicted untoward influence to the environment. Impacts brought about by a development on soils can be best evaluated when quality and comprehensive soil information are available.

Classical land evaluation approach is based on qualitative models that requires only basic structural knowledge of the specific landscape and object of evaluation thus should be rearranged when the land use is changed (Manna *et al.*, 2009). Existing information needs to be in pace with the demands of the planning exercise and therefore should easily be available and understandable. Furthermore, land evaluation has to focus not only for food production options but also for ecological, environmental and social concerns that are progressively more important in the planning process (Rossiter, 2008).

FAO (1989) had outlined the ten (10) steps of the land use planning which are shown in Figure I-2. The LandIS which is the pooling of information and a prerequisite when planning for land resource surveys that leads to the physical evaluation of land for its suitability. An indispensable tool to scientifically guide decision makers in using the land, the LandIS is imperative in choosing the kind of agricultural development especially on marginal highland areas in the Philippines where there is no available integrated information.

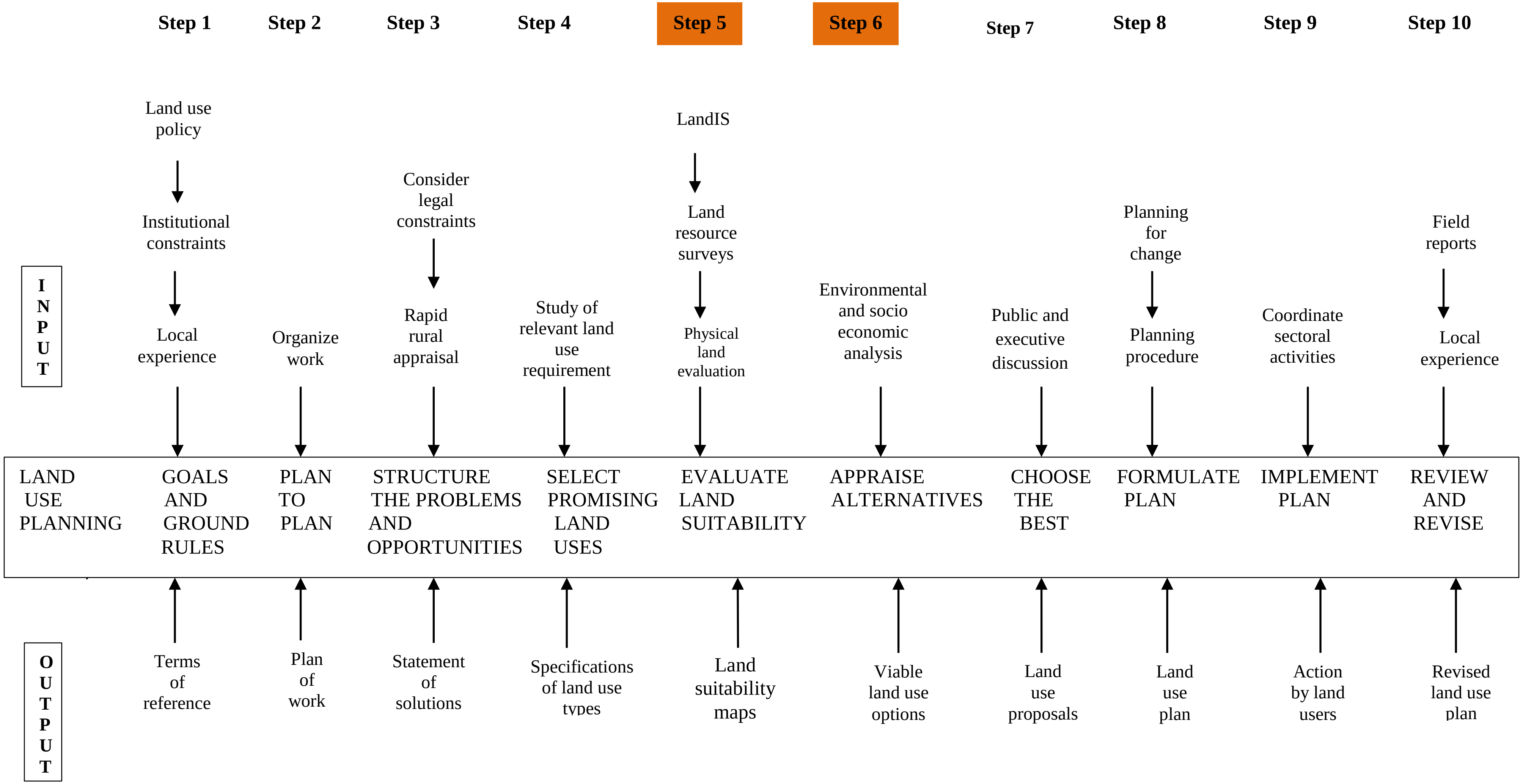


Figure I-2. The land use planning process. (FAO, 1989)

As the SRS is the central component of the LandIS, the reference system contains basic information on the geomorphological characterization, agropedological evaluation, land use information and farmers' crop management practices. Quality information can be achieved if appropriate methodologies are used in data gathering and therefore, researchers need to take those approaches that are fitting to the locality.

5. The general research questions

It is founded that natural and anthropogenic factors influence soil development. However, their effects may differ in locations and situations because of the variations of climate, time of soil formation, soil parent materials, geomorphology, land use and soil management practices. This PhD research had sought to answer the following general questions:

i. What are the soil characteristics and the fertility statuses of highland soils in Mindanao, Philippines?
ii. What are the contributions of the physical environment and anthropogenic activities in soil properties and characteristics?
iii. Do the agricultural practices influence the soil fertility statuses of highland soils?
iv. Do soils vary in terms of capacity in offering essential nutrients to plants?
v. What are the propositions that can be made in order to reconcile the agro-environmental issues in the highlands?

The PhD research is an umbrella project that included geomorphopedological characterization, farmers' land use and management and agropedological evaluation. Particular questions for each study component are highlighted in the specific chapters of this manuscript.

6. The general objectives

The PhD research is a contribution to the sustainable use and management of highland soils. This primarily had sought to answer the aforementioned general questions by gathering information for the highland soils which are thought to be essential for land use planning in agricultural development that highlighted the steps 5 and 6 of Figure 1-2. The study had aimed to establish a regional SRS for the highland agricultural areas in Mindanao, Philippines, in order to respond to the needs of information. To reach the objectives, the PhD work had included a detailed geomorphopedological characterization, farmers' land use and management determination and agropedological evaluation. The benefits that can be gained in the established regional SRS are two-pronged. First is that the derived information will serve as support in coming up with scientifically based decisions in using the land. Second is that the established information can be used in agricultural extension services to farmers in managing their soils at the local level.

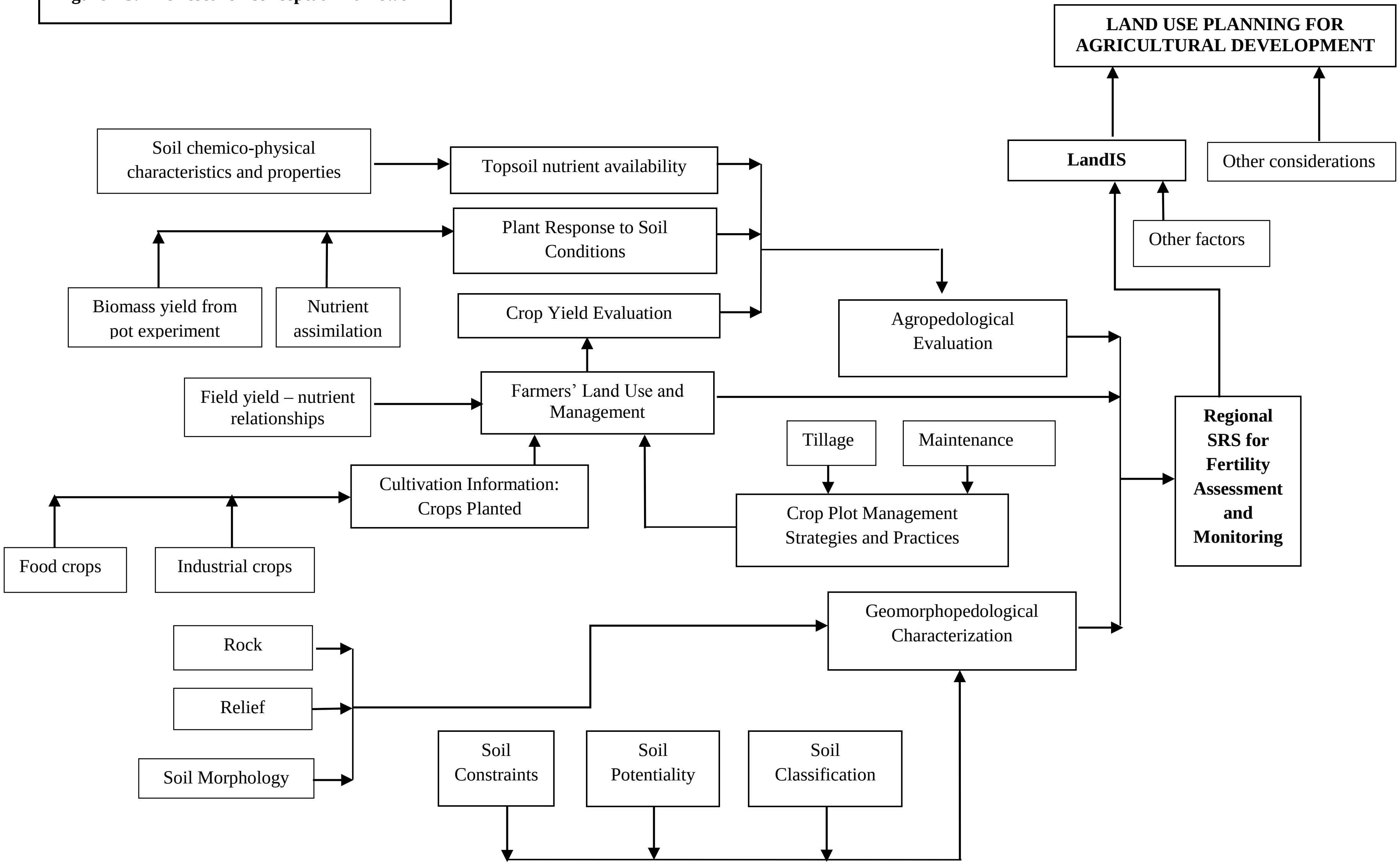
7. The research framework

Figure I-3 presents the research conceptual framework. This shows how an SRS shall contribute to the building of a LandIS and conversely to agricultural development planning in a region. In establishing the SRS, the research had considered three key information themes namely; the geomorphopedological characterization, farmer's land use and management and agropedological evaluation.

Geomorphopedological characterization deals with the investigations of rocks and minerals, relief and soil morphology which shall come up with soil classifications, soil potentialities and soil constraints. Soil physical parameters that were included in the geomorpedophological studies were soil texture, aggregate structure, bulk density, hydraulic conductivity and water retention capacity. The determined soil chemical parameters were soil pH, exchangeable acidity and aluminum (Al), total organic carbon (TOC), cation exchange capacity (CEC), exchangeable calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na), and total element contents for Phosphorus (P), Ca, Mg, K, Na, Al, iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu). Additional soil chemical parameters had included free and amorphous Fe and Al for the soil classifications. Mineralogical analysis was also conducted in representative soil horizons. Soil classification helps to compare and take the benefit of the experiences gathered.

Soil potentialities are the chemico-physical attributes of soils that are essential in crop production. Soil constraints are the physico-chemical limitations of soils that deter crop production. Farmers’ land use and management information consists of soil fertility interventions, such as applications of agricultural inputs, cultivation practices and crops grown. Agropedological evaluation is the assessment of fertility levels in soils. Soil nutrient parameters determined were TOC, total nitrogen (N), available Ca, Mg, K and Na, available P and pH and were matched with the crops through field yield observations. To evaluate the soil fertility in a controlled environment, a pot experiment was conducted to determine the response of a test plant to different types of soils with their inherent nutrient levels. Parameters for test plant analysis were total Ca, Mg, K, Na, P, Al, Fe, Mn, Cu and Zn.

Figure I-3. The research conceptual framework



The approach that adopted the framework and methodology of Bock (1994) which is the integration of geomorphopedological and eco/agropedological information had identified the relationships between soil, rock, relief, land cover and farmers' soil management practices (Figure I-4). The geomorphopedological approach offers a methodology to analyze the respective parts of different factors in soil formation and to understand the spatial distribution as a preliminary step to soil sampling, analysis and mapping of results. The integration of geomorphopedological and agropedological approaches was the jump start of the study and was the bases of site selections and the succeeding study components of the soil umbrella research work which were the identification of pedon locations, crop yield measurement locations and gathering of soil media for pot experiment. Data from rocks, relief, and soil morphology and the soil management of the study location were the basic evidences that were examined in order to draw the picture of how soil properties are functioning and interrelated with each other. Information gathered encompasses the soil characterization and the naming of soil classifications.

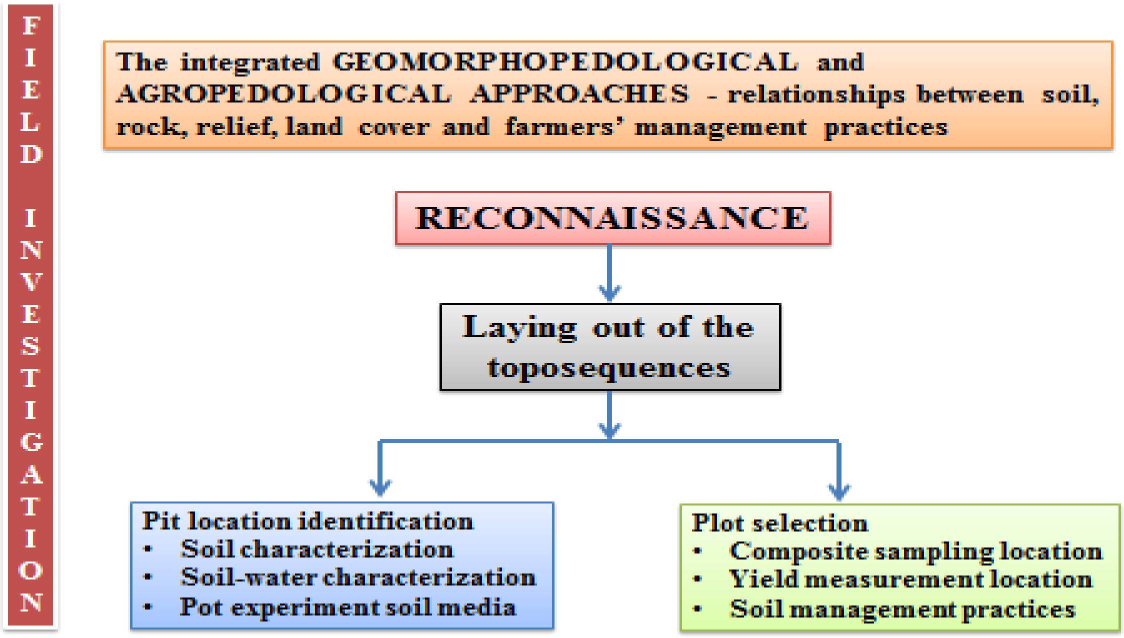


Figure I-4. The initial field investigation framework.

Farmers' land use and management appraisal data has consisted of cultivation information and the cropping management strategies and practices. Cultivation data were on types of crop and their growth requirements. Cropping maintenance information were on the planting systems, cultural maintenance and harvesting. Agropedological evaluation had taken into account the fertility status of the soil. This was made through topsoil sample chemical analyses. Evaluation was made in two ways. The first was by cross referencing the topsoil basic nutrient levels with existing predominant crop yields. This was done by looking into the relationships between crop yields and different nutrient levels in topsoils. This had tried to find out the possibility of calibrating crop yields with soil fertility. The second was by the test plant responses to the different soil types and soil nutrient levels through pot experiment.

8. Organization of dissertation discussions

The discussion organization of this manuscript is as follows: Chapter I, preludes this paper. Chapter II depicts the research study locations. Chapter III presents the geomorphopedology, soil potentialities and constraints of the studied highland locations. Chapter IV states the soil fertility, the yields of existing crops and the farming management and practices in the studied locations. Chapter V communicates the soil fertility assessment and describes its relationships with the plant responses using pot experiment. Chapter VI is the integration of all information into a SRS and the justifications on how this information can contribute to the building of the LandIS as valuable tool for agricultural land use planning. A very brief section in Chapter VI deals with the prospect of Near Infrared Reflectance Spectroscopy (NIRS) on soil analysis for the future. Chapter VII covers the conclusions and recommendations that are formulated from the PhD research which are needed to be done in future engagements.

Chapter II

The highlands of Bukidnon, Northern Mindanao, Philippines: Location of investigation

1. Chapter overview

The Philippine archipelago has a total of 7,100 islands which are grouped into three primary island clusters: (1) the Luzon group of islands in the northern part and Luzon is the largest island, (2) the Visayas group in the central part, and (3) the Mindanao group in the southern part of the country with Mindanao as the cluster's largest island. Mindanao is the second largest island in the country and has six (6) regional divisions (Figure II-1). The island has a total land area of 10.2 M ha with 4.1 M of alienable and disposable lands and 6.1 M ha of forestlands (MDA, 2012). Northern Mindanao is composed of five (5) political subdivisions, the provinces which are: Bukidnon, Camiguin Island, Lanao del Norte, Misamis Occidental and Misamis Oriental.

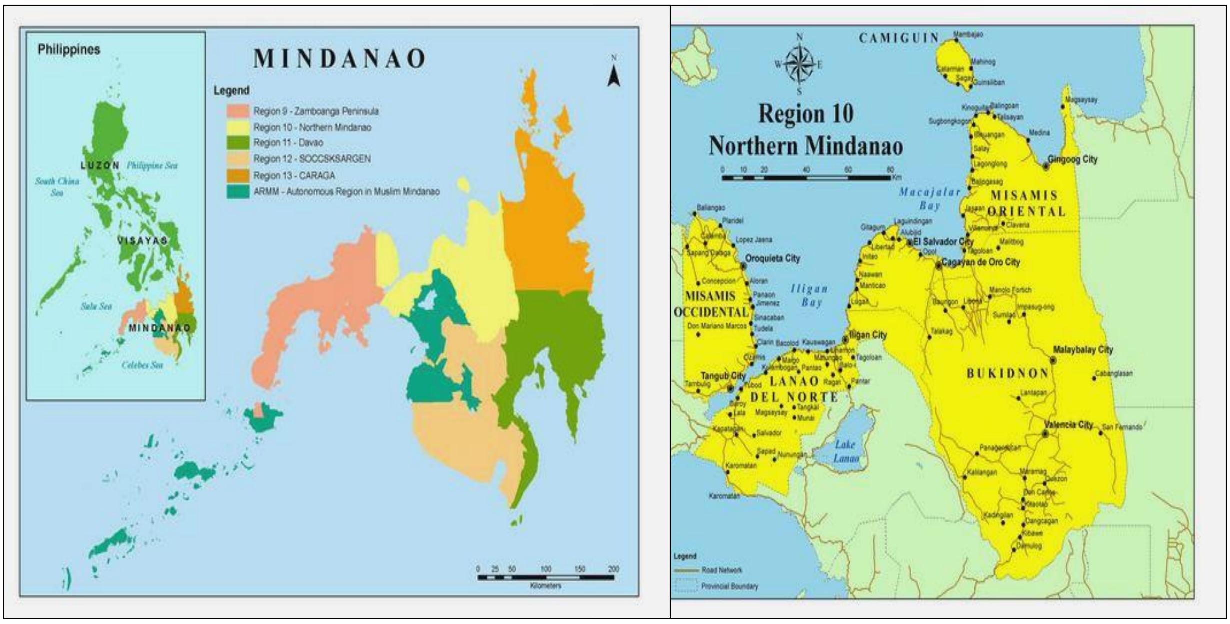


Figure II-1. Map of Mindanao and Northern Mindanao with Philippines inset (Courtesy of Mark Alexis O Sabines, XUCA Geomatics, Philippines)

There are two reasons why Bukidnon Province is the chosen part of Northern Mindanao highlands as the PhD study location. First, Bukidnon is the largest contributor to the agricultural economy and food security of the Northern Mindanao region. However, poverty remains to be high.

Second, the Province has few pedological studies and has undifferentiated soils that are in the mountainous areas (Mariano *et al*., 1950) which are now under intensive cultivation but are still unmapped. The research project was conducted in the upper sub-catchments in the watersheds of two important rivers in Northern Mindanao, the Cagayan de Oro River and the Pulangui River. The specific research site in the upstream of Cagayan de Oro River is Miarayon, Talakag, Bukidnon which is located at the foot of the northwest side of Mt. Kalatungan. For Pulangui River upstream, the specific research location is at Bendum, Malaybalay City, which is positioned at the foot of the western side of Pantadon Range.

This chapter further explains the reasons why Bukidnon highlands are chosen as the place of investigation. This explicitly describes the crop production of the Province and its contribution to the regional and national agricultural economy. Furthermore, this chapter presents the soil information of Bukidnon, and more specifically on soil parent materials, soil forming minerals, soil classification types, location distribution, the soil chemico-physical characteristics and the soil information constraints of the Province.

2. Bukidnon, the chief contributor to the Northern Mindanao agricultural economy

In the Philippines, much of the commercialization of agriculture is found in Mindanao and the crops for export such as pineapple (*Ananas comosus*, Linn), banana (*Musa sapientum* Linn), rubber (*Hevea brasiliensis* (HBK) Muell.-Arg), abaca (*Musa textilis* Nee), sugarcane (*Saccharum officinarum* Linn), cacao (*Theobroma cacao* Linn), coffee (*Coffea spp*.) and coconut (*Cocos nucifera* Linn) are largely produced in this island (Bouis and Haddad, 1990). Bukidnon contributes significantly to the production of these commodities in Mindanao and the Philippines, except for coconut, as this crop grows well in the lowlands and in coastal zones.

Production data of major crops in the province are presented in Table II-1. The area occupied by major crops in the region shows that most of these crops are produced in the Province. The early history of Bukidnon agriculture had pointed out that its lands were already identified as suitable for intensive production of food and for export (Lao, 1992; Putzel, 1992; Mariano *et al*., 1955). The regional rice (*Oryza sativa* Linn) production, the traditional food of most Filipinos and its substitute corn (*Zea mays* Linn.) are largely found in Bukidnon. The Province is a major producer of high value commercial vegetables: carrot (*Daucus carota* var. *sativus*), potato (*Solanum tuberosum* Linn.), cabbage (*Brassica oleracea* var. *capitata*) and tomato (*Lycopersicon esculentum* Mill. var. *esculentum*) in Northern Mindanao and The Philippines. Cassava (*Manihot esculenta* Crantz), ginger (*Zingiber officinale* Rose.) and sweet potato (*Ipomea batatas* Linn. Poir) are the root crops that can be found in Bukidnon. Although sweet potato production is only 23.2% in terms of the planted area in the region, the root crop is important because this is the food of people in the mountain areas where rice or corn is limited or inaccessible. Comparing the provincial crop yield to the regional produce, Bukidnon harvests are mostly higher than of Northern Mindanao.

Table II-1. Area planted and yield of major crops in Bukidnon and Northern Mindanao (2012)

Crop	Area (ha)			Yield (tha^{-1})	
	Bukidnon	N. Mindanao	Percent Area (%)	Bukidnon	N. Mindanao
Rice (*O. sativa*)	88,975	154,712	58.5	4.12	4.19
Corn (*Z. mays*), white	27,546	195,578	14.1	2.37	1.86
Corn (Z mays), yellow	164,554	183,284	87.8	4.74	4.72
Sugarcane (*S. officinarum*)	76,372	76,372	100.0	52.97	52.97
Pineapple (*A. comusus*)	21,000	21,530	91.5	60.90	60.17
Banana (*M. sapientum*), total	20,373	51,433	39.6	57.74	33.42
Banana (*M. sapientum*), Cavendish	16,481	16,628	99.1	66.59	66.30
Coffee (*Coffea spp.*)	9,022	11,632	77.6	0.50	0.51
Sweet potato (*I. batatas*)	620	2,673	23.2	19.74	12.15
Cassava (*M. esculenta*)	13,750	24,440	56.3	22.69	22.87
Tomato (*L. esculentum*)	1,985	2,728	72.8	19.51	18.36
Potato (*S. tuberosum*)	550	550	100.0	11.91	11.91
Carrot (*D. carota*)	104	137	75.9	10.72	9.50
Cabbage (*B. oleracea*)	371	494	75.5	13.67	12.33
Ginger (*Z. officinale*)	570	719	79.3	8.64	7.95
Rubber (*H. brasiliensis*)	6,639	6,851	96.9	1.58	1.58
Abaca (*M. textilis*)	3,100	5,376	57.7	0.47	0.38

Source: BAS (2013)

3. Geography and topography of Bukidnon

Geographically, Bukidnon extends from 07°20’-08°40’N and 124°30’-125°30’E. The Province has a total land area of 829,378 ha in which 335,995 ha are alienable and disposable and 493,385 ha are forest lands (MDA, 2012). The Province is landlocked and is subdivided into three agro-ecological zones (Holmer, 1997) that comprise: (i) the zones of Mt. Kitanglad and Mt. Kalatungan and the Central Cordillera of Eastern part of the Province, at elevations between 1,200-

2,950 m asl, (ii) the high altitude volcanic plains and terraces and the footslopes surrounding the mountainous zones with elevations ranging from 600-1,200 m asl, and (iii) the low altitude volcanic plains, terraces and hills with elevations <600 m asl. Three major rivers and their branches drain Bukidnon. The Northern part of the Province is drained by Cagayan de Oro River and Tagoloan River and their tributaries. Cagayan de Oro River drainage emanates from Mt. Kalatungan and Mt. Kitanglad, and Tagoloan River drainage originates from Mt. Kitanglad (CENRO-Talakag, 1999). Both rivers empty their waters at Macajalar Bay, Misamis Oriental, Northern Mindanao. The headwaters of Pulangi watershed are at Mt. Tago of Kalabugao, Impasug-ong. Three tributaries, the Manupali River that comes from Mt. Kalatungan drains the southeastern part of Bukidnon, the Maladugao and Muleta Rivers that start from the southern part of the Province convey their waters to finally join the Pulangi River and the river empties its waters at Panalisan Point of Sultan Kudarat in the southwestern part of Mindanao Island (PENRO-Malaybalay, 1999).

4. Specific study location descriptions

The study site description takes up the locations with reference to the two upper catchments, a brief account on the village demography, and the specific pedon locations within the defined toposequence.

4.1. The Miarayon sub-catchment

Figure II-2 shows the map of Miarayon which is located at the remotest part of the Batang River sub watershed of the upper Cagayan de Oro River watershed. Figure II-3 is the portion the Geomorphological Map of Talakag depicting the Miarayon sub-catchment. Miarayon is geographically located at 8°01’15”N and 124°47’25”E and it is one of the *barangays* (villages) of the Municipality of Talakag, Bukidnon which is positioned at the northwest slopes of Mt. Kalatungan. Miarayon is 54 km south of Cagayan de Oro City.

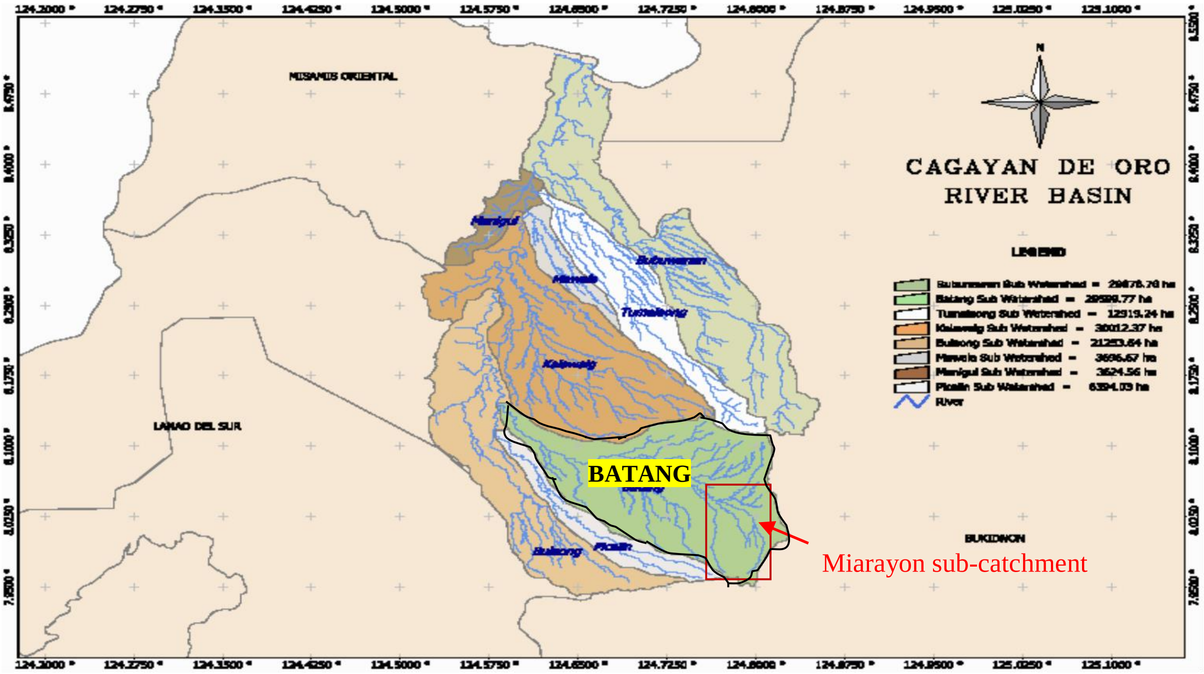


Figure II-2. Cagayan de Oro River watershed map showing the Miarayon sub-catchment within the Batang catchment. Source: DENR Region 10 (2014)

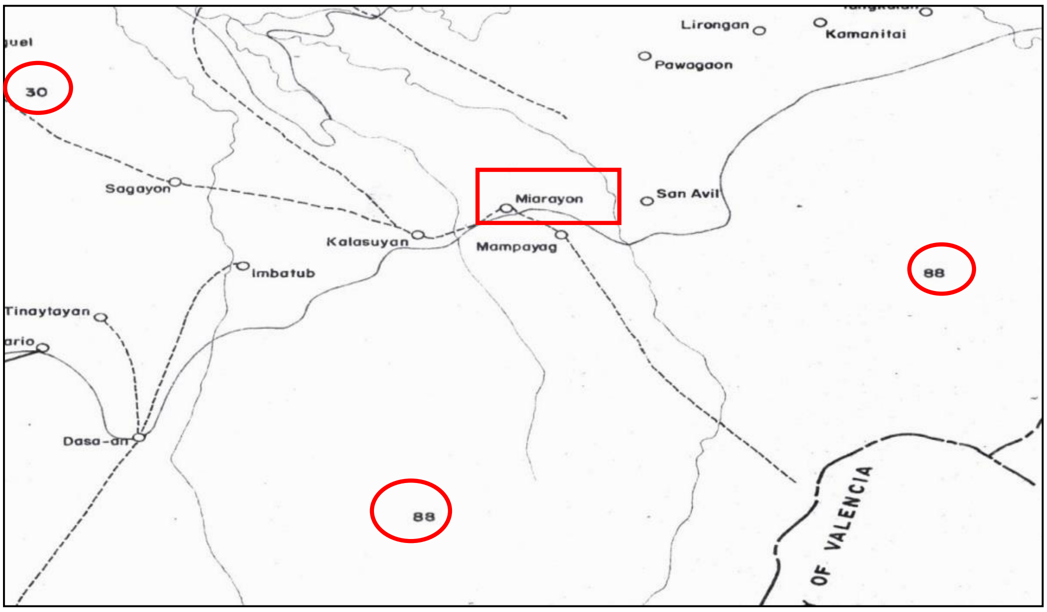


Figure II-3. Geomorphological map of Miarayon sub-catchment.
Scale: 1:50,000
Legend: 30 (undulating upper volcanic footslope) and 88 (volcanic mountains)
Source: Bukidnon Provincial Development Staff (1989a)

The area is accessible via the national highway passing through the Talakag-Lantapan thoroughfare that connects to Cagayan de Oro City at the northwest and Malaybalay City at the east. With an estimated population of 2,602 (NSO, 2011), the community belongs to the *Talaandig* indigenous group, although some members are the *Dumagat* (migrants from the sea or the low landers and other Christian settlers), the Muslims and the *Igorot* (the resettled indigenous groups from northern Philippines).

Miarayon has upper volcanic footslopes and undulating volcanic mountains. The upper slopes and crests of Mt. Kalatungan which separate the municipalities of Talakag in the northwest and Pangantucan in the south are very steep and the middle slopes where Miarayon is located are moderately steep to steep gradients with very long, moderately regular to parallel and generally straight slopes which have deeply dissected gullies with narrow stream divides (CENRO-Talakag, 1999). The studied toposequence is on a long volcanic mountain footslope at the northwest side of Kalatungan. Excluding the forested summit (>1,900 m asl), the toposequuence is divided into the following three parts: (i) the upper part (1,900 to 1,600 m asl), the intermediate part (1,600 to 1,400 m asl) and the lower part (1,400 to 1,300 m asl). The center of Miarayon is located at the intermediate part at approximately 1,450 m asl (Figure II-4).

Figure II-4. Miarayon position relative to Mt. Kalatungan, Talakag, Bukidnon. (Photo credit: L. Bock)

4.2. The Bendum sub-catchment

Located at the eastern upper Pulangi watershed in the Bukidnon part, Bendum is one of the hamlets of Barangay Busdi, Malaybalay City (Figure II-5). Based from the Apu Palaguwan Cultural (APC) Education Center, its geographical location is 8°17’3’ North and 125°16’4” East. A small sub-village, Bendum has 55 households with 309 inhabitants (Richelle, 2010). Ethnicity within the community is composed of the *Pulangiyen* indigenous peoples and the migrants from Bohol and Cebu islands. The migrants resettled Bendum in the late 1980s to early 1990s.

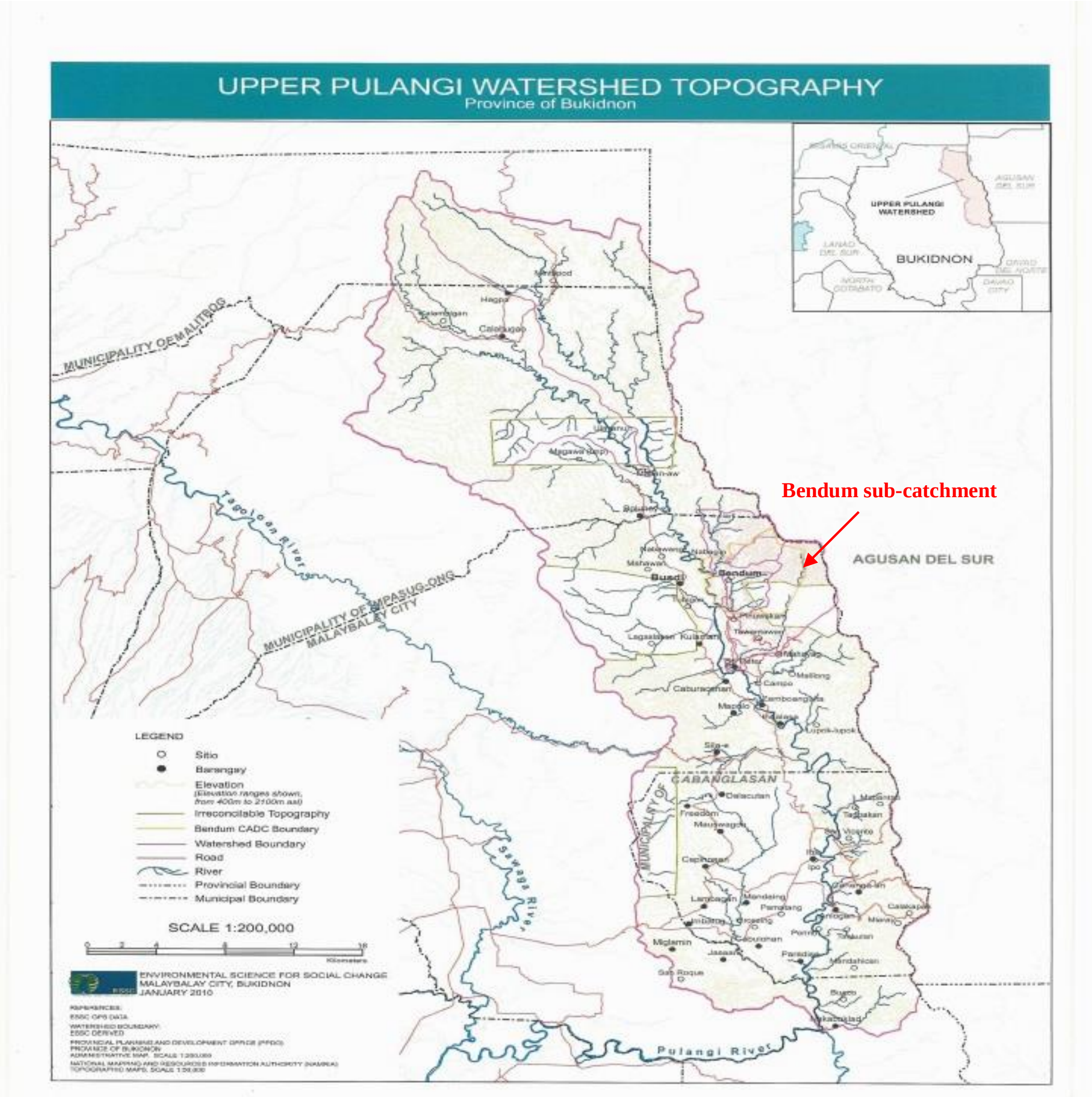


Figure II-5. Upper Pulangi River watershed and the Bendum sub-catchment.
Source: ESSC (2010)

Figure II-6 presents the geomorphological map of the Bendum sub catchment in a 1:50,000 scale. The geomorphological classifications of Bendum vicinities are volcanic mountains, low relief volcanic agglomerate hills, low relief shale/sandstone hills and level to gently sloping collu-alluvial terraces. Bendum is a closed area and generally the vegetation is forest (Figure II-7). Natural forests of mossy and primary growths are found at above 1,000 m asl and secondary growths at lower elevations. Rubber and coffee are Bendum's two dominantly grown tree crops.

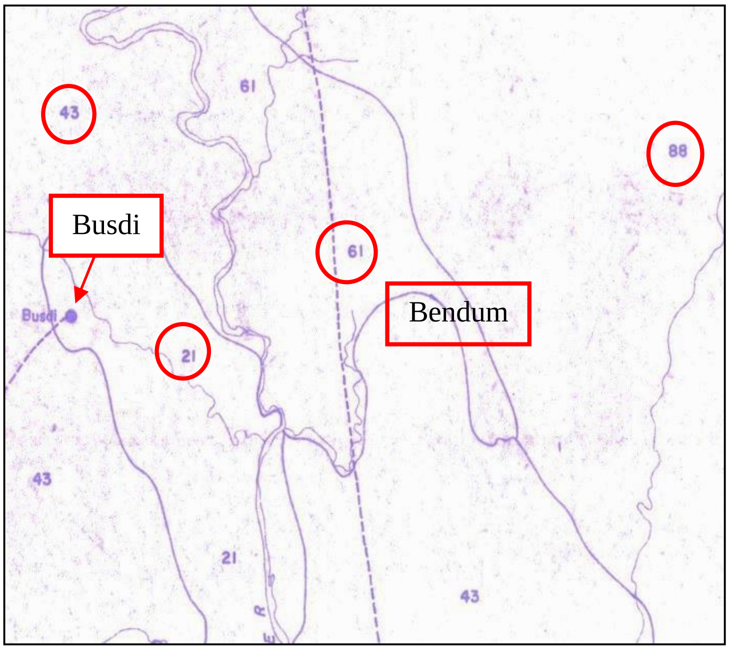


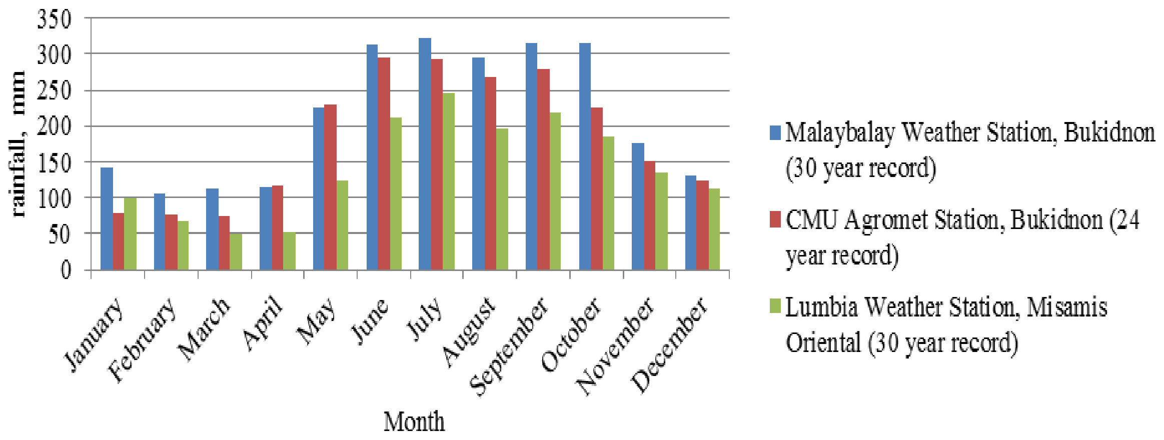
Figure II-6. Geomorphological sketch of Bendum sub- catchment (Scale: 1:50,000)
Legend: 21 (collu-alluvial terraces), 43 (shale/sandstone hills), 61 (volcanic agglomerates), and 88 (volcanic mountains)
Source: Bukidnon Provincial Development Staff (1989b)

Figure II-7. Bendum is generally a forest area with patches of cultivated plots.
Photo credit: L. Bock

5. The Bukidnon climate

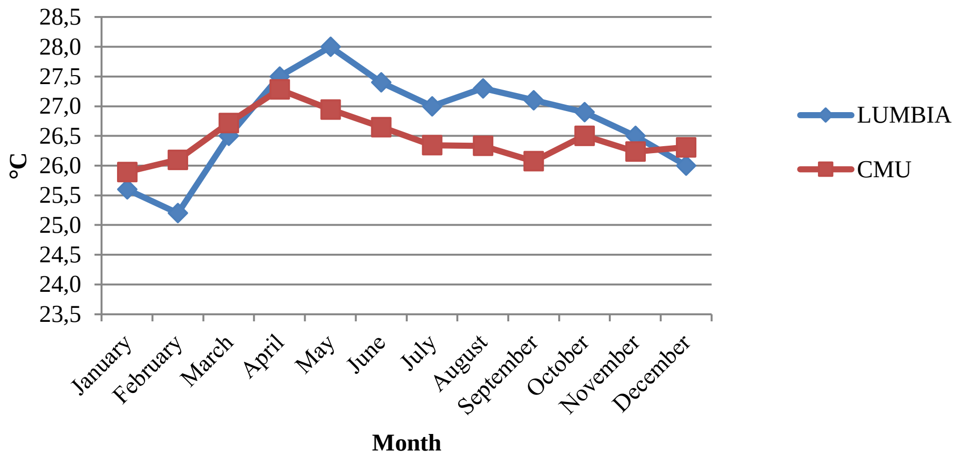
Depending on the age of soil parent materials, influence of climate in soil development had occurred in geologic times which may be different from the present environment. The climate information given is based on the present day data. Climate in the Philippines are classified into four types and the two types that occur in Bukidnon are, Type III in the northern part and Type IV in the southern part (PAGASA-DOST, 2014). Type III has no pronounced maximum rain period but has dry season lasting only for three months. Type IV has a rainfall of more or less evenly distributed throughout the year. Figure II-8 shows the rainfall information in Bukidnon. The 30-year average annual rainfall recorded at Malaybalay weather station located in the northeastern part of Bukidnon is 2,569 mm and in Lumbia weather station positioned at Cagayan de Oro City, central Misamis Oriental is 1,703 mm (PAGASA-DOST, 2014). The 24-year average annual rainfall recorded at Central Mindanao University agro-meteorological station located at central Bukidnon is 2,217 mm (CMU, 2012). Rainfall starts to rise in the month of May and gradually decreases in November. The wettest months are from June to October and the driest months are from February to April. Figure II-9 shows the average temperatures recorded in two meteorological stations. The average temperature in Lumbia

Figure II-8. Mean monthly rainfall record from meteorological stations in Bukidnon and Misamis Oriental, Mindanao, Philippines



Source: PAGASA-DOST (2014) and CMU (2012)

Figure II-9. Average monthly air temperature records of two meteorological stations in Bukidnon.



Source: PAGASA-DOST (2014) and CMU (2012)

is 26.8 °C and in CMU is 26.4 °C. Lowest temperature occurs in the months of January and February and the highest temperatures occur in April and May.

The areas around the volcanic slopes have semi-temperate conditions which can support a broad range of highland crops (SWEMRC, 2013). The 1994-1996 weather data of Manupali Watershed which is near the Miarayon region had an average annual rainfall of 2,825 mm (Poudel *et al*., 2000). For Bendum, the average rainfall intensity recorded in 1997-1998 was 2,213 mm (Walpole, 2002). Miarayon temperature estimation was based on the 24 year average temperature record of 26.4 °C from CMU agrometeorological station having an elevation of 302 m asl (CMU, 2012) and the adiabatic lapse rate of the moist air of 6 °C decrease per 1,000 meter height increase (Donald Ahrens, 2007). Temperature approximation of Miarayon at 1,450 m asl is 19.8 °C which has a little difference from 1994-1996 Manupali watershed average temperature data of 20.3 °C (Poudel *et al*., 2000). Temperature approximation of Bendum at 700 m asl is 24 °C which has only two degrees higher than the 36 months record from 1996-1999 of 22 °C (Walpole, 2002). The temperatures between Miarayon and Bendum do not drastically differ. Therefore, it can be posited that in the present situation, the effects of temperature on the soil weathering process between the two sites is not significantly different because the duration of soil formation is at geological time scale.

6. Bukidnon's geological background and associated rocks

The archipelago which is located in the Pacific seismic belt is the outcome of a complex series of geologic events that involved continental rifting, oceanic spreading, subduction, ophiolite obduction, arc continent collision, intra-arc basin formation and strike-slip faulting which is subdivided into tectonic-stratigraphic blocks, the Palawan-Mindoro Continental Block (PCB) and the Philippine Mobile Belt (PMB) (Aurelio *et al*., 2012). PMB's cretaceous ophiolites strung along the eastern Philippines, which include the northern and southern Mindanao (Aurelio *et al*., 2012) which is described as the undifferentiated volcanic formation in Bukidnon during the Createaceous-Paleogene period which are products of submarine igneous activities (Bukidnon Provincial Development Staff, 1985).

The Philippine fault is the result of the collision of two plates, the northwest moving Philippine Sea plate in the east and the Sunda/Eurasian plate in the west (Yu *et al*., 2013). In Central Mindanao, ash and lapilli that are found along the Philippine Fault represent young andesite to dacitic volcanism (Sajona *et al*., 1997). The Central Cordillera at the eastern portion of Central Mindanao west of Agusan-Davao Basin has north-south string of Quaternary volcanoes from Camiguin Island to Mt. Apo (Sajona *et al*., 1997). Quaternary volcanoes west of Central Cordillera and several of them are active volcanoes which are Mts. Hibok-hibok and Vulcan in Camiguin islands and Mts. Kalatungan, Ragang and several minor cones in mainland Mindanao (Sajona *et al*., 1997). The highland areas which are the specific locations of this PhD research study are Mt. Kalatungan where Miarayon is located and the western side of Pantaron Range at the Central Cordillera where Bendum is sited. Geological formation and rocks of Bukidnon are described in Table II-2. Two stratigraphic units of Bukidnon are illustrated in Figure II-10.

Table II-2. Rock and geological formations of Bukidnon, Northern Mindanao, Philippines.

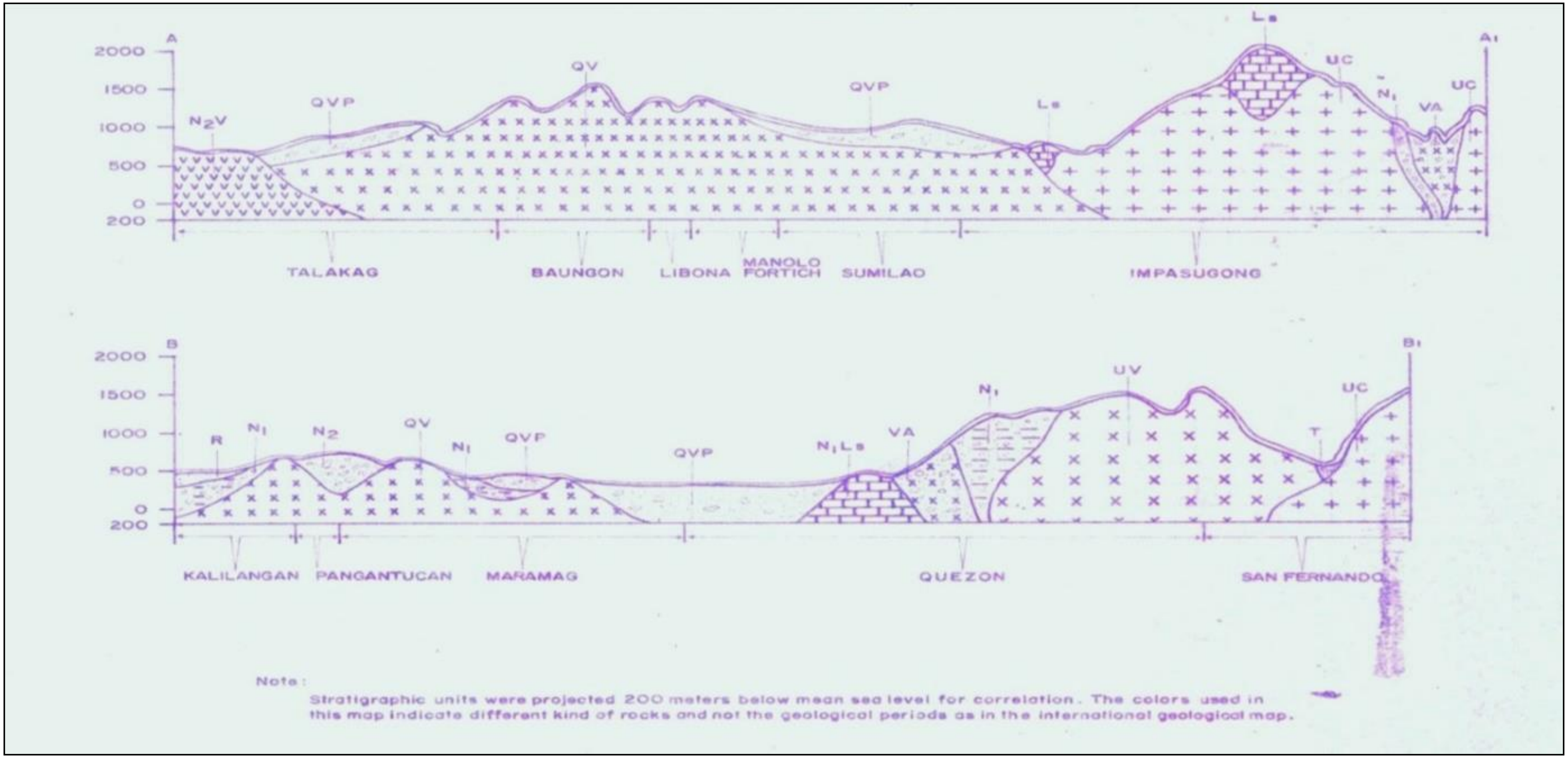
Rocks	Geologic Time Scale	Formation	Map Legend	Description
Sedimentary	Recent	Alluvium	R	Fluviatile sediments in flood plains, oxbows, river basins, fringes of colluviums at the foot of mountains, alluvial fans composed of reworked pyroclastics and basalt fragments.
	Pleistocene	Terraces	T	Fluvial lacustrine deposits of heterogenous

				assemblage of older rock fragments in a silty to sandy matrix. Clay constitutes the top layers.
	Upper Miocene Pliocene	Sandstone and conglomerates	N_2	Shallow sea deposits of sandstone, siltstone, shale, conglomerates and basaltic micro conglomerates, sometimes intercalated with pyroclastics.
	Lower Middle Miocene	Coralline limestone	N_1Ls	Calcareous formation including reef limestone, bioclastic limestone and calcarenite, accented karst limestone.
		Sandstone and shale	N_1	Thick transgressive marine deposits largely massive sandstone layers interbedded with thin siltstone and shale strata.
		Impasug-ong limestone	Ls	Well compacted and subject to slight karst limestone of undetermined age. This should be older than coralline limestone because of stratigraphic position.
Igneous	Pliocene-Quaternary	Pyroclastics	QVP	Volcanic plain or volcanic piedmont deposits, chiefly basaltic pyroclastics (ashes, cinders, bombs, tuff) and other volcanic debris at the foot of volcanoes.
		Quaternary volcanics	QV	Non active volcanic cones and lava flows, mainly basalt, pyroxene andesite with some pyroclastics and basaltic agglomerates intercalation.
	Upper Miocene Pliocene	Basalt and andesite series	N_2V	Submarine lava flows of basaltic and andesitic composition intercalated with pyroclastics of the same composition and clastic sedimentary rocks.
	Oligocene-Lower Miocene	Volcanic agglomerates	VA	Extensive, thick chiefly volcanics consisting of andesitic agglomerates, hornblende andesite either fine grained or porphyritic with some tuff breccia. Tuffaceous shale and greywacke are intercalated with agglomerate.
	Upper Cretaceous Paleogene	Ultrabasics	UC	Undifferentiated ultrabasic rocks, predominantly peridotite, gabbro, dunite, highly fractured and generally serpentinized.
	Cretaceous-Paleogene	Undifferentiated volcanics	UV	Submarine lava flows, largely basalt, spilite and andesite, intercalated with pyroclastics, evident columnar pillow lava.
Source: Bukidnon Provincial Development Staff (1985)				

Central Mindanao was formed by the docking of Eastern and Western Mindanao 4-5 M years ago which is an example of a young collision of two island arcs, the Halmahera and Sangihe arcs that are devoid of continental basement (Sajona *et al.*, 2000). The whole of Bukidnon is of volcanic origin, except for the southern part which is of sedimentary materials and limited alluvial plains along the rivers (Mariano *et al*, 1955). From the 1985 Geological Map of the Philippines, the rocks in Talakag, where the northern part of Mt Kalatungan is located, were formed during the Upper Miocene (N_2V) and during the Pliocene-Quaternary period (QV and QVP). Analysis of rock samples from Mt.

Kalatungan revealed that these are fresh calc-alkaline basalt and moderately fresh shoshonitic basalt and andesite. (Sajona *et al.*, 1997). Calc-alkaline basalt are under-saturated, melanocratic, with abundant olivine, slightly calcic-augite and richer in Na_2O and K_2O than tholeiitic facies. Shoshonitic igneous rocks have high total alkalies, low iron enrichment and are near- saturated silica that is associated with calc-alkaline island-arc subduction volcanism. Sedimentary rocks which are reef limestone formation that are associated with different rock ages are found in high mountains in the Philippines including along common border of Bukidnon, Agusan and South Cotabato and Davao Oriental in Mindanao (Raymundo *et al*., 1985).

Stratigraphy of Impasug-ong (Figure II-10) that encompasses the location of the Upper Pulangui watershed revealed that rocks were formed during the periods of Upper Cretaceous-Paleogene (UC), Oligocene-Lower Miocene (VA), Lower Middle Miocene (N_1 and Ls) and the Pliocene-Quaternary (QVP). Figure II-11 shows the portion of the geological map of Miarayon and Bendum. Miarayon formation is QVP. Bendum vicinity has UC, VA and sandstone and conglomerates during the Upper Miocene Pliocene (N_2) period.



Note:
Stratigraphic units were projected 200 meters below mean sea level for correlation. The colors used in this map indicate different kind of rocks and not the geological periods as in the international geological map.

Figure II-10. Stratigraphic units of Bukidnon geology.

Scale: Vertical 1:50,000; Horizontal 1:400,000

Legend: UV (Cretaceous Paleogene undifferentiated volcanics), UC (Upper Cretaceous Paleogene ultrabasics), Ls (Lower-Middle Miocene Impasug-ong limestone), N_1 (Lower Middle Miocene sandstone and shale), N_1Ls (Lower Middle Miocene coralline limestone), VA (Oligocene-Lower Miocene volcanic agglomerates), N_2V (Upper Miocene Basalt and andesite series), QV (Pliocene-Quaternary volcanics), QVP (Pliocene-Quaternary pyroclastics) and R (Recent alluvium).

Source: Bukidnon Provincial Development Staff (1985)

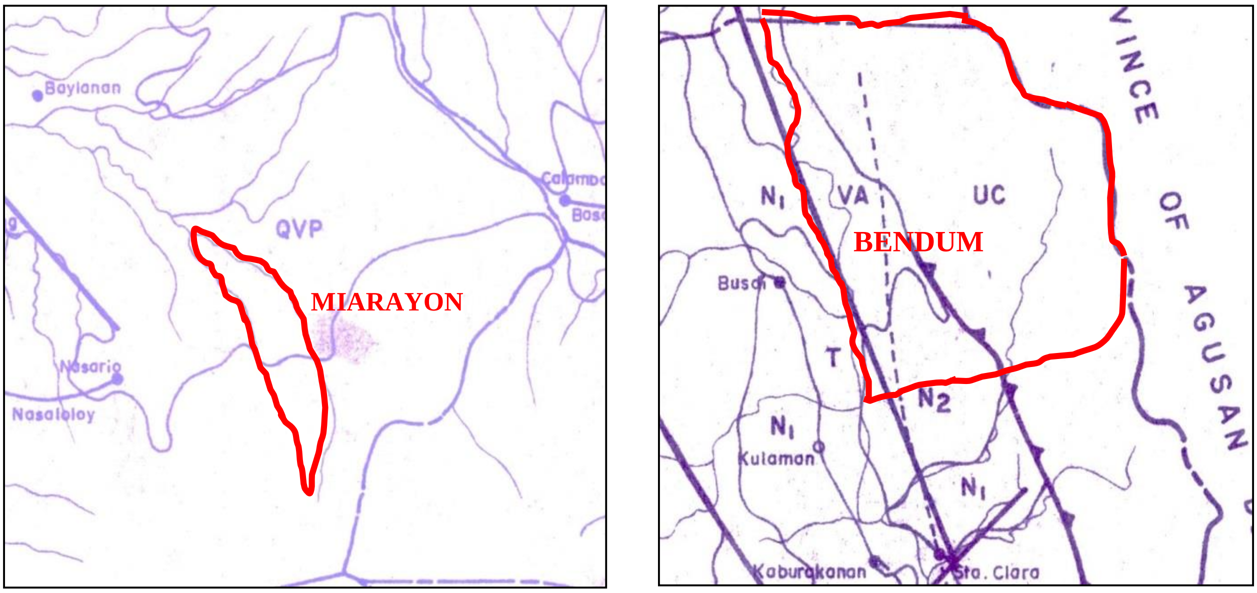


Figure II-11. Portion of geological maps of Miarayon and Bendum
Scale: 1:200,000
Legend: UC (Upper Cretaceous Paleogene ultrabasics), VA (Oligocene lower Miocene volcanic agglomerates), N_2 (Upper Miocene-Pliocene sandstone and conglomerate) and QVP (Pliocene-quaternary pyroclastics).
Source: Adapted from Bukidnon Provincial Development Staff (1985)

7. Bukidnon soils in perspective

The first soil resources inventory in the Philippines started in Batangas in 1903 by Clarence W. Dorsey, which focused on soils for abaca. Much progress was made in the late 1920s, when Dr. Robert Pendleton worked on the sugar lands of Negros Island and simultaneously trained Filipino students (Raymundo *et al*., 1985). The beginning of reconnaissance for soil survey in the Provinces started in 1934, when the National Soil Survey Division was created, but was interrupted during the Second World War (Carating *et al*., 2013).

Soils in the Philippines are grouped according to (1) soil series, (2) soil type, (3) phase of a soil type, (4) complex and, (5) miscellaneous and undifferentiated soils (Mariano *et al.*, 1955). Naming the Philippine soils is by the USDA Taxonomic Classification and nine soil orders are identified namely: Inceptisols (39.%), Ultisols (26.6%), Alfisols (17.1%), Entisols (8.1%), Vertisols (4.5%), Mollisols (3.3%), Andisols (0.23%), Oxisols (0.2%) and some limited Histosols (PCARRD, 2006). Distribution of Bukidnon soils in Order/Great Group classifications with its series are presented in Table II-3. Ultisols occupy a total of area of 49.86% (355,623 ha) of the entire Bukidnon Province and predominates in the plateau. Inceptisols cover a total area 12.04% (95,973 ha). Alfisols cover 7.97% (65,427 ha) and rough broken lands spread over 5.21% (41,905 ha). More than 31% (244,912 ha) of the Bukidnon land are undifferentiated mountain soils and are unstudied. Figure II-12 are the portions of the 1950 Soil Map of Bukidnon (Mariano *et al.*, 1950) which is until now is being used in the Province. These figures show the soils of the two study sites (a) Miarayon, Talakag and (b) Bendum, Malaybalay. Soils in Miarayon at the lower slopes belong to the Kidapawan clayloam (211) and undifferentiated mountain soils (45) in the upper part. Soils in Bendum are all undifferentiated mountain soils (45).

Table II-3. Soils in Bukidnon, Northern Mindanao, Philippines

Topographic Groups(1)	Soil Series(1)	Parent Material(1)	Soil Order/ Great Group(2)	Distribution(1)
Alluvial soils	Maapag clay	Alluvium	Inceptisol	Lowland plains in Managok, Minlawan, Simaya, Nabago, Maapag and Dagatkidavao that covers an area of 2.49%.
	San Manuel silt loam	Recent alluvium deposit	Inceptisol/ Dystropepts	Small areas along Pulangui River near Valencia and south-east of Dologon and covers 0.57% of the provincial area.
	Mailag clay loam	Abandoned river bed	Inceptisol	Found in Mailag and part of the plain of southwest of Maramag with area coverage of 0.23%.
Soils on plateau	Adtuyon clay	Volcanic lava or lahars composed of mixed boulders (basalt and andesite)	Ultisol/ Paleudults, Hapludults	Mostly covers the Bukidnon Plateau, total area is 205,124 ha or 25.52% of the Province
	Kidapawan clay	Similar to Adtuyon clay (presence of boulders)	Ultisol/ Hapludults	Total area covered is 139,189 ha or 17.30%, occurs in the lower slopes of Kitanglad and Kalatungan and in the south and west of Kibawe
	Jasaan clay	Volcanic materials	Ultisol/ Hapludults	Occurs in Alae and its vicinity in the north and central part adjoining Misamis Oriental with 0.95% area coverage.
	Calauaig clay	Metamorphic rocks (Schist)	(no classification)	Total area is 4,363 ha or 0.54% of the Province, found in the low grassy hills east of Malaybalay
	Faraon clay	Limestone	Inceptisol/ Eutropepts	Occurs in the low limestone hills between Kisolon and Tankulan, in three separate hills along Sayre Highway and Kibawe in the southern part. Total area is 10,296 ha or 1.28% of the Province.
	Bolinao clay	Limestone residues	Inceptisol/ Eutropepts	Occupies 1,952 ha or 0.25% of the Province and occurs in the north-western part of Bukidnon.
	Alimodian clay	Sedimentary rocks (shale)	Alfisol/ Hapludalfs	Covers 15,726 ha or 1.79% of the Province. These are the low smooth hills north and north-west of Tankulan and the hills in Kiliog.
	La Castellana clay	Igneous materials (mainly basalt and andesite)	Alfisol/ Hapludalfs	Total area is 45,254 ha or 5.63% of the Province. Covers Musuan Volcano and similar hills west of Maramag.
	Tacloban	Shale and	Alfisol/	Total area is 4,447 ha or 0.55% of the

	clay	associated rocks	Hapludalfs	Province and occupies the southern part of adjoining Cotabato Province
	Macolod clay	Weathered volcanic materials	Inceptisol/ Eutropepts	Covers an area of 52,921 ha or 6.58% of the Province and occupies the southern part of the Province along Pulangui and Muleta Rivers
Miscellaneous land types	Rough broken lands		Occurs east of Impasug-ong continuing to a large portion of Malitbog in the northern part of the Province with coverage area of 5.21%.	
	Mountain soils, undifferentiated		Mt. Kitanglad, Mt. Kalatungan and the whole portion bordering the Agusan and Davao Provinces: Pantadon Range and Mt. Malambo. This covers 30.47% of the entire province.	
Source: $^{(1)}$Mariano et al (1955) and $^{(2)}$PCARRD (2006)				

Although, it was mentioned that most of the Bukidnon soils are derived from volcanic

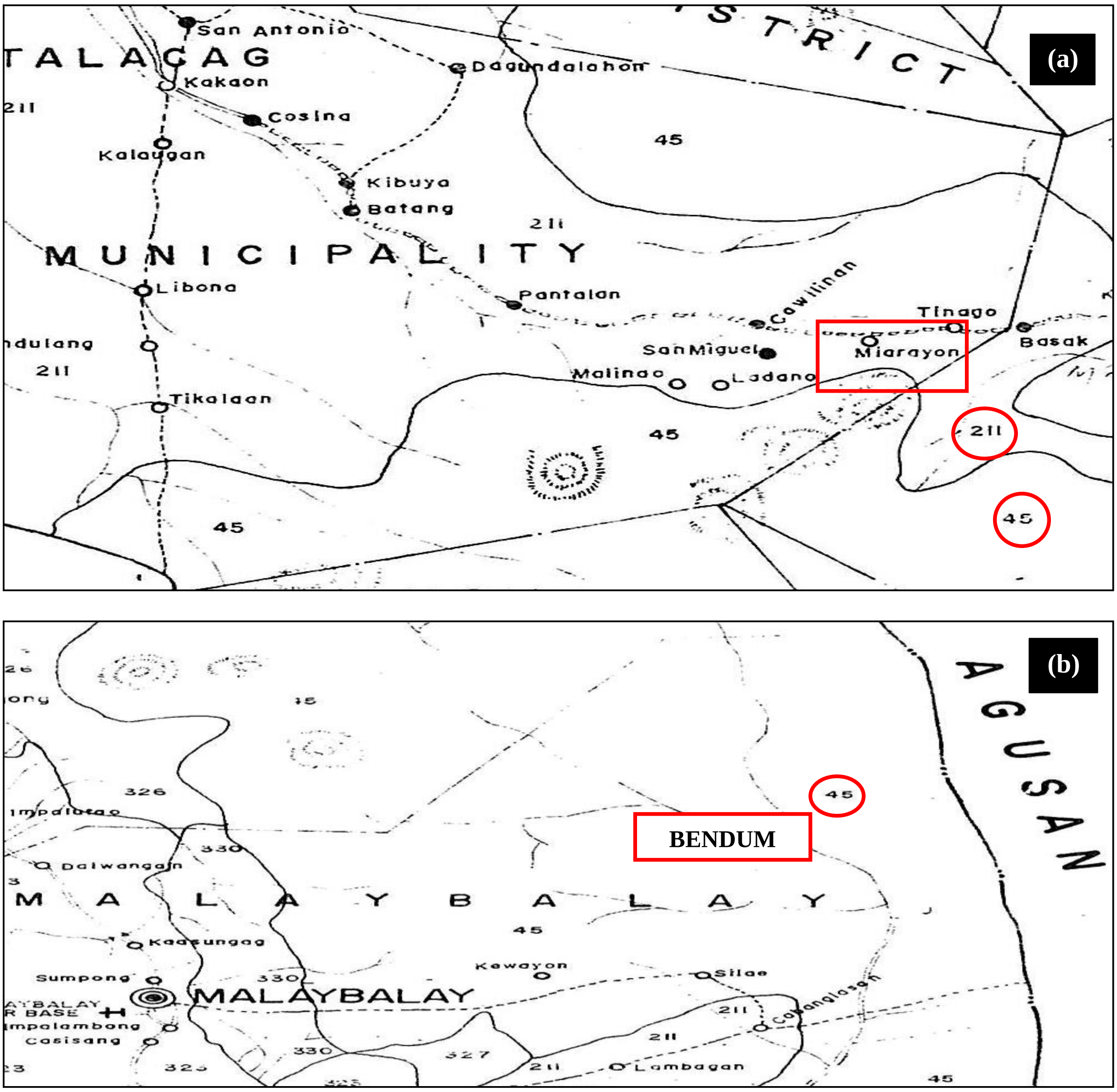


Figure II-12. Portions of Bukidnon Soil Map showing (a) Miarayon, Talakag and (b) Bendum, Malaybalay.
Scale: 1:250,000
Legend: 45 (undifferentiated mountain soils), 211 (Kidapawan clayloam)
Source: Mariano *et al.* (1950)

materials, there is no Andisol (in USDA Soil Taxonomy) or Andosol (FAO-WRB Classification) that is reflected in the soil map. Soils with andic properties are produced by moderate weathering of mainly pyroclastic materials. The diagnostic criteria of soils with andic properties by IUSS Working Group WRB (2006) are: (1) $\geq$2% $Al_{ox} + ½ Fe_{ox}^2$, (2) bulk density of $\leq$0.90 kg dm^{-3}, (3) phosphate retention of $\geq$85%, (4) with organic carbon <25% by mass and (5) meets requirements of an albic horizon if occurring under tephric materials. Navarrete *et al*. (2009) posited important pedogenic processes that formed the soils that are derived from basaltic rocks are weathering, loss of bases, acidification, desilification, ferrugination, clay formation, translocation and structure formation.

8. Mineralogical studies on Bukidnon soils

Information on rocks and minerals are useful in identifying the degree of weathering and the elements that can be found in soils which can be verified by soil laboratory analyses. Allophanes and imogolites are indicators of volcanic material derived soils (Poudel and West, 1999; Bertrand and Fagel, 2008; Kimsey, *et al*, 2011; Levard *et al*., 2012; Mileti *et al*., 2013). Study on steep lands in Bukidnon namely: San Jose, Sabacan, Himaya and the alluvial plains of Musuan, Maramag revealed the presence of gibbsite, quartz, halloysite and goethite (Auxtero, *et al*., 1996). In a study in Intavas, Impasug-ong, at elevation of 1,200 m asl, hornblende, weathered particles composed of mica, quartz and volcanic glass, gibbsite and halloysite were detected (Bacatio, *et al*., 2005). In the volcanic slopes of Mt. Kitanglad, halloysite, gibbsite, goethite, hematite and cristobalite were identified and the presence of allophanes and imogolites were detected (Poudel and West, 1999) which are associated with rocks or materials of volcanic origin.

9. Bukidnon soil types and morphology review

In Bukidnon, most of the soils are of volcanic origin (Mariano *et al*., 1955) and therefore this gives the possibility of the presence of Andisol in the province. Only few studies have conducted on the physico-chemical and mineralogical properties, genesis and classification of soils in Mindanao and Bukidnon (Auxtero *et al*., 1996; Bacatio *et al*., 2005). In Bukidnon, there are mountain soils that are not studied yet. These areas may give more information on the potential existence of Andisols in the Province.

Soils in steep lands and uplands of Sabacan, Himaya and San Jose are classified, using the USDA Soil Taxonomic Classification, as Typic Hapludalf and Lithic Dystropept and the alluvial plains in Musuan are Typic Tropaquept (Auxtero *et al.,* 1996). The Typic Hapludalf soils are deep, well drained soils suitable for upland cultivation but Lithic Dystropept soils require proper drainage as these are underlain with hard rock at 50 cm of the mineral surface. The soils that were utilized for rice are the Typic Tropaquepts. Intavas soils which represent cultivated, highland marginal soils are classified as Oxic Dystrudepts (Bacatio *et al*., 2005). Poudel *et al*. (2000) identified the soils in the geomorphic units of Manupali Watershed according to FAO classification system as: soils in the Mountains (1400-1900 m asl) as Silic Andosols, Haplic Acrisols and Dystric Cambisols, in the Upper (700-1400 m asl) and Lower Footslopes (370-700 m asl) soils were Lixic Ferralsols similar to those in alluvial terrains.

In the 1950 Bukidnon Soil Map, no soil is classified as Andisol Soil Order or Andosol Soil Group although most of the soil parent materials are of volcanic origin. Mineral weathering can dramatically change soil mineralogy and chemistry (Mileti *et al*., 2013) and as cited by Poudel and West (1999), during the weathering process Andisol loses its unique properties and changes into other Soil Orders including Inceptisol, Alfisol, Entisol, Oxisol, Spodosol, Vertisol, Mollisol and Ultisol. Andic properties can be retained if the soil is undisturbed or protected. The study of Tsui *et al*. (2013) revealed that Andisol are found at higher elevations and in locations of thick vegetation growth. In the tropics, the resilience of Andepts (the Sub Order of Inceptisol) by older volcanoes or earlier are rare, except in higher altitudes, because their evolution to other soil groups is comparatively a rapid process because of warmer temperature (Foss *et al*., 1983).

The Philippines have soils which were classified as Andepts; the Hydric Dystrandepts (inclusion of Tigaon series) that are found on the slopes of Mt. Isarog, Camarines Sur, the Hystrandepts around 800 m elevation in Mt. Makiling of Laguna Province (unclassified areas), possibly Eutrandepts on the slopes of volcanic peaks (Raymundo *et al.*, 1985). Similarly, Foss *et al.* (1983) had noted the presence of Eutrandepts near Los Banos, Laguna. In Bukidnon, there are unclassified areas which are around volcanic mountains, such as in Mt. Kitanglad, Mt. Kalatungan. The whole portion bordering Agusan and Davao Provinces, Pantadon Range and Mt. Malambo have no information on soils. Pedological research in Bukidnon are not intensified, thus information on soils with “andic” characteristics are scarce.

10. Physical characterization of Bukidnon soils

The 1955 Soil Survey Report of the Bukidnon Province had summarized the physical description of the soils according to horizon depth, color, texture, moisture, stoniness, compactness, soil structure, consistency, root penetration, occurrences of mottles, internal and external drainage (Mariano *et al*., 1955). Auxtero *et al*. (1996) made soil descriptions as follows: (1) Typic Hapludalf and Lithic Dystropept on the steep lands of Sabacan, Himaya and San Jose are coarse-textured, with moderate to coarse sub-angular blocky structure subsoil, while on the uplands are fine-textured with granular to weak sub-angular blocky structure, (2) Typic Hapludalf and Lithic Dystropept are more friable when dry than Typic Tropaquept of the alluvial soil, (3) in Typic Tropaquept, the rising of the water table has affected the soil colors and mottles in the subsoil and zones of low chroma indicate the occurrence of reduction-oxidation process. Poudel and West (1999) described the soil morphological unit in Manupali Watershed as follows: the surface horizons of all pedons were brown to dark brown, has fine to medium granular structure and are very friable to friable when dry and moist consistency. Water retention is high because of the allophanes and allophane-like materials. Intavas soil, which is classified as Adtuyon clay, (Mariano *et al.*, 1955) has very dark aggregate surfaces that become lighter in the lower horizons, fine loamy texture, slightly sticky and plastic with bulk density that ranged from 0.85 to 1.18 kg dm^{-3} (Bacatio *et al*., 2005).

11. Chemical characterization of Bukidnon soils

Patches of studies were conducted on the chemical properties of soils which may denote the status of soil fertility in the Province like soil pH, soil organic carbon, available phosphorus and cation exchange capacity. The soil pH, otherwise referred to as the soil reaction, provides information on the acidity or basicity of the soil that indicates the chemical properties of the soil and its influence on the nutrient availability. Table II-4 shows the soil pH values derived from these soil studies in highland areas of the Province. Soil pH in Bukidnon is generally acidic. St. Peter is close to the foot of Pantadon Range, which is the barangay adjacent to Bendum, and San Jose is in the eastern part of central Bukidnon. Sungco, Kibangay and Manupali watershed are within the footslopes of Mt. Kitanglad. Miarayon, Lirongan and San Miguel are located on the footslopes of Mt. Kalatungan. San Jose is located south of Malaybalay City, Sabacan, Himaya and Musuan areas are located in Maramag Muncipality, which are heading towards the southern part of Bukidnon.

Table II-4. Soil pH values in some highland locations in Bukidnon, Philippines.

Location	Soil pH (H_2O)	Land Use	Sources
St. Peter, Malaybalay (near Bendum)	5.5-6.0	Cultivated	CAO (2010)
Intavas, Impasug-ong	4.8-5.6, at plow layer, 5.0	Cultivated lands	Bacatio *et al.* (2005)
Sungco, Lantapan	5.5	Vegetable areas	Holmer (1997)
Kibangay, Lantapan	5.6	Vegetable areas	Lapoot *et al.* (2010)
Manupali Watershed, Lantapan	4.2-6.3, mean 5.4	Forest and cultivated lands	Poudel and West (1999)
Miarayon, Talakag	5.1	Vegetable	Tatoy *et al.* (2001)
Lirongan, Talakag	4.9	Vegetable areas	
San Miguel, Talakag	5.1	Vegetable areas	
San Jose, Malaybalay	5.1 (topsoil), 5.0 (subsoil)	Forest areas	Auxtero *et al.* (1996)
Sabacan, Maramag	5.1-5.3 (topsoil), 5.0-5.2 (subsoil)	Forest areas	
Himaya, Maramag	4.9-5.6 (topsoil), 4.6-5.5 (subsoil)	Forest areas	
Natural Forest, CMU, Musuan, Maramag	5.7-5.9 (topsoil), 5.5 (subsoil)	Forest areas	
Pasture, CMU, Musuan, Maramag	4.8-5.1 (Ap horizon), 4.8-5.0 (subsoil)	Grasslands	
Rubber, CMU, Musuan, Maramag	4.9 (topsoil), 5.0 (subsoil)	Agroforest lands	

Volcanic soils have generally high in SOM compared to non-volcanic soils (Sandoval *et al.*, 2007) due to the fixation of organic materials by amorphous materials in soils. The slow mineralization of SOM in volcanic soils inhibits the release excessive carbon (C) through time and therefore C is conserved in the soil. The SOM of Bukidnon soils varies from low to high depending on the location. SOC values in Intavas soil is 4.3% which irregularly decreases at depth (Bacatio *et al*., 2005). The SOC values in the Miarayon region are as follows: in Lirongan, 9.3%, in Miarayon, 17.2% and San Miguel, 18.3% (Tatoy *et al*., 2001).

Volcanic soils have extremely high P retention (Poudel and West, 1999; IUSS Working Group WRB, 2006; Mejias et *al*., 2013), so that 85-90% of inorganic Phosphorus (P) that is added to the soil will be unavailable to crops (Mejias *et al*., 2013). PCARRD (2006) had mentioned the unavailable forms of P as follows: (1) apatite, an original source of P, (2) Ca, Fe and Al phosphates are secondary sources, and (3) organic combinations. At low pH (<5.5) phosphate ions combine with Fe and Al, and at high pH (>8.0) with Ca to form compounds that are not readily available to plants (Landon, 1991). Holmer (1997) found out that only 3% of the total samples analyzed have available P >25 mg kg^{-1} by Bray 2 method. The P retention of surface horizons of mountain pedons in the upper Manupali watershed ranged from 94-98%, while the other pedons had ranged from 63-81% (Poudel and West, 1999). Intavas soils have P retention range of 58-78%, with the plow layer having the highest values (Bacatio *et al.*, 2005). The surface soil has relatively high P retention. This is because it is affected by the deposition of volcanic materials on top of pre-existing soils that made up the recent soils which are substantiated by its dark soil color and high organic carbon residency.

Cation exchange capacity (CEC) assesses the overall soil potentiality, the possible soil response to fertilizer application and a guide in identifying the clay minerals in soils (Landon, 1991). The CEC values of mountain soils in Manupali watershed ranged from 7.5-24.2 $cmol_+$ kg^{-1}, in the upper footslopes, 5.0-21.7 $cmol_+$ kg^{-1} and for the lower footslopes. 9.0-24.2 $cmol_+$ kg^{-1}. The CEC values in Kibangay, Lantapan was 6.34 $cmol_+$ kg^{-1} (Lapoot *et al*., 2010). Intavas soil has CEC range of 7.4-17.3 $cmol_+$ kg^{-1} with the topsoil has the highest (Bacatio *et al*., 2005).

12. Chapter Conclusion

The inequitable distribution of land resources, not only in the Province but the whole country as well, had led the marginal farmers to encroach on highland areas even on fragile slopes. With the changes in demographic and socio economic conditions, the demands of land had also increased. Small patches of farming areas for subsistence eventually will become permanent plots either for food or cash crops.

The choice of Bukidnon Province as the area of the study was based on important and interacting situations in agriculture and soil resource use. First, Bukidnon, is the largest contributor to the agricultural economy and food security of Northern Mindanao, the province however remains to be poor. It is the food basket of the region and its produce is not only for the domestic consumption but also for export. Crop yields at macro-level indicate that Bukidnon has higher values than other provinces in the region in terms of commercial agriculture. Second, there is lack of pedological studies in the Province. Highland soils in Bukidnon are undifferentiated and therefore are unmapped. These areas are supposed to be the frontiers of Philippine agriculture, however, these are already under intensive cultivation. With the lack of soil information, the Province is fitting to be the project site.

Philippine soils are classified according to the USDA Soil Taxonomic Classification and the Soil Series is the pedological mapping unit. With few pedological studies in Bukidnon Province, it was found out that Bukidnon soils are associated with volcanic parent materials. However, the Bukidnon soil map has no soil that is neither classified as Andosol/Andisol nor have ‘andic’ properties qualifier. In the recent pedological studies, only the Manupali watershed study had reported that the mountain soils of the study location are soils that belong to this Soil Group/Soil Order. Soils at higher elevation are still considered as potentially fertile. These are shown by the high SOM and CEC. Because of its volcanic heritage, the soils are generally acidic. Soils in the highlands are increasingly used as crop production sites, even if these are still undifferentiated.

With the soil information gathered, it is deemed necessary to determine the geomorphopedology, soil potentialities and constraints in the highlands of Bukidnon, Northern Mindanao. The choice of parameters that were studied can answer the research questions on the characteristics and fertility statuses of the soils in the region and the underlying factors that influence highland soil development. Findings of this part of the research are discussed in the succeeding chapter.

Chapter III

Geomorphopedology, potentialities and constraints identification of Bukidnon highland agricultural soils, Northern Mindanao, Philippines

1. Chapter Overview

Geomorphopedology is an integration of two important disciplines in earth science, geomorphology and pedology which deals with the arrangement, differentiation and shaping of landforms and the process of soil formation (Gerrard, 1992). Geomorphopedology establishes the balance between the pedological processes that concern with deep soil variation and the geomorphological processes which are responsible for soil erosion and deposition. The toposequence is a concept that is employed in studying the changes in soil morphology which is attributed to the elevational positions and local hydrology across a hillslope (Wysocki *et al*., 2000). In this concept, the soil investigation starts at the ridge and goes down the valley bottom because the movement of soil particles and water is directed downwards. Dalrymple *et al*. (1968) had introduced a hypothetical nine unit land surface model which is defined in terms of morphology and contemporary processes that provides the technique in studying landforms (Figure III-1). As this model is hypothetical, it cannot be assumed that in a studied location all land surface units shall be present or the land surface shall occur as sequenced.

Soil morphology is a body of information for a particular soil type which is taken from an *in situ* investigation through the full description of the soil profile. A soil profile is a vertical section of the soil which shows the different soil horizon characteristics and the soil parent material (Landon, 1991). Soil profile examination can be done by looking into a road cut, digging soil cores using an auger, excavating a soil pit, fully describing the horizons and taking soil horizon samples for laboratory analyses (Landon, 1991; Brady and Weil, 1999; Jahn *et al*., 2006). Constituted soil information are soil horizon thickness or depth, color and mottle occurrence, texture and consistency, structure, compaction, root penetration, biological properties, internal drainage, stoniness and soil pH (Landon, 1991; Jahn *et al*., 2006). Horizons are composed of natural aggregates which are a few

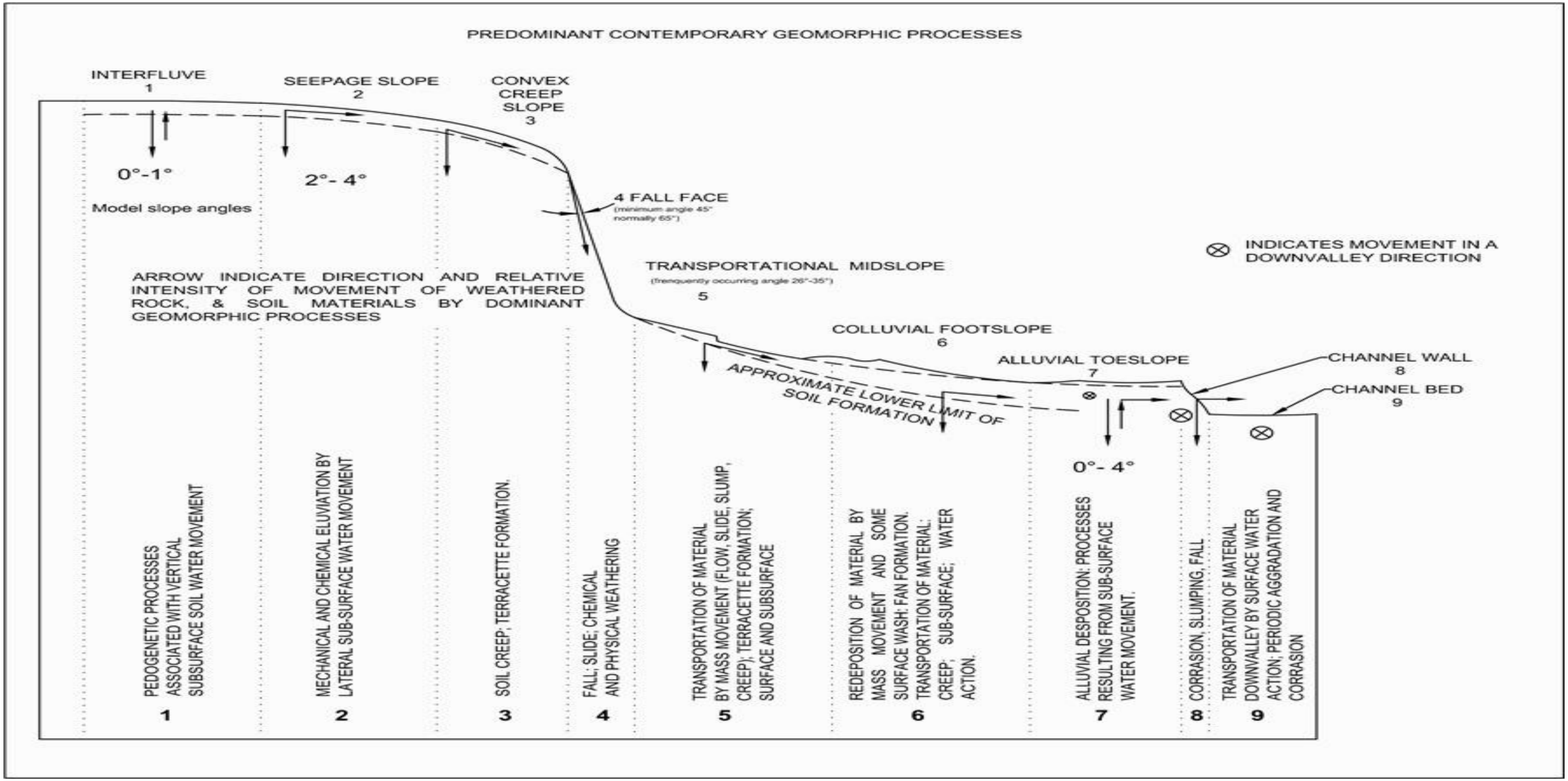


Figure III-1. Diagrammatic representation of the hypothetical nine unit land surface model.
Source: Dalrymple *et al.* (1968)

centimeters thick that reflect the physical, chemical and biological processes which have taken place in the soil (Sumner and Wilding, 2000).

To better understand the soil profile formation, immediate location shall be observed according to its position in the landscape, the presence of rock outcrops, vegetation cover and land use, slope, aspect and soil management. The field observation is the first step in classifying the soil that leads to more detailed studies. Soil morphological data are indispensable information in determining the potentialities and constraints of soils.

Potentialities of a soil are sets of qualities that favor plant cultivation. For instance, by looking into each of the horizon in a soil profile, the thickness of a surface horizon indicates the volume of soil where nutrients are stored which can provide a good environment for plant growth because the penetration of the root system is not restricted. Thick topsoil can also offer convenience in plowing as there would be fewer impediments due to stones and rocks. The statuses of soil chemico-physical characteristics and properties are indicators of a promising soil environment. Soil constraints are those limiting factors that impede crop growth and orientate soil management. These data also come from the physical and chemical studies of the soil profile. These are the soil characteristics and properties that make the soil quality inferior and therefore unfavorable for the growth of crops.

In this chapter, the physical, chemical and mineralogical data that were derived from the study are presented in order to come up with detailed pedological information of the two upper watersheds in Bukidnon Province. The pedon locations relative to the configuration of the landscape were significantly taken into consideration as these critically affect the soil formation. This chapter further presents the details of the research methodologies employed and the study results from both sites.

2. Significance of the study

The Philippine soils need detailed pedological studies to serve as bases for sustainable land management (Navarrete, 2011). Pedological studies in Mindanao (Bacatio *et al*., 2005) and in Bukidnon (Auxtero *et al*., 1996) are scarce. Pedological investigation is essential for in-depth analysis of soils that aid in determining the development capacity of these soils for as many uses as possible. These yield basic information in establishing a working knowledge in understanding the properties (physical, chemical and biological), their dynamics within the soil, their potentialities and constraints.

Several questions should be addressed to contribute to the pool of information of a Soil Reference System for highland soils to substantiate the scientific bases for decisions in using the land. For Bukidnon highlands, particularly Miarayon and Bendum, the following questions were raised.

i. What are the rocks and minerals that are found in undifferentiated soils in Bukidnon highlands? What are the similarities and differences in terms of mineralogical properties? How do they affect soil formation and soil mineral reserve?

ii. What are the soil properties and their classifications? What are the similarities and differences of soil characteristics in different highland locations?

ii. What are the potentialities of highland soils? How do soils in different highland areas compare with each other in terms of these qualities? How do these potentialities contribute to improve crop production?

iv. What are the constraints of highland soils? How do different highland soils compare with each other in terms of these qualities? How do these constraints generally hinder crop production?

3. Objectives of the study

Because geomorphopedological data on soils in Mindanao and likewise in Bukidnon are scarce, the study was conducted to basically generate comprehensive information on morphological characteristics of highland soils, identify their potentialities and constraints. To answer those aforementioned questions, specifically, the study had aimed to: (i) identify the soil mineralogical properties, (ii) characterize the soil and identify their properties in order to classify the soils, (iii) point out the soil potentialities and constraints, and (iv) verify the suitability of crops to the existing soil environment.

4. Methodology

The methodology section presents the summary of both the field investigations and laboratory analyses of the soil samples. The groundwork was initiated to gain preliminary information about the sites and to meet the locales who would be the potential collaborators of the research work. Specific field activities were on augerings and determining toposequences, identifying soil pit locations and soil sampling. Laboratory works were for the analyses for prescribed soil chemical parameters.

4.1. The Miarayon fieldwork

Early stages of the work were made before field investigations had started to ensure that the soil research in Miarayon shall progress. The first visit was conducted from 15 to 17 February 2010 by the PhD student to familiarize the study location and establish rapport with the community. A rapid survey was conducted to have a general appreciation of the accessibility to the areas, the land formations, the predominant crops grown, the community and its leadership system. The formal work started in February 2011 with the geomorphopedological investigation by Lebrun (2011) as the jump start of the soil research in Miarayon. After dealing with the community leaders, the PhD researcher had to negotiate down to the individual land-owner or farmer to gain access to the specific pit and sampling locations.

Field reconnaissance had adopted the framework and methodology in Bock (1994). A total of 36 augerings (Figure III-2) that were distributed along the main toposequence was made during the fieldwork in February to April 2011 (Lebrun, 2011). Another set of 31 augerings were made during the second wave of field work in February to April 2012 to define the transversal toposequences across secondary landforms (Barbieux, 2012). Lebrun (2011) had identified the locations of the nine (9) soil pits that represented the geomorphopedological diversity (dividing line, steep and undulating piedmont), slope forms and steepness within the three classified parts of the toposequence.

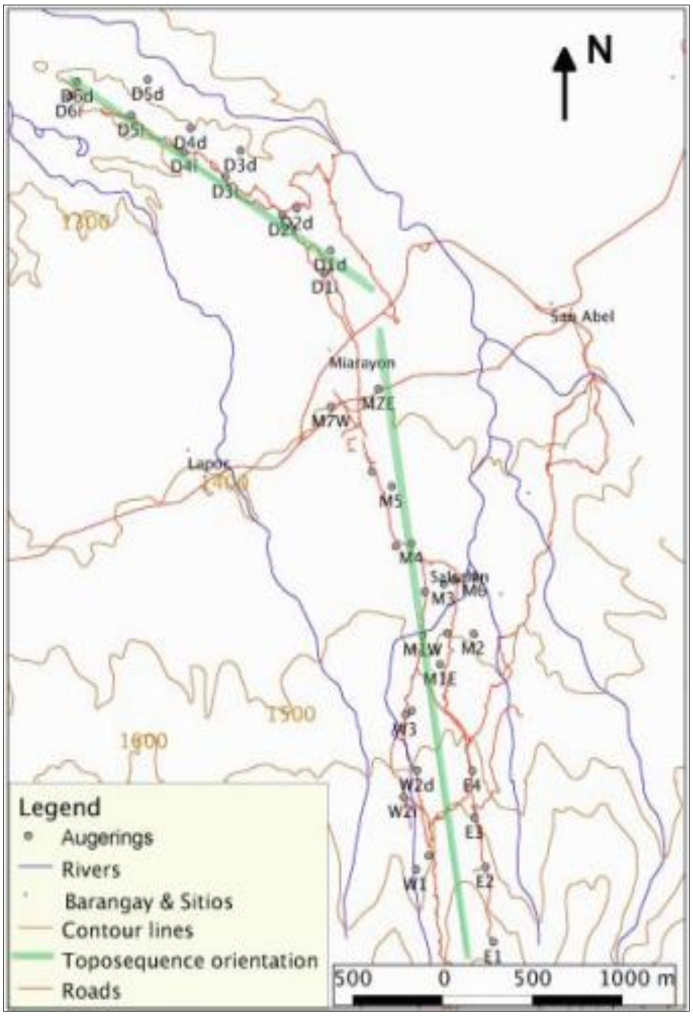


Figure III-2. The path of Miarayon augering series.
Source: Lebrun (2011)

These were described according to Delecour and Kindermanns (1977). Figure III-3 shows the Miarayon toposequence. Soil samples were taken from each pit horizon for laboratory analyses. Soil bulk density samples using 100 cm^3 core samplers were also gathered from each pit location and were brought to the Hydraulics Engineering Laboratory of ULg-GxABT to determine the water retention capacity of the soil. Saturated soil conductivity was measured using the Eijkelkamp tension-infiltrometer and a mini disk infiltrometer to assess the parameter variability along the transversal topsequences (Van Daele, 2012) and soil texture determination was done by feel method.

4.2. The Bendum fieldwork

Unlike in Miarayon, which the direct contact with the community to know the locales were made in several visits, the Bendum groundwork had started through ESSC, the lead partner of the CUD-PIC EPaM Project in the Philippines. The organization took charge in informing the community that a soil research shall be conducted in the area. A visit was made in March 2010 by a student from ULg-GxABT in coordination with ESSC to conduct her research project on the geomorphopedological characterization and agropedological evaluation of Bendum (Richelle, 2010).

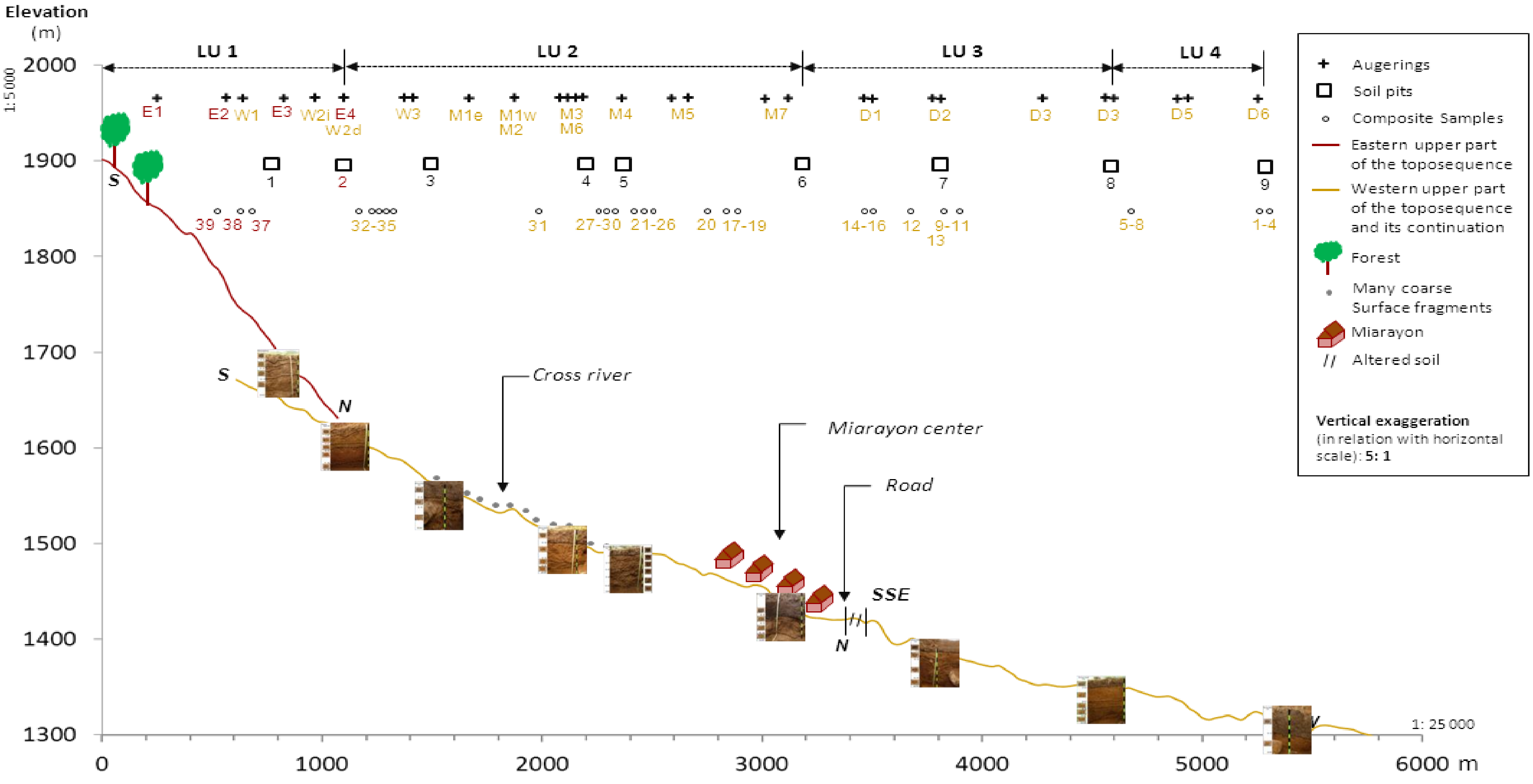


Figure III-3. The Miarayon toposequence. (Adapted from Lebrun, 2011).
Drawing courtesy of Marck Alexis O. Sabines, Geoinformatics Unit, Xavier University, Philippines

A total of 22 augerings were made for the two defined complementary toposequences during the fieldwork in March to April 2010 (Richelle, 2010). The two toposequences had defined the positions of the 13 pedon locations (Figure III-4). Toposequence 1 that defined the top and the middle parts of the sequence, has elevation range of 1,400-800 masl, which is from the mossy forest down to ESSC property, has six pedon locations (BP2, BP7, BP8, BP4, BP3 and BP5). Toposequence 2, that outlined the middle and low parts of the sequence, with elevation range of 900-550 m asl, which is from the sloping grassland, southwest of APC Education Center, down to Pulangui River has defined seven pedon locations (BP10, BP9, BP6, BP14, BP13, BP12 and BP11). Like in Miarayon, all pedons were fully described. However, for the soil classification and analyses of total elements, these were only done in BP3, BP5, BP9 and BP14 because the investigations were focused in Bendum production areas.

Saturated soil conductivity was measured by Van Daele (2012) at the cultivated areas along Toposequence 1 (Pedons BP3 and BP5) and Toposequence 2 (Pedons BP9 and BP14). Van Daele (2012) had also taken soil bulk density samples from the four pedon locations to determine their soil water retention capacity. Soil textural analysis had used the feel method (Lebrun, 2011).

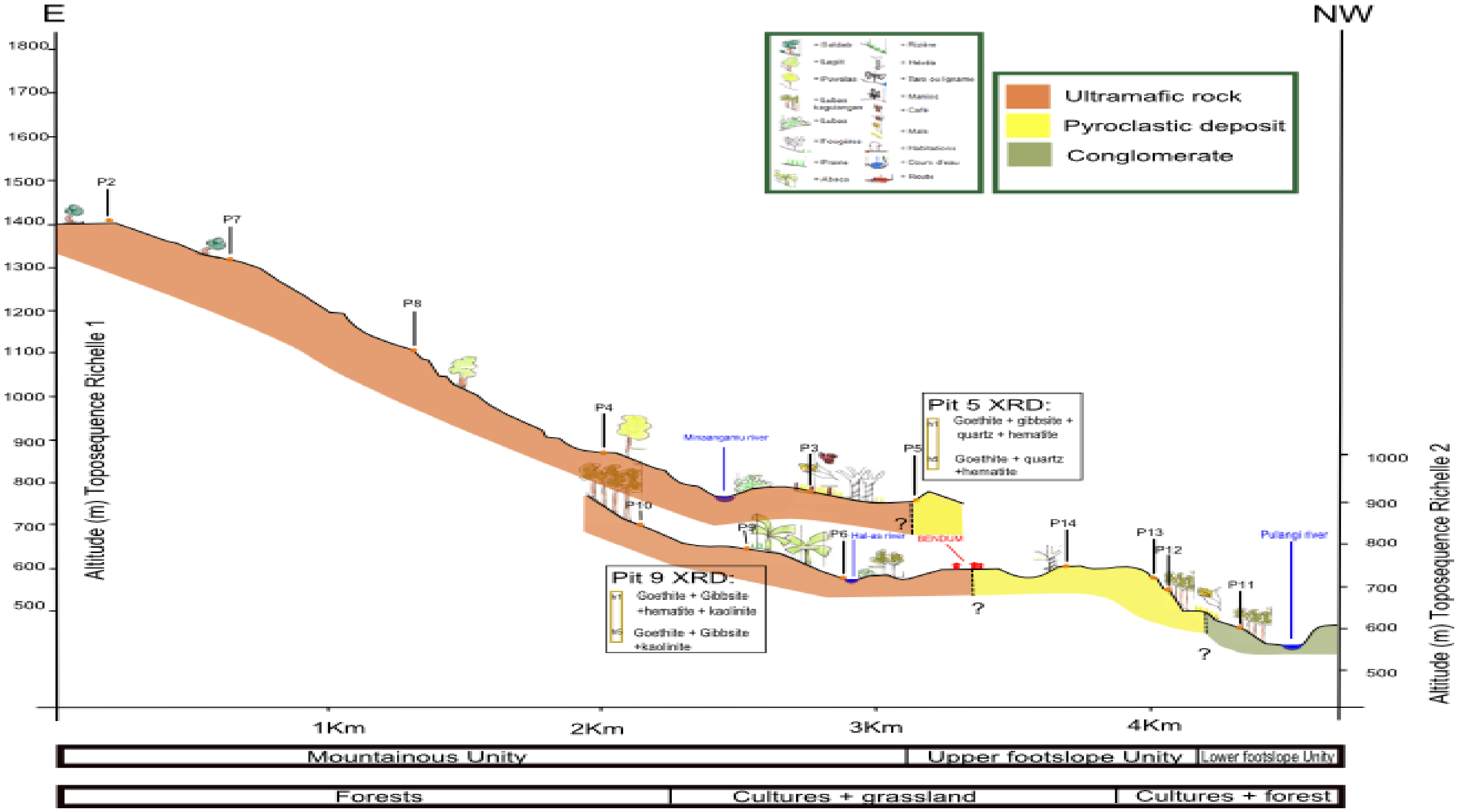


Figure III-4. The Bendum Toposequences
Adopted from Richelle (2010) and redrawn by Maurissen (2014)

4.3. Soil laboratory work for Miarayon and Bendum soil pit samples

For Miarayon, samples from all pits (MP1 to MP9) were analyzed. For Bendum, only samples form the four pits in the production areas were analyzed (BP3, BP5, BP9 and BP14). Taken from individual horizons in each soil pit at different field locations, the soil samples were contained in individual plastic bags and were brought to Xavier University Soil Laboratory, Cagayan de Oro City, Philippines. These were air dried and weights of 200 g from each sample were separated and shipped to the Soil Science Unit of ULg-GxABT, Gembloux, Belgium.

At ULg-GxABT, the soil samples were disaggregated and passed through a 2 mm-size sieve and were then oven dried at 40°C for 48 hours. For total element and organic carbon analyses, 20g of each sample were disaggregated in an agate mortar and then were sieved at 200 µm. The soil pit samples were analyzed at ULg-GxABT Pedology Laboratory. The parameters determined were residual humidity, pH (water and 1n KCl at 2.5:1 ratio), exchangeable acidity and exchangeable Aluminum (Al) using the Yuan method for extraction, and atomic absorption for Al quantification and titration for exchangeable acidity measurement, total organic carbon (TOC) by adapted Springer Klee method, allophanes test by Fieldes and Perrot (1966), cation exchange capacity (CEC), and exchangeable calcium (Ca), magnesium (Mg), potassium (K), sodium (Na) using the Metson method for extraction. Quantification of exchangeable Ca and Mg was done by atomic absorption spectrophotometry (AAS). Exchangeable K and Na were measured through flame emission spectrophotometry (FES). Furthermore, total elements that were analyzed for Miarayon were P, Ca, Mg, K, Na, Al, iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) using the tri-acid mineralization Except for total P which had used the colorimetry with molybdate solution, the rest of all total elements were quantified by AAS. For Bendum, total element analyses were only for Ca, Mg,K, Na, Al and Fe. Complementary analyses for sesquioxides were conducted to check the criteria of possible andic, nitic and/or ferralitic characteristics. Total reserve bases (TRB) was calculated by summing up the total element content on Ca, Mg, K and Na. Free and amorphous Al and Fe were extracted by sodium dithionite-citrate bicarbonate (DCB) solution and by ammonium oxalate-oxalic acid (Blakemore Method) respectively, then measured by AAS. Selected profile samples on oriented powders were subjected to first X-ray diffraction screening to possibly identify the clay minerals. Retention curves at pF 1.0 (midway between saturation and field capacity), at pF 1.6 to 1.8 (field capacity for sand), at pF 2.0 and 2.5 (field capacity for loam), at pF 2.8 to 3.0 (field capacity for clay) at pF 3.7 (temporary wilting point) and pF 4.2 (permanent wilting point) were established and bulk density values were obtained (Van Daele, 2012).

5. Results and discussions

Results and discussions present the soil groups that are found in Miarayon and in Bendum, the morphological characteristics, the soil forming minerals, the physical potentialities, the chemical potentialities, the morphological limitations and chemical limitations.

5.1. Miarayon Soil Groups

From the World Reference Base of Soil Resources (IUSS Working Group WRB, 2006), Miarayon Soil Groups are Cambisols, a Para acric Cambisol and Umbrisols. Cambisols is summarily characterized by IUSS Working Group WRB (2006) as having a: "(i) striking difference between soil horizons (color, structure or carbonate content), (ii) medium to fine-textured materials, mostly colluvial, alluvial and Aeolian deposits, derived from a wide range of rocks, (iii) slight to moderate weathering of parent materials and absence of significant amount of illuviated clay, organic matter (OM) and Al and/or Fe complex, and are (iv) located in mountainous terrains in all climates under a broad range of vegetation." Cambisols in Miarayon are found in open positions such as in interfluve crests, flat surfaces and in convex slopes where Pedons MP1, MP5, MP7 and MP8 (Figure III-5) are located. Pedon MP1 is in the upper part of the main toposequence while MP8 is in the lower part. Both pedons have brownish black (10YR2/3 and 10YR3/2, respectively) top horizons and are positioned on a linear divide with a convex slope.

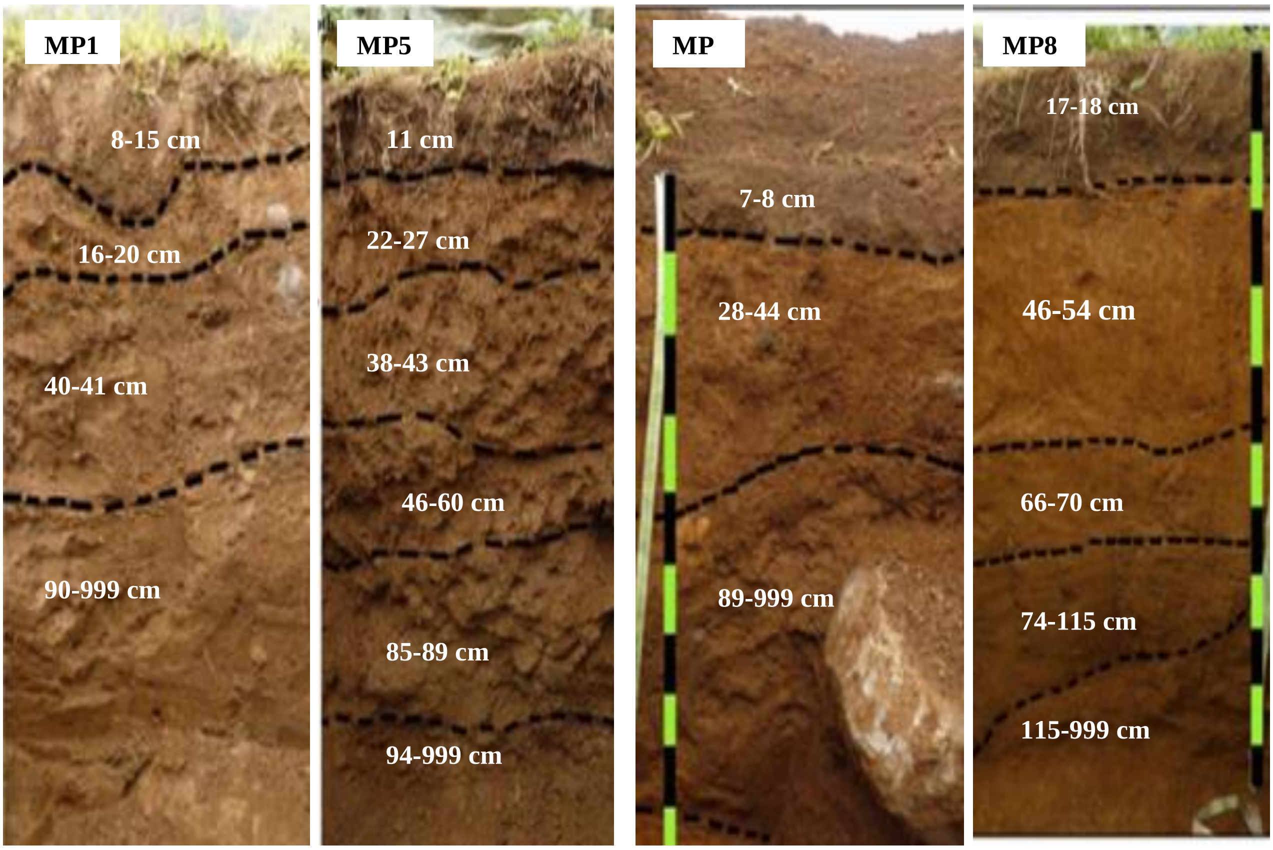


Figure III-5. Cambisols in Miarayon are found on flat and convex positions (Photo credit: F. Lebrun).

Pedon MP5, with brownish black (10YR2/3) topsoil, is on a wavy mesorelief and a convex slope in the middle of the field. Pedon MP7, which is sited in the lower part of the main topsequence, is on a rectilinear crest has brownish black (10YR3/2) topsoil. Cambisols can be utilized in a wide variety of agricultural uses (Driessen *et al*., 2001; IUSS Working Group WRB, 2006). Cambisols in humid tropics occur predominantly at medium altitudes and mountain regions and also in deposition areas and in eroding lands at lower altitudes where they occur alongside with genetically residual soils such as Acrisols and Ferralsols (Driessen *et al*., 2001).

Acrisol is characterized by the presence of higher clay content in the subsoil than in the topsoil especially because of clay migration leading to an argic horizon (IUSS Working Group WRB, 2006). This soil can be briefly described as: “(i) strongly weathered acid soils with low base saturation at some depth, (ii) extensively derived from weathering of acid rocks that are undergoing further degradation, (iii) having pedogenetic differentiation of clay content with lower amount in the topsoil and higher in the subsoil with the leaching of cation bases because of the humid environment and degree of weathering. In Miarayon, Pedon MP2, is Para acric Cambisol because the soil has characteristics of being a Cambisol by its dark brown (10YR3/3) color in the top horizon and of the features of a buried Acrisol in the lower horizons by its dull reddish brown (10YR4/4-4/3) color (Figure III-6). This pedon is positioned in the upper part of the long slope with open and flat mesorelief. In this case, it is theorized that deposition of relatively new materials over an older soil formation had occurred in the past because of the presence of redder subsoil which had shown a striking difference in its soil morphology.

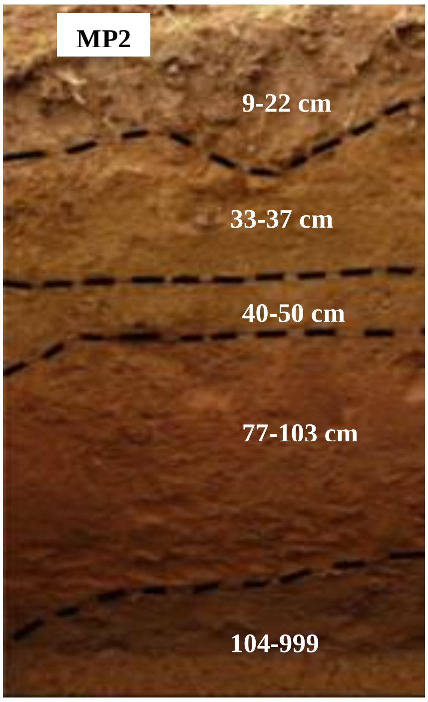


Figure III-6. MP2 is Para acric Cambisol. (Photo credit: F. Lebrun)

Soil Group Umbrisol was briefly described by Driessen *et al.* (2001) and IUSS Working Group WRB (2006) as: "(i) soils with dark topsoil, (ii) weathering material of siliceous rock, (iii) profile development has dark brown surface horizon, in many cases over a cambic subsurface horizon with low base saturation." Umbrisols are found in footslope, toeslope and concave mesorelief. Pedons MP3, MP4, MP6 and MP9 belong to Soil Group Umbrisol (Figure III-7). Pedon MP3 is on a concave mesorelief which is situated on a toeslope of a transversal toposequence in the upper part of the main toposequence. It is located ten meters away from a developing gully which is a shallow and intermittent watercourse. Pedon MP4 is situated on a wavy mesorelief with a concave middle part. Both pedons MP6 and MP9 are on concave mesorelief. Pedons MP6 is situated down the long footslope of the main toposequence and MP9 is sited on the toe slope of the transversal toposequence in the lower part. The presence of thick hedges, (i.e. wild sunflowers) at the foot of the slope obstructs the movement of colluvial materials farther down. Umbrisols are found in the Miarayon landscape because of its cold temperature and the pedons' positions along the toposequence are subjected to more moisture exposure.

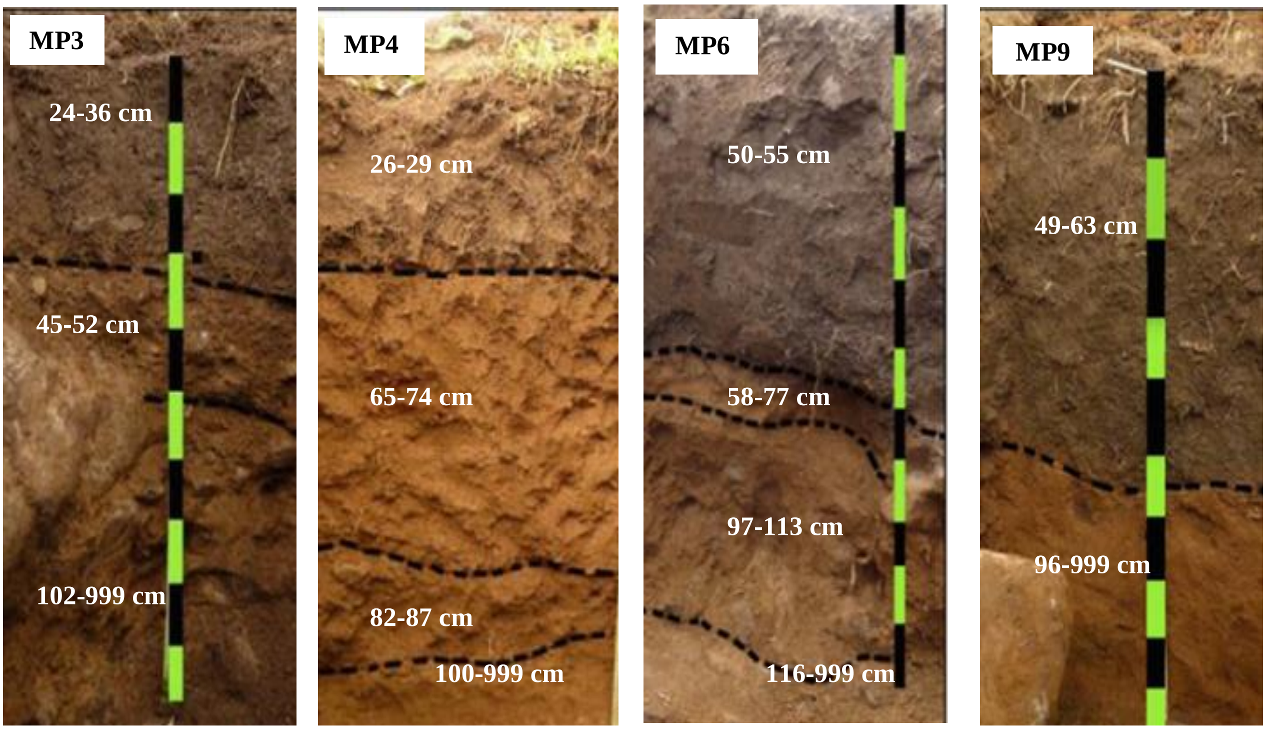


Figure III-7. Umbrisols in Miarayon. (Photo credit: F. Lebrun)

Soils with andic features are ecologically important because of their fertility and their susceptibility to land degradation (Mileti *et al*., 2013). Table III-1 presents the soil classification, position, elevation and slope of all pedons. The required characteristics that would qualify a soil to have Andic properties are: (1) if Al_{ox} + ½ Fe_{ox}^{2} is $\geq$2%, (2) bulk density of $\leq$0.90 kgdm^{-3}, (3) phosphate retention of $\geq$85%, (4) with organic carbon <25%, and (5) having albic horizon if occurring in a tephric condition.

Table III-1. Soil classification, qualifiers, position, elevation and slope of studied pedons in Miarayon, Bukidnon.

Location	Pedon	Soil Classification	Coordinates	Elevation (m asl)	Slope (%)	Position	Land use
Upper Part	MP1	'Andic' Cambisol	N7°59'51" E124°47'40"	1687	3	Interfluve, convex,	Fallow field at the time of investigation
	MP2	'Andic' Para acric Cambisol	N8°00'02" E124°47'51"	1660	14	Slope, linear side	Fallow field at the time of investigation
Intermediate Part	MP3	'Andic' Umbrisol	N8°00'12" E124°47'40"	1548	1	Toeslope, wavy landform, concave	Corn
	MP4	'Andic'	N8°00'37"	1489	7	Toeslope, wavy	Fallow field at

		Umbrisol	E124°47’52”			landform, concave	the time of investigation
	MP5	‘Andic’ Cambisol	N8°00’40” E124°47’42”	1496	10	Convex slope, wavy landform	Fallow field at the time of investigation
	MP6	‘Andic’ Umbrisol	N8°01’10” E124°47’34”	1427	3	Toeslope, concave	Carrot field
Lower Part	MP7	‘Andic’ Cambisol	N8°01’39” E124°47’17”	1363	4	Interfluve, rectilinear	Fallow field at the time of invetigation
	MP8	‘Andic’ Cambisol	N8°01’52” E124°46’58”	1348	2	Level, convex outline	Carrot field
	MP9	‘Andic’ Umbrisol	N8°02’38” E124°46’39”	1302	3	Toeslope, concave outline	Potato field

Allophanes test (Fieldes and Perrot, 1966), confirmed the presence of amorphous components in all pedons (Lebrun, 2011). Analysis for sesquioxides (Al_{ox}+½ Fe_{ox}^2) and P retention of representative pedons were based on the sections of the toposequence (upper, intermediate and lower parts) and their positions, that is MP1 (interfluve of the upper part), MP2 (linear slope, with striking difference on soil colors between the top horizons and sub horizons), MP3 (representative for a toeslope, upper part), MP5 (convex position in the intermediate part), MP7 (interfluve in the lower part). Table III-2 shows the P retention and sesquioxides analyses of selected pedons in Miarayon. Pedons MP3 and MP5 topsoil and subsoil, Pedon MP1 topsoil and Pedon MP7 subsoil are within the requirement of the first criterion. Pedons MP1, MP2 and MP7 topsoil and subsoil are within the second criterion, and the bulk density taken at the topsoil was met in Pedons MP1, MP2, MP3, MP5, MP6 and MP7. Results revealed that, except for criterion (v) an albic horizon on a tephric condition,

Table III-2. P retention and sequioxides in two horizons of selected pedons in Miarayon.

Location	Pedon	Horizon	Al_{ox} + ½ Fe_{ox}^2 (%)	P retention (%)
Upper Part	MP1	H1	3.01	87
		H3	0.88	97
	MP2	H1	1.54	96
		H4	0.47	98
Intermediate Part	MP3	H1	1.78	68
		H2	2.92	69
	MP5	H1	2.85	63
		H4	2.74	76
Lower Part	MP7	H1	1.40	91
		H4	2.28	95
		Average	1.99	84

Source: Barbieux (2012)

which in this case, not for Miarayon soils, all criteria were satisfied, however, these were not always met in the same location.

5.2. Bendum Soil Groups

Of the 13 pedon locations identified in the two toposequences defined in Bendum, four of them which were located in the cultivated areas where classified according to the soil groups. Based from the World Reference Base for Soil Resources (IUSS Working Group WRB, 2006), Soil Groups in the production areas of Bendum are Acrisol, Nitisol and Cambisol (Figure III-8). Pedon BP3 belongs to the Acrisol Soil Group. Acrisols are soils that have higher clay content in the subsoil than the topsoil, among other properties, as a result of pedogenetic processes especially clay migration (IUSS Working Group, WRB, 2006). BP3 which is located along the first toposequence is situated on an open surface, flat mesorelief with a relatively dense meadow cover next to a corn field. The pedological cover is continuous and is >80 cm (Richelle, 2010).

Pedons BP5 and BP9 belong to the Nitisol Soil Group. Nitisols, as characterized by IUSS Working Group WRB (2006), have: “(i) deep well-drained, red tropical soils with a clayey subsurface horizon that has typical nutty structure, blocky structure elements with shiny ped faces, (ii) has finely textured weathering products of intermediate to basic parent rock, in some regions rejuvenated by recent admixtures of volcanic ash, (iii) Nitisols are found in level to hilly land under tropical rain forest or savannah vegetation, and (iv) profile development has red or reddish-brown soils with nitic sub-surfaces of high aggregate stability”. Generally, Nitisols are considered fertile in spite of their low level of available P and their normally low base saturation, thus they are used for farm and plantation crops (Driessen *et al*., 2001). It was observed that in BP3 and BP5 profiles, fragments of broken pisoplinthic iron pan have been locally observed.

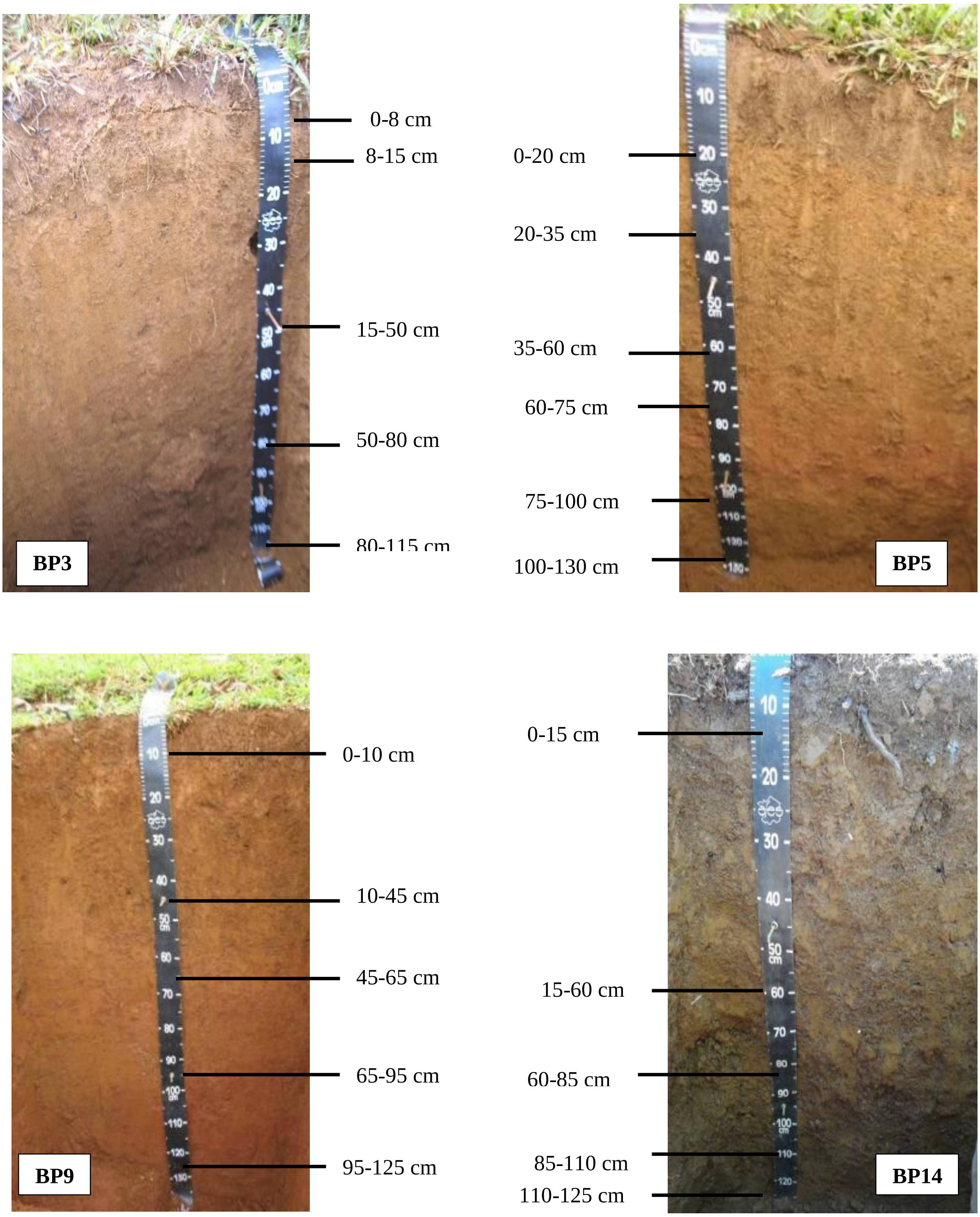


Figure III-8. Soil pedons of Bendum production areas: BP3 (Acrisol), BP5 and BP9 (Nitisol) and BP14 (Cambisol).
Photo credit: Richelle (2010)

Pedon BP5, also along the first toposequence, is situated in a relatively flat position with a continuous pedological cover >80 cm (Richelle, 2010). Pedon BP9 is situated along the second toposequence having 8% slope grasslands with occasional planted fruit trees. Pedological cover is discontinuous but was observed that this was within the thickness of even 130 cm (Richelle, 2010). Pedon BP14 belongs to the Cambisol Soil Group. It is situated on a flat surface with convex microrelief with rubber plantation, ferns and grasses. Table III-3 presents the soil classification, position, elevation and slope of all pedons.

Table III-3. Soil groups, position, elevation, slope and land cover of studied pedons in Bendum, Bukidnon.

Location	Pedon	Soil Group	Coordinates	Position	Elevation (m asl)	Slope (%)	Land cover
Toposequence 1	BP3	Pisoplinthic Acrisol	N 8°16’23” E 125°16’55”	Open, flat mesorelief	785	20	Relatively dense meadow next to a corn field
	BP5	Ferralic Nitisol	N 8°17’21” E 125°16’43”	Open, relatively flat surface	760	5	Dense meadow, planted with fruit trees
Toposequence 2	BP9	Acric Nitisol	N 8°16’55” E 125°17’1”	Open, relatively flat surface	770	8	Meadow with fruit trees
	BP14	Haplic Cambisol	N 8°16’48” E 125°16’27"	Flat surface, convex mesorelief	760	5	Rubber plantation, fern and grasses ground flora

5.3. Morphological characterization

This section presents the morphological characteristics of Miarayon and Bendum soils. Information on stoniness and rockiness, presence of rock fragments with their stage of weathering, soil texture and color are described.

5.3.1. Morphological characteristics of Miarayon soils

Table III-4 shows the summarized morphological descriptions of the studied nine pedons. The soil types of Miarayon are Cambisol, “Para acric Cambisol” and Umbrisol. Cambisols are found in open, flat and convex positions which exhibit characteristics of recently formed soils. Umbrisols are found in footslopes, toeslopes and in concave positions which indicated that deposition of materials have certain influence on the topsoil.

Soil color is affected by the physical (size of particles, moisture content) and chemical factors (concentrations and forms of elements such as Fe and bases and presence of SOM in the soil environment. Plice (1942) outlined some points on soil color: (i) Dark brown and blackish-colored (hues of 7.5YR) soils are found mostly in depressed areas or in places where SOM has undergone decomposition under a temporarily excessive-moisture condition. (ii) Hematite, because of its reddish streak, may have contributed to the reddish soil color (hues of 7.5R to 10R) although the redness is not directly proportional to the amount of hematite in the soil and the variations in reddish color can be affected by the sizes of particles, the density and degree of agglomeration of iron crystals. (iii) The lighter brown color tending toward yellowish brown (hues of 10YR, 2.5Y and 5Y) are most dominated by hydrated forms of iron oxide. (iv) The chocolate brown to maroon color (hues of 2.5YR to 5YR) is believed to have low silica content of the parent material with highly oxidized iron plus soluble organic matter.

Miarayon soils have brownish black to dark brown surface horizons. Cambisols have subsurface soil horizons that are either brown or yellowish brown. Umbrisols have dark brown subsurface soils. The Para acric Cambisol has strongly weathered gravels with dark brown surface horizon but the subsurface colors are dull reddish brown. Surface horizon textures of all pedons are sandy loam, sandy clay and sandy clay loam except for Pedon MP3 that has clay loam which is very near to a watercourse. For the subsurface horizons, the soil textures are silty clay loam and silty clay except for Pedon MP3 that has sandy clay loam.

Identified Soil Groups have shown their differences on the thicknesses of their surface horizons. Umbrisols are relatively thicker than Cambisols and the Para acric Cambisol. Surface horizon thickness in Umbrisols range from 28-56 cm. This is due to the deposition of alluvial materials in the pedon near the watercourse (Pedon MP3) and colluvial materials from the upslope (Pedons MP4, MP6, and MP9). Surface horizon thicknesses in Cambisols range from 8-18 cm which is believed to be an indicator that there is vulnerability of topsoil removal due to sheet and rill erosion in rectilinear and convex positions. The Para acric Cambisol topsoil (Pedon MP2) has a mean thickness of 16 cm. This is similar to Cambisol, the only difference is that the subsoil is clay.

Table III-4. Summary of morphological properties of Miarayon soils.

Location	Pedon	Landforms (FAO, 2005)	Land Use	Surface stones and rocks	Coarse fragments in the profile	Texture	Color
Upper Part	MP1	Sloping land, medium gradient mountain, middle slope	Long fallow, pastureland	Stones (25-60cmØ), Cobbles (7.5-25cmØ)	10% at 40 cm, very weathered	Surface, sandy clay loam; silty clay loam, subsurface	Brownish black (10YR2/3) surface; dull yellowish brown (10YR4/3), brown (10YR3/4) to dark brown (10YR4/4) subsurface
	MP2	Sloping land, medium gradient mountain, middle slope	Long fallow, pastureland	Rock outcrops and stones	2 cm size, not weathered; 0.5 cm size, very weathered	Surface, sandy clay, clay in the next horizon, silty clay to silty clay loam at deeper depths	Dark brown (10YR3/3) surface, brown (10YR4/6); reddish brown (5YR4/4) to dull reddish brown (5YR4/3) subsurface
Inter-mediate Part	MP3	Sloping land, medium gradient mountain, toe slope	Cultivated, shallow rooted crops	Mixture of rocks, stones, cobbles and gravels (2-7.5 cm Ø and 0.2-2.0 cm Ø)	10% rocks on surface; 80-90% subsurface at 30 cm size, andesite and tuff	Surface, clay loam; succeeding horizons, sandy clay loam	Brownish black (10YR2/2) surface; dark brown (10YR3/4, 4/4) subsurface
	MP4	Sloping land, medium gradient mountain, lower slope	Long fallow, pastureland	Stones and cobbles	Surface, fine to medium gravels, 4%; subsurface, coarse gravel to boulders, 10-90%	Surface, sandy clay loam; silty clay loam thereafter	Brownish black (10YR2/3) surface; brown (10YR4/6, 4/4) to yellowish brown (10YR5/5) subsurface
	MP5	Sloping land, medium gradient mountain, lower slope	Cultivated, shallow rooted crops	Rock outcrops in upslope, stones in downslope	Surface, 20% fine to medium gravels, unweathered; subsurface, 2-5% moderately weathered, at 85 cm depth, 60% stones and boulders	Surface, sandy loam; subsurface ranges from sandy loam sandy clay loam	Brownish black (10YR2/3)surface; dark brown (10YR3/4, 3/3), brown (10YR4/4) to yellowish brown (10YR5/4) subsurface
	MP6	Level land, depression, toe slope	Cultivated, shallow rooted crops	Stones and cobbles	Surface, 1% gravels, unweathered; subsurface, 50% moderately weathered to 90% fine gravels to large boulders	Surface, sandy clay loam; subsurface, silty clay loam to silty clay	Brownish black (10YR2/3) surface; dark brown (10YR3/4) to brown (10YR4/4) subsurface
Lower Part	MP7	Level land, plateau, crest	Fallowed	Stones and cobbles	Surface, no coarse fragment; subsurface, 5% coarse gravels to 20% coarse gravels and boulders, weathered, 1% highly weathered	Surface, sandy clay loam; subsurface silty clay loam to silty clay	Brownish black (10YR3/2) surface; brown (10YR4/4), dark brown (10YR3/4) to yellowish brown (10YR5/6) subsurface

					gravels		
	MP8	Level land, plateau, crest	Fallowed	Stones and cobbles	No rock fragment found	Surface, sandy clay loam, subsurface silty clay	Brownish black (10YR3/2) surface; bright brown (7.5YR5/6), brown (10YR4/6, 4/4) to dark brown (10YR3/4) subsurface
	MP9	Sloping land, medium gradient hill, toeslope	Cultivated, shallow rooted crops	Stones, cobbles and big gravels	Surface, 1% fine and coarse gravel, highly weathered; subsurface, 60% weathered coarse gravels to boulders	Surface, sandy clay loam; subsurface, silty clay loam	Brownish black (10YR2/2) surface; dark brown (7.5YR3/4) subsurface
Source: Lebrun (2011)							

5.3.2. Morphological characteristics of Bendum soils

Table III-5 shows the summarized morphological descriptions of the nine pedons located in along the two defined toposequences in Bendum. However, the naming of pedons was only made for BP3, BP5, BP9 and BP14 in the cultivated areas. These pedons are situated in the undulating surface that lie between the upper forested part and the slope of to Pulangui River of the Bendum toposequence. As mentioned, the soils in these cultivated areas are Acrisol, Nitisol and Cambisol. Topsoil thicknesses of Bendum soils in cultivated areas are similar to the Cambisols in Miarayon. This is because the positions of their profiles are found in flat or exposed positions which are very much different from the locations of Umbrisols in Miarayon. The Acrisol has topsoil thickness of 15 cm, the Nitisols have 10-20 cm and the Cambisol has 15 cm. The Cambisol has the presence of weathered gravels which could mean that the soil is undergoing an evolution.

Table III-5. Summary of morphological properties of soils in Bendum cultivation areas.

Location	Pedon	Landform (FAO, 2005)	Land Use	Surface rocks and stones	Coarse fragments	Texture	Color	Soil pH
Toposequence 1	BP3	Sloping land, medium gradient mountain, toeslope	Dense grasses next to a corn field	No rock outcrops, no stones recorded	Surface, 5% concretions (Fe/Mn <5mm size) and, 10% rounded stones	Surface, sandy clay loam to sandy clay; subsurface, clay loam	Surface, brown (7.5YR4/4); subsurface, bright brown (7.5YR5/6, 5/8)	Surface, 5.5; subsurface , 5.0

	BP5	Level land, plain, bottom flat	Dense grasses	No rock outcrop, no stones recorded	Surface, 3% Fe/Mn concretions (<5mm Φ), 10% Fe/Mn nodules, with weathered rocks at last horizon	Surface, sandy clay loam, subsurface, clay loam	Surface, dark brown (10YR3/3); subsurface, bright brown (7.5YR5/6), at depths, reddish brown (2.5YR4/6) with purple nodules, yellow shiny faces, brown (7.5YR4/6)	Surface, 4.5-5.0; subsurface 4.5-4.0
Toposequence 2	BP9	Sloping land, medium gradient mountain, lower slope	Grasses with fruit trees	No rock outcrop reported	Stones are absent in the entire profile	Surface, sandy loam; subsurface silty clay to clay loam	Surface, brown (7.5YR4/6); subsurface, reddish brown (5YR4/6, 2.5YR4/8)	Surface, 5.5 subsurface 6.0-7.0
	BP14	Level land, plain, higher part	Rubber	No rock outcrop reported	Surface, 5% gravels; subsurface, none	Surface, sandy clay loam; subsurface silty clay to clay loam at greater depths	Surface: Brown (7.5YR4/3), subsurface, dull brown (7.5YR5/4), brown (7.5YR4/4), bright brown (7.5YR5/6) for all horizons	Surface, 4.5; subsurface 4.0-4.5
Source: Richelle (2010)								

5.4. Rocks, minerals and total elements

Soil is the result of rock weathering and the parent materials, consolidated or unconsolidated, influence soil formation (Grotzinger *et al.*, 2007). Knowing the associated rocks and minerals is useful in identifying the degree of weathering and the elements found in soils that can be verified by soil laboratory analysis.

5.4.1. Rock, minerals and total elements in Miarayon soils

Miarayon soils are developed from volcanic plain or volcanic piedmont deposits, chiefly basaltic and pyroclastics (ashes, cinders and bombs, tuff) and other volcanic debris at the foot of volcanoes (Bukidnon Provincial Development Staff, 1985). Analysis of rock samples from Mt. Kalatungan by Sajona *et al.* (2000) revealed that these are calc-alkaline basalt (0.27 Ma, very fresh, no secondary minerals), shoshonitic basaltic andesite (0.52 Ma, moderately fresh with <3% modal secondary minerals). The analysis of a rock sample that was taken from the vicinity of MP2 in Miarayon revealed that rock is trachy-andesite (Table III-6). The sample contains 54.87% SiO_2 and $K_2O + Na_2O$ of 8.59% (Maurissen, 2014). These extrusive igneous rocks are intermediate composition between trachyte and andesite which are dominated by plagioclase feldspar. In Table III-6, it should be noted that the concentrations of Al and Fe in rocks are the same as in soils while for Ca, Mg, K and Na, their concentrations in rocks are ten times higher than in soils.

Table III-6. Analysis results of representative rock sample from Pedon MP2 location of Miarayon (%).

Sample	**Lithology**	**Al_2O_3**	**BaO**	**CaO**	**Cr_2O_3**	**Fe_2O_3**	**K_2O**	**MgO**	**MnO**	**Na_2O**	**P_2O_5**	**SO_3**	**SiO_2**	**SrO**	**TiO_2**
MP2	Pyroclastic deposit	18.76	0.11	3.44	<0.01	7.53	4.56	2.32	0.14	3.93	0.81	0.01	54.87	0.04	1.25

Source: Maurissen (2014)

Representative horizon samples in each of the nine pedons were selected for mineral identification by using first X-ray diffraction screening on oriented powders (Barbieux, 2012). The possible minerals identified in the five groups of samples were as follows: (i) amphibole and gibbsite in Pedon MP1 topsoil and Pedons MP4, MP6 and MP9 stony subsoil that are on concave positions, (ii) albite and gibbsite in the topsoils of Pedons MP2, MP4, MP6, MP7, MP8 and MP9 non stony topsoil and Pedons MP1, MP7 and MP8 subsoil of open/convex positions, (iii) anorthite and labradorite in Pedon MP5 topsoil and subsoil, (iv) anorthite and kaolinite in Pedon MP2, redder (5YR) subsoil, and (v) gibbsite, low tridymite in Pedon MP3 subsoil. Aforementioned minerals are associated with volcanism of basaltic and/or andesitic character.

The generic formula for amphibole is $NaCa_2(Mg,Fe)_4$, $Al_3Si_6O_{22}(OH,F)_2$ (Mac Kenzie and Adams, 2011). Albite, the sodic end member of the plagioclase series, ($[Na_{100\%}, Ca_{0\%}]\ AlSi_3O_8$) is colorless or milky-white plagioclase of the feldspar group which is found in granite and various igneous rocks (Licker, 2003). Gibbsite, a mineral form of aluminum hydroxide ($Al[OH]_3$) is one of the Andosol weathering products that has high values of Alo and P retention which generally has high rates of hydration (Quantin, 1986). Ndayiragije and Delvaux (2003) have also linked the occurrence of gibbsite, allophanes and kaolinite with intense leaching of silica in a perudic Andosol. Kaolinite is an aluminum silicate mineral with 1:1 crystal lattice and has a formula of $2Al_2O_3H_2O.2SiO_2$ (Landon, 1991).

A feldspar mineral, anorthite ($[Ca_{100\%}, Na_{0\%}]\ Al_2Si_2O_8$), calcic end member of the plagioclase series, is Ca rich which occurs in mafic igneous rocks (Licker, 2003). Labradorite ($[Ca_{70\%}, Na_{30\%}]$

$Al_2Si_2O_8$) is a feldspar mineral and intermediate to calcic member of the plagioclase series which are found in common igneous rocks such as basalt and gabbro (Licker, 2003). As member of the plagioclase series, it has 50-70% anorthite in composition (Mac Kenzie and Adams, 2011). Tridymite (SiO_2) is a high temperature polymorph of quartz which are in a form of minute tubulars, white colorless pseudo-hexagonal crystals or scales which are found in cavities of felsic volcanic rocks (Licker, 2003).

Maurissen (2014) found out that minerals in thin sections of the soil samples from MP1, MP2, MP3, MP5 and MP7 are plagioclase and clinopyroxene. He further identified the presence of hematite in the top and sub-horizons of MP2 and in the sub-horizon of MP5. Plagioclase is a series of minerals of the feldspar group in accordance to the percentages of Ca and Na contents (Mc Kenzie and Adams, 2011). Clinopyroxene is a mineral that has $Ca(Mg,Fe)SiO_6$ composition (Mc Kenzie and Adams, 2011). The mineral analyses results of Miarayon in Barbieux (2012) and in Maurissen's mineral analyses in thin sections are congruent. Anorthite, labradorite and albite belong to the plagioclase group. Amphibole is associated with clinopyroxene because both are ferromagnesian minerals. Summary of mineralogical analysis results for Miarayon are presented in Table III-7.

Table III-7. X-ray diffraction mineralogical analyses results of Miarayon soils.

Pedon	Barbieux (2012) 1st screening	Maurissen (2014)
MP1H1	Amphibole, gibbsite	Gibbsite
MP1H3	Albite	
MP2HI	Gibbsite, albite	
MP2H2		Gibbsite, hematite
MP2H4	Kaolinite, anorthite	Hematite
MP3H1		Feldspar, gibbsite
MP3H2	Gibbsite, low trydimite	Feldspar, goethite
MP4H1	Albite, gibbsite	
MP4H3	Amphibole, gibbsite	
MP5H1	Anorthite, labradorite	Feldspar
MP5H4	Anorthite, labradorite	Feldspar, gibbsite, hematite
MP6H1	Gibbsite, albite	
MP6H3	Amphibole, gibbsite	
MP7H1	Gibbsite, albite	Gibbsite
MP7H4	Gibbsite, albite	Gibbsite, feldspar and hematite
MP8H1	Gibbsite, albite	
MP8H3	Gibbsite, albite	
MP9H1	Gibbsite, albite	
MP9H2	Amphibole, gibbsite	

By looking into the composition of minerals that were identified in Miarayon soils, the presence of elements for the plants such as Ca, Mg, K, Na, P and Fe, and Al, which constrains growth, are expected although elements such Ca, K and Na become rare when soils are highly weathered. Table III-8 shows the total elements in all Miarayon soil pedons although it should be noted that different units which are used are at different scales. It is observed that pedons at the intermediate part of the toposequence relatively have higher contents of total basic elements especially in MP5.

Table III-8. Total element contents of Miarayon soils.

Topo-sequence	Pedon	Horizon	Ca	Mg	K	Na	TRB	P	Al	Fe	Mn	Zn	Cu
			mg/100g				cmol/ kg	mg/ 100g	%		ppm		
Upper part (1,900-1600 m asl)	MP1	1	436	337	153	350	69.6	120	6.56	8.23	299	48	148
		2	249	260	64	202	44.0	63	8.51	3.47	348	54	255
		3	84	224	22	100	27.4	64	12.33	3.52	630	97	456
		4	62	263	10	79	20.2	110	10.54	9.19	809	118	400
	MP2	1	288	220	69	238	44.3	66	11.24	9.39	231	48	104
		2	143	213	22	148	31.6	36	12.13	3.86	224	48	107
		3	57	118	22	99	17.4	36	9.07	4.16	394	57	169
		4	35	113	11	75	14.6	32	8.08	4.05	524	65	356
Inter-mediate part (1,600-1,400 m asl)	MP3	1	952	685	430	610	140.6	350	7.76	6.16	1506	93	143
		2	638	667	823	773	140.8	263	8.54	8.03	1017	94	206
		3	527	916	621	657	145.6	174	7.66	7.72	749	77	209
	MP4	1	594	575	311	514	106.8	277	9.32	6.63	1254	102	116
		2	240	207	188	240	44.1	326	11.30	6.84	1096	93	141
		4	426	629	210	447	97.5	287	7.77	6.13	997	104	97
	MP5	1	984	819	923	1080	186.2	288	6.57	7.30	930	82	168
		3	748	856	680	772	158.0	243	4.72	7.21	731	67	198
		4	944	843	830	1034	181.9	176	8.45	7.29	940	88	235
		5	1063	973	739	897	190.1	188	10.37	7.39	680	91	200
	MP6	1	582	616	151	488	104.4	388	6.86	5.44	588	55	78
		2	471	527	151	381	86.9	184	8.93	7.57	302	52	104
		4	228	287	316	246	53.6	96	11.60	3.89	339	80	200
Lower part (1,400-1,300 m asl)	MP7	1	183	180	32	160	31.5	82	7.36	6.89	606	92	252
		2	136	219	51	94	30.1	66	14.30	3.98	588	55	78
		3	47	79	21	82	13.0	49	8.28	3.65	302	52	104
		4	38	82	13	80	12.5	48	9.77	8.42	339	80	200
	MP8	1	248	223	58	205	40.9	147	10.73	7.68	606	92	252
		2	78	113	19	93	17.7	63	16.07	9.88	265	45	62
		3	34	56	10	69	9.6	39	11.93	9.38	698	56	64
		5	45	57	6	99	11.4	99	13.68	4.66	265	45	62
	MP9	1	346	205	119	258	48.0	170	11.50	9.33	2109	273	122
		2	202	210	32	149	34.9	128	11.25	8.76	1836	106	147

Source: Lebrun (2011)

Soil development in Miarayon is affected by both natural and anthropogenic factors. The total element contents in soils matched with the detected minerals and verified that these minerals are natural potential sources of those elements. These can be seen in the data wherein there are lesser variations of total element contents in the subsoil. The anthropogenic effects on total Ca is shown in its concentration within the individual pedon. Total Ca is highest in the top horizons. During interviews, farmers revealed that they add chicken litters (chicken dung plus rice hull) to the soil. Chicken feed formula contains Ca additives such as dicalcium phosphate, oyster shells and ground limestone. Therefore, the long term effects of chicken litters addition on Ca levels in Miarayon soils cannot be discounted.

Although K_2O shares a relatively higher percentage composition in rocks compared to CaO, MgO and Na_2O, total K is the lowest compared to Ca, Na and Mg. This is because in the competition between K^+ and Ca^{2+} in the soil matrix, K is more easily leached by water than Ca. Furthermore, since K is needed by plants in larger quantities, the element is taken up by vegetation. The effects of soil management on K can be seen in the K levels of individual horizons. In most pits, K is relatively higher in the top horizons than in the sub horizon except in MP3 and MP6. Farmers revealed that they also use K containing fertilizers such as muriate of potash and NPK. The lower amounts of K in the topsoil of MP3 can be attributed to leaching. MP3 is located near a waterway and water may have leached the element down to the subsoil. Looking into the total P's trend relative to its concentration within individual profile, except in MP4, relatively substantial amounts are present in top horizons which can be attributed to the addition of P containing fertilizers by farmers.

Observing the general trend of total element concentrations in all profiles, high levels are found in the intermediate part of the toposequence. The highly probable explanation of successive mudflows would clarify the perception of this geomorphopedological context. Looking back at Figure III-3, the intermediate part, LU2, which generally is gently sloping, immediately succeeds the upper part, LU1, with relatively steep slope. The colluvial movement of volcanic material in the upper part may have been deposited in the intermediate part. The deposition of these materials that had covered pre-existing soils may have been very thick and therefore the supply of nutrients from extrusive volcanic debris is abundant. Moreover, because of the thickness of the deposits in these areas, the chemical characteristics of pre-existing soils may not have influenced the recent soil features. It should be noted that the depths of profiles that were examined are only a little over a hundred centimeters.

5.4.2. Rocks, minerals and total elements in Bendum soils

From Figure II-4 of Chapter II, the geological formation in the Bendum vicinity has rocks which are composed of ultrabasic, volcanic agglomerates, sandstone and shale, and sandstone and conglomerates. These geological formations are described in Table II-2 of Chapter II. Maurissen (2014) made a detailed study of the rocks in Bendum. These are as follows: the upper part which are the forested mountains approaching to the cultivated areas have (i) ultramafic, coarse-grained rocks which are serpentinized and are rich in olivines, clinopyroxenes and orthopyroxenes, (ii) serpentinites (green and black) which are the results of weathering of ultramafic rocks, (iii) amphibolites which are composed of amphiboles and plagioclase feldspar with little quartz, (iv) the pyroclastic deposits that are found in the middle part approaching the cultivated areas which are composed of different fragments, less crystallized rocks and with pore spaces, and (v) the andesites in the toeslope of the toposequence approaching Pulangui River.

The ultramafic in the mountainous areas and the pyroclastic deposits in the upper footslopes are the concern of this PhD study because these are the rocks that are found in the vicinity of Bendum production areas which are the sites of the soil investigation. Table III-9 shows the rock analysis results from the pit locations in the production areas of Bendum. Rock samples B28 and B60 are both lherzolites that represent the ultramafic rocks along Toposequence 1 which were taken at higher elevations close to BP3 and BP5 and down to Toposequence 2 which was also taken near BP9 respectively. Lherzolite is an olivine-rich rock along with orthopyroxene, having less Ca but high in chromium clinopyroxene. Rock sample B39, which has 50% plagioclase, that was taken near BP14 represents the pyroclastic deposit (Maurissen, 2014). Looking into the rock samples, MgO is highest in terms of the basic elements present but the amounts differ in rock samples. Sample B60 has the highest MgO content (42.92%) followed by B28 (33.63%) while sample B39 has only 5.40%. Calcium contents (CaO) in Bendum rock samples vary and that those in ultramafic rock samples are rather low (B28, 3.24% and B60, 0.89%) compared to that of sample from pyroclastic deposit (B39, 11.65%). Potassium content (K_2O), Na (Na_2O) and P (P_2O_5) are low in concentrations. Iron (Fe_2O_3) is the second dominant element in Bendum rock samples and Al (Al_2O_3) is relatively higher in samples from pyroclastic deposits.

Table III-9. Analysis results of representative rock samples from Bendum cultivation areas (%)

Sample	Lithology	Al_2O_3	BaO	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SO_3	SiO_2	SrO	TiO_2
B28	Ultramafic	3.84	0.01	3.25	0.36	8.44	0.01	33.65	0.12	0.35	0.01	0.07	43.67	<0.01	0.16
B28-D	Ultramafic	3.84	0.01	3.23	0.36	8.45	0.01	33.62	0.12	0.35	0.01	0.07	43.59	<0.01	0.15
B60	Ultramafic	0.89	0.02	0.46	0.22	8.76	0.01	42.90	0.11	0.13	<0.01	0.01	40.29	<0.01	0.01
B60-D	Ultramafic	0.89	0.02	0.46	0.20	8.82	0.01	42.93	0.11	0.13	<0.01	0.01	40.22	<0.01	0.01
B39	Pyroclastic deposit	19.17	0.02	11.93	10.93	10.93	0.46	5.40	0.19	2.93	<0.01	<0.01	48.42	<0.01	0.83

Source: Maurissen (2014)

Most of the rock formations in Bendum are igneous in origin, both extrusive as in andesite, basalt, and intrusive as gabbro, peridotite, and the plutonic rock dunite (Table II-2). Representative horizon samples in each of the four (4) pedons in the cultivated areas were selected for identification of probable mineral by using first X-ray diffraction screening on oriented powders (Barbieux, 2012). Table III-10 shows the results of mineralogical analysis by X-ray diffraction.

It was reported that there are six kinds of minerals detected in the representative samples from surface and subsurface horizons. These were: (i) gibbsite which was found in all pedon samples, (ii) rutile-hematite and feldspar which were spotted in both topsoil and subsoil samples of Pedons BP3, BP5 and BP9, (iii) anorthite which was found in the surface and subsurface of Pedons BP14, (iv) unknown mineral which was noted in Pedon BP14. Rutile (TiO_2) is a reddish-brown mineral which is common in acid igneous rocks, in metamorphic rocks, and as a residual grain in beach sand while hematite (Fe_2O_3) is an iron mineral which is an important iron ore (Licker, 2003). In another analysis made by Maurissen (2014), goethite was present in BP5 and BP9 horizons and quartz was in BP5 horizon. Goethite is the result of weathering iron-rich minerals. The presence of gibbsite in all samples from pedons in the cultivated areas may indicate that soils in Bendum have undergone desilicating process during weathering. Gibbsite corresponds to the older soils that develop under wet climate condition (Quantin, 1986).

Table III-10. X-ray diffraction mineralogical analyses results for Bendum soils.

Pedon	Barbieux (2012) 1st screening	Maurissen (2014)
BP3 H1	Rutile-hematite, gibbsite, feldspar	
BP3H4	Rutile-hematite, gibbsite, feldspar	
BP5H1	Rutile-hematite, gibbsite, feldspar	Goethite, gibbsite, hematite, quartz
BP5H4	Rutile-hematite, gibbsite, feldspar	
BP5H5	Rutile-hematite, gibbsite, feldspar	Goethite, hematite, quartz
BP5H6	Rutile-hematite, gibbsite, feldspar	
BP9H1	Rutile-hematite, gibbsite, feldspar	Goethite, gibbsite, hematite
BP9H4	Rutile-hematite, gibbsite, feldspar	
BP9H5	Rutile-hematite, gibbsite, feldspar	Goethite, gibbsite, kaolinite
BP9H6	Rutile-hematite, gibbsite, feldspar	
BP14H1	Andesite-anorthite, gibbsite, unknown mineral	
BP14H4	Andesite-anorthite, gibbsite, unknown mineral	

Since Bendum rocks ranged from mafic to ultramafic, it can be expected that there are soils in these areas that may contain high amounts of Mg and Fe. Table III-11 shows the total elements found in horizon samples of soil pedons located in cultivated areas of Bendum. Results in the total Mg in soils corroborated with the rock analysis results. Total Mg is high where ultramafic rock samples were taken while the total Mg content in the soils where the pyroclastic rock samples were found is low.

The total Ca values of pedon samples do not conform to the results of the rock sample analysis on CaO. If the parent rock has influenced the Ca contents, it can be expected that BP14 should have high total Ca because the sample rock which was taken from the site has the highest percentage of CaO. Moreover, the possible presence of anorthite, the calcic end member of the plagioclase series, can make one expect that higher Ca concentration can be detected.

However, BP14 registers the lowest total Ca than the rest of the pedons examined (Table III-11). Moreover, for the individual horizons within each profile, total Ca is concentrated in the top horizons of BP5, BP9 and BP14 while in BP3, the element is concentrated in the top and subsoils. According to the information gathered by Richelle (2010), lime was applied in these areas as follows: BP3 (in 2000), BP5 (in 2004), BP9 (in 2005) and BP14 (in 2005). It was noted that BP3 is located down the slope of a cultivated plot. It is posited that the Ca derived from application of lime, aside from the lixiviation process, lime particles have been eroded and buried in this location as part of the colluviums. Therefore, the Ca concentration in Bendum cultivated soils is caused also by anthropogenic activities.

Table III-11. Total element contents of the pedon samples in Bendum.

Topo-sequence	Pedon	Horizon	Ca	Mg	K	Na	TRB	P	Al	Fe	Mn
			mg/100g				cmol$_{+}$/kg	mg/ 100g	%		ppm
Topo-sequence 1	BP3	1	174	1211	98	63	114.9	27	6.79	22.88	235
		4	142	1461	92	78	134.6	12	7.75	25.98	318
	BP5	1	164	872	101	119	88.6	51	9.70	23.13	186
		4	66	854	114	69	80.4	13	9.62	27.28	145
		5	60	931	190	61	88.1	11	8.70	27.32	112
		6	57	1064	142	76	98.5	9	9.91	17.10	55
Topo-sequence 2	BP9	1	133	578	114	60	60.3	32	9.47	25.11	111
		4	44	347	82	72	36.3	6	9.00	35.66	325
		5	44	370	102	76	38.9	4	9.21	35.10	359
		6	47	338	104	382	49.8	6	12.20	31.05	374
	BP14	1	104	69	63	67	15.4	48	15.08	11.44	31
		4	43	70	81	69	13.5	37	13.59	10.83	28

Source: Barbieux (2012)

Parent rock materials are factors that affect the levels of total K, Na, Al, Fe and Mn. Table III-11 shows that the values of total element content are rather similar within the pedon or higher amounts are found in subsoils. The P content of rocks is low ($\leq$0.01%), however, total P are still found in all pedons. Similar to total Ca, total P is generally concentrated at the top horizon. As these pedon locations are all in cultivated areas, although farmers had said that they no longer apply fertilizers because of their economic difficulties, one can speculate that the total P concentrations are partly the results of fertilizer applications in the past.

5.5. Soil potentialities

Soil potentialities are soil attributes that provides favorable conditions for plant growth. These are physical and chemical characteristics and properties which are the soil positive factors in crop production.

5.5.1. Potentialities of Miarayon soils

To identify the potentialities of Miarayon soils, soil physical parameters investigated were texture by feel method, bulk density, hydraulic conductivity, water retention and ease of tillage. Texture, bulk density and soil structure are soil physical characteristics. Hydraulic conductivity and water retention are physical properties. Ease of tillage was assessed by its texture, its bulk density, farmers' interview in the field and by the stoniness of the area. Chemical characteristics are acidity, the presence of organic matter, levels of soil nutrients that are essential for the plants, and the capacity to store and exchange these nutrients are chemical properties.

5.5.1.1. Physical potentialities of Miarayon soils

Coarser soil texture is more vulnerable to soil degradation (Bowichean *et al*., 2013). This is because coarse textured soil has high water percolation rates and nutrients stored are easily lost through lixiviation. Soil texture is one of the factors of soil erosion because it affects both detachment and transportation of particles by water or wind, the eroding agents (Lal, 1988). More fine sand and silt make soil highly erodible. Soil texture influences workability in a soil (Fischer *et al*., 2008) which is essential in crop cultivation. Soil texture and aggregation are important factors that affect the infiltration rate, hydraulic conductivity, field capacity, permanent wilting point and water holding capacities of soil, and therefore can be used in correlation studies with soil-water related properties.

Soil texture estimation by feel method revealed that Miarayon soils are sandy loam to silty clay loam. From Table III-12, Pedons MP1, MP4, MP6, MP7, MP8 and MP9 have sandy loam topsoils and silty clay loam to silty clay subsoils, which are also, except for Pedon MP8, stonier. Pedon MP2 which is Para acric Cambisol is more clayey. Only MP3 which is located near a watercourse has finer topsoil. MP5 has coarser and more homogenous texture with the stoniest topsoil. Owing to the soils' medium texture, the croplands could be easier to till. However, the presence of stones and rocks in the areas has made tillage difficult, although stones and rocks, when weathered can supply elements to the soil nutrient pool. Difficulties in tillage due to the presence of stones and rocks are discussed in the soil constraints topic.

Table III-12. Physical properties of Miarayon soils.

Location	Pedon	Soil texture(a)	Soil Structure(a)	Land condition at investigation	Bulk density (b)	Hydraulic conductivity		Field capacity(b)	Permanent wilting point(b)	Available water	
					kg/dm^3	cm/h (b)	Class (c)	cm^3/cm^3	cm^3/cm^3	cm^3/cm^3 (b)	Irrigation suitability(c)
Upper Part	MP1	Sandy clayloam	Crumbly, platy	Fallow	0.73	6.04	Moderate	0.60	0.49	0.11	Low
	MP2	Sandy clay	Crumbly	Fallow	0.81	7.18	Moderately rapid	0.55	0.43	0.12	Medium
Intermediate Part	MP3	Clayloam	Crumbly	Newly plowed field	0.73	17.09	Very rapid	0.46	0.32	0.14	Medium
	MP4	Sandy clayloam	Crumbly, platy	Fallow	0.98	0.15	Very slow	0.52	0.38	0.14	Medium
	MP5	Sandy loam	Subangular blocky, platy	Planted with young carrots	0.87	22.56	Very rapid	0.49	0.37	0.12	Medium
	MP6	Sandy loam	Crumbly	Planted with young carrots	0.70	31.50	Very rapid	0.47	0.32	0.15	Medium
Lower Part	MP7	Sandy clayloam	Crumbly	Fallow	0.86	4.39	Moderate	0.36	0.27	0.09	Low
	MP8	Sandy clayloam	Crumbly	Newly plowed field	0.97	0.91	Slow	0.53	0.43	0.10	Low
	MP9	Sandy clayloam	Crumbly	Planted with young potatoes	0.91	18.70	Very rapid	0.34	0.26	0.08	Low

Source: (a)Lebrun (2011); (b)Van Daele (2012); (c)Landon (1991)

Table III-12 presents the physical properties of Miarayon topsoils. Increased bulk density stresses the plant's root system because of mechanical resistance of soil to root penetration. Dense soils have low spaces that can be occupied by air and water and therefore, the supply of these two important plant's inputs are limited. Bulk density values at 0-15 cm depth of about 1.5 kg-dm^{-3} had markedly reduced corn root growth (San Valentin, 1985). Furthermore, dense soils have low permeability and therefore, this could pose a risk of waterlogging in soil which can be detrimental to the crop. Miarayon soils are highly aggregated and are fluffy. The study of Bertrand and Fagel (2008) found out that the Andosols of south-central Chile have bulk density of 0.85 kg dm^{-3}. The bulk density values in Miarayon generally range from 0.70-0.98 kg dm^{-3} (Van Daele, 2012). Except for Pedons MP4, MP8 and MP9, all bulk density values were <0.90 kg dm^{-3}, thereby satisfying one of the criteria of a soil having 'andic' properties (IUSS Working Group WRB, 2006). Bulk density values of Miarayon connote that the soil is suitable for root crops. Less compact soils enable plant roots to easily penetrate.

Infiltration measurements are affected by vertic properties, low aggregate stability, macroporosity, coarse fragments, presence of impending thin layers, biological activity, anisotropy and water content profiles (Mc Kenzie and Cresswell, 2002). A balance on water conductivity reduces the tendency of waterlogging in soil which provides a good environment for the plant root system. The more available water in soil, the more favorable to plants as this will serve as moisture reserve for plant's use especially during long dry periods. The very rapid downward hydraulic conductivity in Miarayon soils was associated with tillage and organic matter content (Van Daele, 2012). Pedons MP3, MP5, MP6 and MP9 were recently tilled at the time of investigation while Pedons MP1, MP2, MP4, MP7 and MP8 were on fallow. High values of soil conductivity were also observed in the vicinity: after an overnight hard rain, there was no trace of waterlogging in production fields, except on depressed location and in those areas where water table is probably high. High water conductivity in soil prevents waterlogging, which is favorable to crops. Excessive moisture in the soil will affect its growth and consequently its yield. In Landon (1991), the high value of field capacity is 0.45 cm^3/cm^3 and for available water is 0.23 cm^3/cm^3. In Miarayon, the water content at field capacity of soil is generally high. However, the available water content is low to medium. With the values of water holding capacities, Miarayon soils and their suitability for irrigation is from low to medium. The lower the water holding capacities of the soil, the more frequent the water application shall be as water will easily be lost due to its removal from the soil-water reservoir by percolation, by evaporation or by plant uptake.

5.5.1.2. Chemical potentialities of Miarayon soils

Topography is an influential factor in SOM because it modifies the climate and soil textural factors and the redistribution of water within the landscape (Baldock and Nelson, 2000). The effects of high organic matter in soil are the increase in water infiltration rate and retention. This is because SOM enhances soil aggregation and its fine particles increase the surface area to adsorb water molecules and nutrients. Since high SOM improves soil aggregation, this consequently will cause the decrease in soil bulk density. High SOM increases the soil's resistance to erosion (Landon, 1991). Decline in SOM is an indicator of biological degradation with main consequences of which are physical degradation, loss of nutrients and increase runoff and erosion (FAO, 1979). SOM is conventionally quantified in terms of TOC (Buol, 2008). As summarized by Landon (1991), values of TOC (Walkley and Black method) and its interpretation are: >20%, very high; 10-20%, high; 4-10%, medium; 2-4%, low; and <2, very low. In Miarayon, the TOC values were medium to high in topsoil and there were pedons that had medium TOC in subsoils. TOC contents in topsoil ranged from 5.3-11.6% and 0.2-2.9% in subsoil. Pedons MP1, MP3 and MP6 had values higher than 10%. Pedons MP2, MP4, MP5, MP7, MP8 and MP9 had values that ranged from 4.6 to 8.1%. Even in subsoils, TOC is well distributed especially in the intermediate part of the toposequence. Subsoils of Pedons MP1, MP3, MP4 and MP6 were within the medium values. The high TOC in concave positions or at slope bottom, together with the relatively low temperature and moist condition in Miarayon, have led to the formation of Umbrisols due to the deposition of colluvial and/or alluvial materials.

CEC is the sum of exchangeable cations that a soil can absorb (Brady and Weil, 1999) and therefore should be part of the overall assessment of soil's potential fertility (Landon, 1991). The higher the CEC, the larger the capacity the soil can store the cations which eventually are useful for the plants. Very high CECs are associated with humus compared to those exhibited by inorganic clays especially kaolinite and Fe, Al oxides (Brady and Weil, 1999). Topsoil CEC at pH7 values of Pedons MP1, MP3, MP5, MP6, MP7 and MP9 are >40 $\text{cmol}_{+}\text{kg}^{-1}$ is very high (Landon, 1991). Except for Pedon MP8, all subsoils CEC values were from medium to high. In the intermediate part, SOM is related to CEC, therefore the impact of SOM on the soils is apparent (Figure III-9). Except for Pedon MP5, more amounts of total Ca in all pedons are found in the top horizons (Figure III-10).

Relatively high exchangeable Mg values were detected in Pedon MP9 topsoil (0.89 $\text{cmol}_{+}\text{kg}^{-1}$) and subsoil (0.86 $\text{cmol}_{+}\text{kg}^{-1}$) and in the lowest horizon of Pedon MP1 (0.71 $\text{cmol}_{+}\text{kg}^{-1}$), topsoil (0.88 $\text{cmol}_{+}\text{kg}^{-1}$) and subsoil (0.67 $\text{cmol}_{+}\text{kg}^{-1}$) of Pedon MP2. Of the exchangeable bases, Ca is the most dominant with the highest level in the topsoil (11.05 $\text{cmol}_{+}\text{kg}^{-1}$) of Pedon MP3.

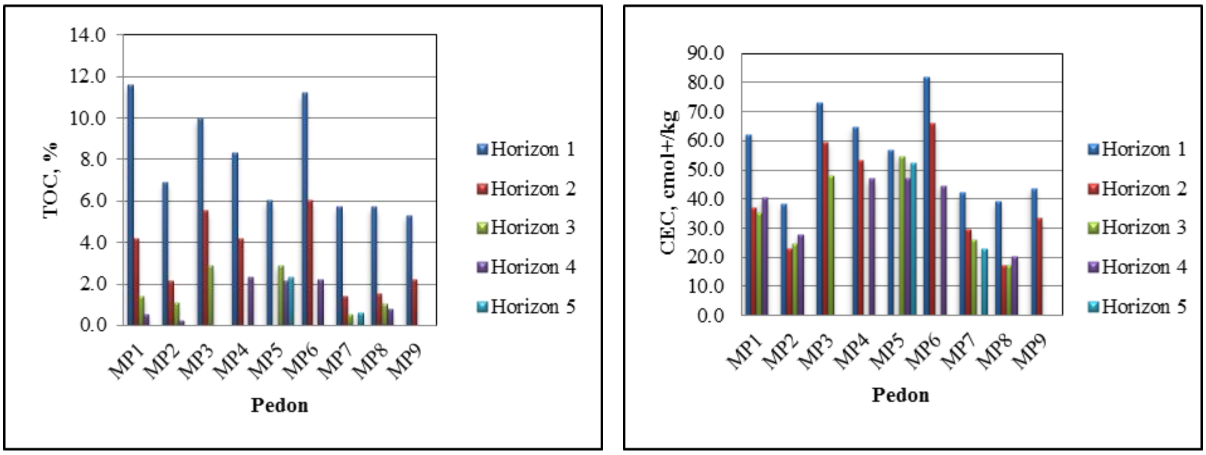


Figure III-9. TOC and CEC of Miarayon topsoils.

Figure III-11 shows the sum of exchangeable bases of the first horizons of all pedons. The intermediate part of the toposequence has relatively high sum of bases because of exchangeable Ca.

First two highest values of exchangeable K are in the subsoils of Pedon MP3 (1.21 $cmol_{+}kg^{-1}$ and 0.98 $cmol_{+}kg^{-1}$) and the rest of the remaining values ranged from non-detectable to 0.29 $cmol_{+}kg^{-1}$ which are considered low for tropical soils (Landon, 1991). Although Na is not a critical element for plants except in excessive amounts, exchangeable values are very low and this element does not pose risk of toxicity to crops.

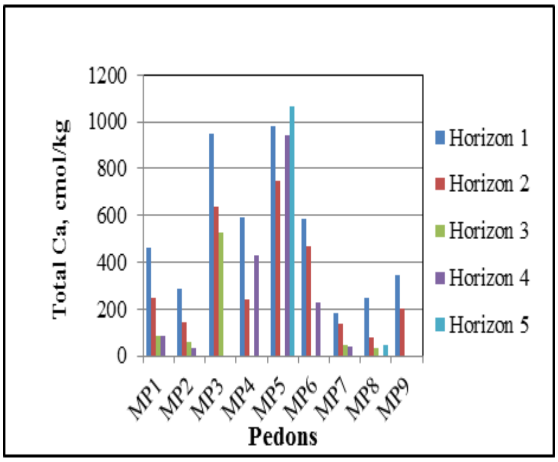


Figure III-10. Total Ca in Miarayon soils.

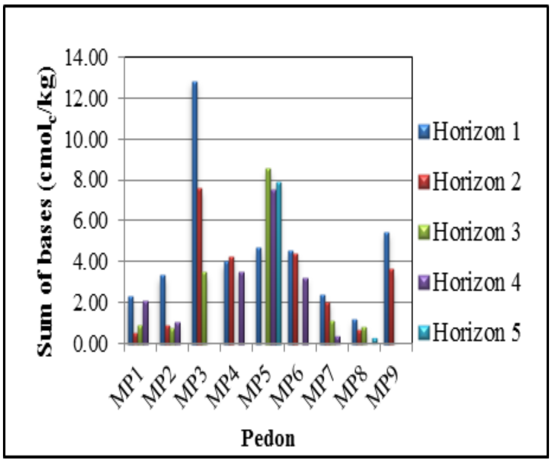


Figure III-11. Sum of exchangeable bases in Miarayon soils.

Potential element reserves can also be reckoned from the total element contents. The total element contents are the supplies of nutrients which can be gleaned from their release during the weathering process. Table III-13 presents the potential element reserves in one hectare at a depth of the first horizon of pedons in Miarayon soils by utilizing the values of total element contents in Lebrun (2011). For the uniformity of data manipulation, the estimation has considered the first 20 cm depth of the soil pit for the reason that crops in Miarayon are shallow-rooted and that cultivation is limited to the topsoil. Using the bulk density values in Van Daele (2012), the weight of soil with a surface area of one hectare at a depth of the first 20 cm depth which is expressed in tons/ha-m was calculated. Nutrient supply was estimated from the total element contents of the first horizon which are expressed in terms of tons of element content per ha-m volume of soil. Furthermore, the data on bulk density was for topsoil only because it cannot be assumed that the density values are the same as those along the one meter-depth of the studied pedons. It can be noted that the intermediate part has the highest amounts of TOC, total element contents of P, Ca, Mg and K. Potential nutrient reserves are also dependent on the bulk density of the soil. The estimated potential nutrient reserves would serve as the potential nutrient that can be lost in the topsoil due to soil erosion.

Table III-13. Potential total element reserves in one hectare at a depth of the pedon's first 20 cm in Miarayon soils.

Location in the Toposequence	Land Unit	Pedon	Soil Quantity			Estimated total element reserve									
			Bulk density(a)	Depth	Soil weight(b)	TOC		P		Ca		Mg		K	
			kg/dm^3	m	t/ha-m	per cent(c)	t/ha-m	mg/100g(c)	t/ha-m	mg/100g(c)	t/ha-m	mg/100g(c)	t/ha-m	mg/100g(c)	t/ha-m
Upper Part	1	MP1	0.727	0.20	1454	11.6	168.66	120	1.74	463	6.73	337	2.90	153	2.22
		MP2	0.809	0.20	1618	6.9	111.64	66	1.07	288	4.65	220	3.56	69	1.11
Intermediate Part	2	MP3	0.732	0.20	1464	10.0	146.40	350	5.12	952	13.93	685	10.02	430	6.30
		MP4	0.955	0.20	1920	8.3	159.36	277	5.13	594	11.40	575	11.04	311	5.97
		MP5	0.873	0.20	1746	6.0	104.76	288	5.03	984	17.18	819	14.30	923	14.37
		MP6	0.683	0.20	1366	11.2	152.99	338	4.62	582	7.95	616	8.41	151	2.06
Lower Part	3	MP7	0.891	0.20	1782	5.7	101.57	82	1.46	183	3.26	180	1.60	32	0.57
		MP8	0.966	0.20	1932	5.7	110.12	147	2.84	248	4.79	223	4.31	58	1.12
	4	MP9	0.910	0.20	1820	5.3	96.46	170	3.09	346	6.29	346	6.30	119	2.17

Note:

(a) Source: Van Daele (2012)

(b) Calculated from the weight of the bulk volume soil in one hectare at first 20 cm depth with reference to their corresponding soil bulk density

(c) Source: Lebrun (2011)

5.5.2. Potentialities of Bendum soils

Soil texture, bulk density, infiltration, field capacity and water retention are the physical soil attributes. The total Mg in some locations is the soil chemical potentiality.

5.5.2.1. Physical potentialities of soils in Bendum cultivated areas

Pedons BP9 has sandy loam topsoil while Pedons BP3, BP5, BP14 have sandy clay loam. Subsoils of the four aforementioned pedons are clay loam to silty clay. It can also be noted that stones, if they are present at plowing depth (20 cm), cannot hamper the tillage operation because they are of manageable sizes. Table III-14 presents soil physical properties of soils in Bendum production areas. The bulk densities of the production areas ranged from 0.91 to 1.26 kg dm^{-3}. The water content at field capacity values (0.40-0.50 cm^3 cm^{-3}) and the possible total porosity in Bendum soils are high but its available water is low (0.09-0.14 cm^3 cm^{-3}).

5.5.2.2. Chemical potentiality of soils in Bendum cultivated areas

Mafic to ultra-mafic rocks represent basic igneous rocks with increasing amounts of Fe, Mg and Ca (Grotzinger *et al*., 2007). Analysis of Bendum rock samples revealed that the ultramafic rocks have high Mg content (Table III-9). Figure III-12 shows the average values of total basic elements content in Bendum profile soil samples. The high amounts of MgO in rocks are also reflected in the analysis results for total basic element content. Magnesium is the highest (Figure III-12). Sodium is not necessarily a critical nutrient until its concentration is too high for the crops. In Bendum production areas, Na concentrations do not pose a threat to the plants as these are very low.

Table III-14. Physical properties of Bendum topsoils.

Location	Pedon	Soil texture(a)	Soil structure(a)	Land condition at investigation	Bulk density(b)	Hydraulic conductivity		Field capacity(b)	Permanent wilting point(b)	Available water	
					kg/dm^3	cm/h(b)	Class(c)	cm^3/cm^3	cm^3/cm^3	cm^3/cm^3 (2)	Irrigation suitability(c)
Toposequence 1	BP3	Sandy clay	Not recorded	Planted with young corn	0.96	9.24	Rapid	0.43	0.29	0.14	Medium
	BP5	Sandy clayloam	Not recorded	Fallow	1.26	0.27	Very slow	0.47	0.36	0.11	Low
Toposequence 2	BP9	Sandy loam	Not recorded	Fallow	1.13	4.54	Moderate	0.47	0.34	0.13	Medium
	BP14	Sandy clayloam	Not recorded	Planted with rubber trees	0.91	33.21	Very rapid	0.40	0.32	0.08	Low

Source: (a)Richelle (2010)
(b)Van Daele (2012)
(c) Landon (1991)

Table III-15 presents the potential element reserves in one hectare at a depth of the first 20 cm of pedons in the soils of Bendum cultivated areas. Bulk density values are derived from Van Daele (2012). The calculation procedures in determining the soil weights use the formula for Miarayon soils. The figures for total element contents are from Barbieux (2012) and estimations were made similar to the Miarayon procedure. It can be noted that the bulk density of soil is influential in the potential element reserves. The potential element reserve is the estimate of the amounts of essential nutrients that could be found in the top soil which is also the potential amounts of nutrients that can be lost due to soil erosion.

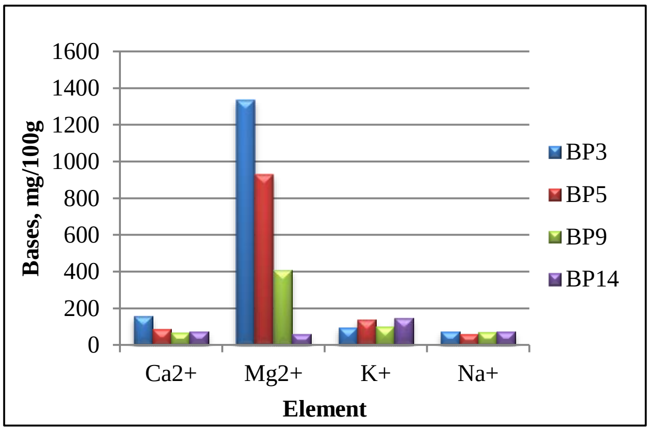


Figure III-12. Average values of total basic element content in each profile for Bendum soils.

Table III-15. Potential total element reserves in one hectare at a depth of the pedon's first 20 cm of soils in Bendum cultivation areas.

Location	Land Unit	Pedon	Soil Quantity			Estimated total element reserve									
			Bulk density(a)	Depth	Soil weight(b)	TOC		P		Ca		Mg		K	
			kg/dm³	m	t/ha-m	per cent(c)	t/ha-m	mg/100g(c)	t/ha-m	mg/100g(c)	t/ha-m	mg/100g(c)	t/ha-m)	mg/100g(c)	t/ha-m)
Toposequence 1	Cultivated	BP3	0.964	0.20	1446.0	2.0	28.92	27	0.39	174	2.52	1211	17.51	98	1.42
	flat surface	BP5	1.257	0.20	1885.5	2.4	45.25	51	0.96	164	3.09	872	16.44	101	1.90
Toposequence 2	Cultivated	BP9	1.127	0.20	1690.5	3.4	57.47	32	0.54	133	2.25	578	9.77	114	1.97
	flat surface	BP14	0.912	0.20	1368.0	2.9	39.67	48	0.66	104	1.42	69	0.94	63	0.80

Note:

(a) Source: Van Daele (2012)

(b) Calculated from the weight of the bulk volume soil in one hectare at first 20 cm depth with reference to their corresponding soil bulk density

(c) Source: Barbieux (2012)

5.6. Soil Constraints

Soil constraints can be attributed to morphological limitations and chemical inadequacies that are deterrent to crop growth. Morphological limitations were steep slopes, field undulations, stoniness and presence of rock outcrop, waterlogging and forest encroachment. Chemical inadequacies are low pH, Al toxicity risks and low available P.

5.6.1. Morphological limitations of Miarayon soils

Observed morphological limitations are varied and are according to pedon location along the toposequence. Cultivation fields in the upper part are constrained with slope. It was observed that the production sites has encroached the upslope. Steep slope makes tillage operation difficult and cultivation would also hasten soil erosion. It was further observed that cultivation of steep slope had no attempt of employing soil erosion protection measures. Farmers would plow the field more than once for the land preparation in a cropping. During the last plowing, it does not matter whether it is along or against the direction of the slope (Figure III-13).

Prevalence of stones especially if it is disintegrating assures the supply of freshly weathered soils laden with the inherent nutrients from the parent materials. Stones in the surface and in the profile affect the infiltration and hydraulic conductivity of the soil. The more stones that are in the soil profile, the smaller are the usable soil volume. The presence of rock outcrops and stones at plowing depth will hamper tillage operations. Stoniness and presence of rock outcrops are evident in the intermediate part. Ninety per cent of fine gravels and large boulders were found in Pedon MP3 at about 50 cm depth. At MP5, the surface of the field has 20% stoniness and down to 85-100 cm depth has 60% rock fragments. It is further observed that stones were removed to be used as fence of the production plot. Stones and rocks slowed down the animal-drawn plowing operation.

Landform, slope angle and microtopography are factors that affect water management (FAO, 1989). Flat and convex surfaces are more exposed to insolation and the evaporation of water in soil is high. Moisture tends to accumulate at the bottom of the slopes and in concave surfaces because these are less exposed to the heat of the sun and the surrounding environment. Slope variations in the production plots were evident. Highly undulating land makes soil tillage and management more complicated than relatively flat areas. This would cause non uniformity of crop growth because soil nutrient and moisture are not evenly distributed within the field.

Figure III-13. Physical constraints of Miarayon soils. (Photos: L. Bock and G. Calalang)

5.6.2. Chemical property limitations of Miarayon soils

At pH <5.5, metallic elements will be mobilized and this will be released to the soil solution. Although metallic elements are micronutrients for the plants, for instance excessive amounts of Al and Fe would create toxicity risk to plants. At this pH <5.5, P combines with Al and Fe in soil to form complexes making P unavailable to plants (Landon, 1991). In Table III-16, Ooms (1992) outlined a guideline in interpreting soil pH values (1:2.5, soil-water ratio) for highland soils of Northern Thailand.

Table III-16. Guidelines in interpreting soil pH values (1:2.5 soil-water ratio).

Rating	pH value	Interpretation
Very high	>8.5	Strongly alkaline soils, Ca and Mg likely to be unavailable, maybe high Na, possible B toxicity
	7.6-8.4	Moderately alkaline, decreasing availability of P and B to deficiencies at higher values.
High	7.1-7.5	Slightly alkaline, above 7.0 increasing disadvantage of deficiency of cobalt (Co), copper (Cu), Fe, manganese (Mn) and zinc (Zn).
	6.6-7.0	Near neutral, preferred range for most crops.
Medium	6.0-6.5	Slightly acid
	5.3-5.9	Moderately acid, lower end of range, too acidic for some crops
Low	4.6-5.2	Strongly acid, possibly Al toxicity and excess Co, Cu, Fe, Mn and Zn, deficient in Ca, K, N, Mg, molybdenum (Mo), P, S and B (below pH 5)
Very low	<4.5	Extremely acid

Source: Ooms (1992)

Miarayon topsoils are generally acidic (pH H_2O, 4.7-5.5). The pH H_2O in topsoil and subsoil in the upper part (Pedons MP1 and MP2) and lower part (Pedons MP7, MP8 and MP9) of the toposequence are <5.5. Miarayon rock sample analysis results revealed that Al shares 18.75% of the total solid elements (Maurissen, 2014) which is the source of Al in the soil solution that can affect the availability of other essential nutrients. Soils with more Al consequently have less basic elements available and Al affects the absorption of other nutrients by crops. Iron content of 7.53% in the rock sample (Maurissen, 2014) when released into the solution will affect the mobility of other nutrients too. Analysis of composite samples from the vicinities of Pedons MP1 and MP2 (upper part) and Pedons MP7 and MP8 (lower part) is always <1 mg/100g although total P values had reached to 350 mg/100g. Phosphorous retention ranged from 60-97% (Barbieux, 2012). Large part of P is in organic form which is a component of the organic matter in soil. Low P availability can be considered as a constraint because it cannot be utilized right away by the growing crops although these are slowly released in the soil solution with time.

Exchangeable Al in the surface horizons of MP7 and MP8 had 1.59 and 1.81 cmol₊kg^{-1} respectively. However, the still high topsoil cation exchange capacities (CEC) of MP7 and MP8 (42.0 and 38.9 cmol₊kg^{-1}) may tend to buffer the risk. The ratios of exchangeable Al and ECEC are shown in (Table III-17). Sensitive crops can possibly be affected if Al :CEC is ≥ 30% (Landon, 1991). For the purpose of assessing Al toxicity risk, the ECEC is used because this is the CEC at which the condition of the soil is simulated. In Miarayon, MP1, MP7 and MP8 have ratios >30% and therefore these locations have the potential risk of Al toxicity. If we compare the CEC values of all pedons in Miarayon, MP7 and MP8 pedons have the lowest topsoil CEC and TOC values (Figure III-14). This can be a sign that land degradation in these locations had reached.

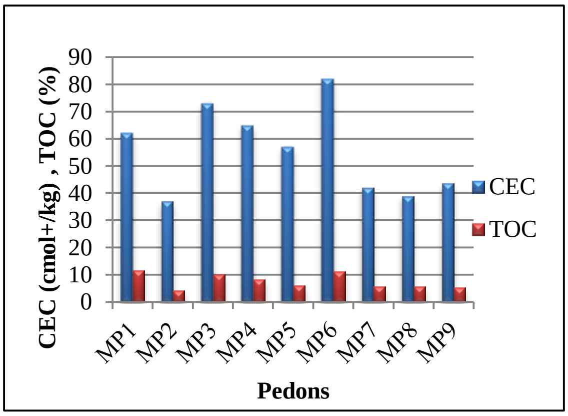


Figure III-14. CEC and TOC of pedon topsoils in Miarayon.

Table III-17. The ratio between exchangeable Al and ECEC of top horizons pedon samples of Miarayon.

Parameter	MP1	MP2	MP3	MP4	MP5	MP6	MP7	MP8	MP9
pH H_2O	5.2	5.2	5.5	5.0	5.2	5.0	4.9	4.7	4.8
Exch. Al (cmol₊kg^{-1})	1.17	0.56	0.17	1.27	0.84	1.04	1.59	1.81	1.08
ECEC (@ pH 4.65 (cmol₊kg^{-1})	3.83	4.32	13.42	5.64	5.80	5.77	4.41	3.49	6.99
ExchAl:ECEC (%)	30.55	12.88	1.27	22.52	14.48	18.02	36.05	51.86	15.45

Note: Exchangeable Al and ECEC values are from Lebrun (2011)

5.6.3. Morphological limitations of soils in Bendum cultivation areas

Figure III-15 shows the soil morphological constraints of Bendum soils. There are cultivation fields that are constrained with steep slope. It was observed that there are production sites that are situated in fragile slopes (>18%) that are no longer suitable for planting of shallow rooted crops. Similar to the upper part of Miarayon, the cultivation of steep slopes in Bendum has no attempt of employing soil erosion protection measures. Since Bendum is a mountainous area, generally cultivated fields have undulating surfaces. There are some parts in Bendum production areas which are waterlogged. In Toposequence 1, the areas between Pedons BP3 and BP5 have stagnant water, which are also used as wallowing sites for water buffaloes. In Toposequence 2, this can also be found in the vicinity of Pedon BP9 and in the road towards Pedon BP14. In Toposequence 2, silty clay subsoils are found in Pedon BP9 and BP14. Soils and landslides are evident in Bendum vicinities.

Figure III-15. Physical constraints of Bendum soils (Photos: G. Calalang and L. Bock)

5.6.4 Chemical limitations of soils in Bendum cultivation areas

Bendum topsoils are highly acidic with pH H_2O that range from 4.0-5.5. In the production areas of the two toposequences, both topsoil and subsoil of Pedons BP5 and BP14 had pH value of <5.5. Subsoil of Pedon BP3 has also pH value of <5.5. Pedon BP9, the pH in the topsoil is within the threshold limit and the subsoil has pH values of >5.5. Table III-18 presents the P concentration values, total Al and total Fe. BP14 which has the lowest pH had the highest amounts of total Al and the lowest amounts of total Fe.

The data shows that in these soils, available P is very low (<1mg/100g). Phosphorus retention ranged from 78-93%. Bendum soils have low organic matter, much lower than in Miarayon that ranged from 2.0-3.4% in the topsoils and 0.10-2.8% in the subsoils. The presence of active Fe (0.16-0.71%) may inhibit the availability of other nutrients. The unavailability of P could worsen if the nutrient is blocked by either Al or Fe hindering the plant absorption of P.

Table III-18. P concentration values, total Al and total Fe of soils in Bendum cultivation areas.

Location	Pedon	Horizon	pH*	Total P (mg/100g)**	P retention (%)**	Total Al (%)**	Active Al/Alox (%)**	Total Fe (%)**	Active Fe/Feox (%)**
Topo-sequence 1	BP3	H1	5.5-6.0	27	93	6.8	0.22	25.9	0.40
		H4	5.0	12	90	7.8	0.30	26.0	0.32
	BP5	H1	4.5-5.0	51	93	9.7	0.21	23.1	0.21
		H4	-	13	90	9.6	0.14	27.3	0.14
		H5	4.5-5.0	11	89	8.7	0.16	27.3	0.16
		H6	4.0	9	89	9.9	0.27	17.1	0.27
Topo-sequence 2	BP9	H1	5.5	32	93	9.5	0.45	25.1	0.45
		H4	-	6	85	9.0	0.27	35.7	0.27
		H5	6.5	4	78	9.2	0.42	35.1	0.42
		H6	6.5-7.0	6	86	12.2	0.34	31.0	0.34
	BP14	H1	4.5	48	92	15.1	0.23	11.4	0.23
		H4	4.0	37	91	13.6	0.71	10.8	0.71

Source: *Richelle (2010)
**Barbieux (2012)

Volcanic rocks in Bendum have relatively high amounts of Ca and Mg, however, low concentrations are detected in some soil pedons. Moreover, when there is severe lixiviation of bases in soils with high amounts of Fe, what would be left will be unproductive laterites. However, at the moment, soils in Bendum have not reached yet this aforementioned severe situation. The presence of allophanes in soils, of Nitisols and Cambisols show that the soil does not desperately need the moves for utmost interventions. However, such are warning signs that conservation should be part of soil management.

6. Chapter conclusion

The specific questions that were answered to achieve the study objectives were on the similarities and differences between two sites in terms of rocks and soil forming minerals, soil morphology and classification, the soil potentialities, and the soil constraints.

6.1. Soil classification and morphology comparisons between Miarayon and Bendum soils

Cambisols, Umbrisols, and the Para ‘acric’ Cambisol are the Soil Groups that were noted in Miarayon. Cambisols, Nitisols and Acrisols were observed in Bendum production areas. Miarayon has dark topsoils that ranged from brownish black to dark brown. The subsoils have brown chroma: from dark brown, brown to yellowish brown except on the area which has Para ‘acric’Cambisol where the subsoil has reddish color. Bendum has brown, bright brown and reddish brown topsoils, with dark brown in one profile that was near the Pulangui River. For the subsoils, most of these ranged from bright brown to yellowish brown, with two profiles having reddish brown subsoils and one with greenish gray subsoil. Miarayon profiles medium soil texture with high quantities of coarse fragments in the profile. Bendum soils were generally heavy compared to Miarayon soils with little or no weathering of rock fragments in the profiles.

6.2. Soil forming minerals detected in Miarayon and Bendum soils

The only Miarayon rock formation is the Pliocene-Quaternary volcanic pyroclastics which is relatively recent. The five Bendum rock formations are relatively earlier. These are the ultrabasic rocks from the upper Cretaceous-Paleogene period, volcanic agglomerates from the Oligocene-lower Miocene period, sandstone conglomerates from the upper Miocene-Pliocene period, sandstone and shale from the lower-middle Miocene period. A number of minerals that were detected in soils are common in both sites (Barbieux, 2012 and Maurissen, 2014).

The minerals that are found in Miarayon soils are varied, except for gibbsite which is present in all soil profiles in the toposequence. Hematite and albite of the alkali feldspar are identified in the upper and lower part of the toposequence, but is not spotted in the intermediate part. Plagioclase feldspar where anorthite and labradorite belong and amphibole and goethite are observed in the intermediate part. For Bendum, hematite, feldspar and quartz are present in the areas where ultramafic rock samples were taken. Andesite and anorthite are present in soil samples collected from the pit location where pyroclastic rocks samples were taken. Gibbsite is present in all Bendum soil profile samples that were examined.

6.3. Physical properties of Miarayon and Bendum soils

Miarayon soils are characterized by sandy loam to sandy clay loam in the top horizons and silty clay loam to silty clay in the sub horizons. Bendum soils are sandy clay loam at the top horizons and silty clay to clay loam. Data for hydraulic conductivity are highly variable. For both sites, it can be observed that those areas which were cultivated at the time of investigation have rapid to very rapid hydraulic conductivity. The data further show that the macroporosity which is caused by plowing and other soil disturbances have affected the soil permeability. The water contents field capacity of the soils in both sites are high but the water holding capacities are low. This would mean that the water content at permanent wilting point of these soils is high. If the area shall be irrigated, the soil needs more amounts of water in order to satisfy the soil water requirement until the plants will be able to extract water from the soil. The average bulk density in Miarayon soils is lower compared to Bendum and therefore, Miarayon soils are probably suitable for root crops.

6.4. Miarayon and Bendum soil potentialities

Soil texture in Miarayon topsoil is coarser than in Bendum. Miarayon and Bendum have high hydraulic conductivities because these are associated with tillage. However, Miarayon soils have higher available water than Bendum soils. This would mean that Bendum soils can hold water tightly making it unavailable for plant's use. Although Miarayon soils have low bulk densities compared to Bendum soils, these values (bulk densities) are within the low to medium level

Miarayon soils have high TOC which are also well distributed in the subsoils. Bendum soils have low TOC values, even very low in subsoils. In Miarayon, Ca is a dominant cation while in

Bendum, it is Mg. Miarayon soils TRB are well distributed in the profile of two pedon locations in the middle part of the toposequence (MP3 and MP5). Similarly, Bendum soils TRB are well distributed in the profile of two pedons (BP3 and BP5) of the Toposequence 1. Potential nutrient reserves can be influenced by the total element contents, bulk density and thickness of the soil horizon.

6.5. Miarayon and Bendum soil constraints

Low bulk density can also be considered as a constraint because this would make topsoil vulnerable to soil erosion which Miarayon soils have. Some of Miarayon and Bendum fields have undulating soil surfaces. Presence of rock outcrops and stones within the profile are found in the intermediate part of Miarayon toposequence while in Bendum production areas, no rock outcrop and very few weathered stones were recorded. Both locations have waterlogged areas.

Both sites have low pH (<5.5). Miarayon has high proportions of exchangeable Al in the topsoils of pedons in the upper and lower parts of the toposequence which denotes an eminent risk of Al toxicity because of its low pH. The presence of high proportions of active Fe may inhibit the plant’s intake of nutrients. Both sites have low available P although the total P is relatively high. The high proportions of Mg and Fe in Bendum soils may have come from those ultramafic rocks which are found in the rock formations of the area.

6.6. The natural and anthropogenic influences in Miarayon and Bendum soil development

Development of Miarayon and Bendum soils in cultivated areas are both influenced by natural and anthropogenic factors. The parent rock materials have naturally influenced the total element contents in soils in both areas. This is highlighted by the congruency of some elements that are present in rock samples, in soil minerals and in the profile soil samples. The geomorphology too had influenced the classification of soils are highlighted by the soil color, the thickness of top horizons, and in some observations, the total concentration of total elements in the profile. The anthropogenic influences are the soil cultivation itself, the soil management practices particularly the application of fertilizers and lime as amendments. Applications of agricultural inputs are easily spotted by their concentrations in the top horizons of the soil profile.

This part of the study was to investigate and establish information on the physico-chemical characteristics and properties, the potentialities and constraints of highland soils. Information gathered can be a sound guide on soil management and land use choices particularly in those undifferentiated areas of Bukidnon highlands. However, there is need for these data to be linked with their effects on highland cultivation. This can be done by cross referencing the information with topsoil fertility and crop performance in terms of yields which is the subject in Chapter IV.

Chapter IV

Topsoil fertility assessment at plot level in association with predominant crop yields in Bukidnon highlands, Northern Mindanao, Philippines

1. Chapter overview

Favorable conditions for crop growth can be gauged according to the standards which are the results of scientific studies on soil physical, chemical and biological conditions. These are known as soil quality parameters. Keeping other factors constant (climate and soil physical factors), crop yields are indicators of the soil nutrient status and the appearance of symptoms can be visual manifestations of nutrient anomalies. Natural and anthropogenic factors have caused the variations of soil fertility in a catchment. The natural factors are the parent rock materials and processes that influence soil development. Anthropogenic factors are those soil and crop management practices that modify the soil conditions such as addition of external inputs to achieve the desired soil quality and the length of time the soil had been cultivated. The subject of investigation in this soil fertility assessment and monitoring were the topsoil samples that were taken from selected plots that are closely located in the studied soil pedons. These samples were taken at 20 cm depth which was based on the depth of penetration of an animal-drawn plow. The depth of penetration is the vertical distance from the point of share up to the moldboard of the plow where the ribbon of soil is overturned during plowing.

Fertility assessment and monitoring at plot level were conducted in the Miarayon and Bendum sub-catchments through the interpretation of topsoil analyses results and measuring the yields of predominant crops. The crops that were examined in Miarayon were carrot (*Daucus carota* var. *sativus*), corn (*Zea mays* L.) and potato (*Solanum tuberosum* L.), and in Bendum, corn, ginger (*Zingiber officinale* L.) and sweet potato (*Ipomea batatas* L.). These crops that were measured for their yields were chosen because they are predominantly cultivated in the study sites and the crops are all pulled out every harvest thus the yields can be quantified in a single cropping. The investigated crop plot for yield measurement results were georeferenced and therefore these point out to which part of the catchment has better crop production yield and the soil fertility as well. Associations between topsoil analyses results and the yields of these crops were tested to understand the relationships between the two sets of parameters. Crop yields can be indicators of topsoil quality status and one can estimate the yield at a particular level of nutrients in the soil.

2. Significance of the study

Commercial vegetables like carrot, potato, cabbage (*Brassica oleraceae* L., *var. capitata*), cauliflower (*Brassica oleraceae* var. *botrytis*), pepper (*Capsicum spp.*), tomato (*Lycopersicon esculentum* Mill. var. *esculentum*) and pea (*Pisum sativum*) are mostly produced in Bukidnon Province. Estimates of carrot and potato production volumes in 2012 were 1,115 and 6,551 metric tons, respectively (BAS, 2013). The regional production of these two commercial vegetables is only found in Bukidnon.

Corn is a primary crop of Bukidnon. The yellow variety dominates the production which is mostly used as raw materials for poultry and livestock feeds. The white variety is the secondary staple food and is a substitute for rice (*Oryza sativa* L.). In Miarayon and Bendum, white corn is produced for home consumption. Sweet potato and other root crops are sources of food in the highlands therefore are also important. When rice and corn are not accessible, root crops are good substitutes. Abaca, coffee, rubber and ginger are the cash crops of Bendum farmers.

Volcanic soils that can support intensive commercial farming (Raymundo and Vicente, 1985; Poudel and West, 1999), like those in Bukidnon areas where high value commercial vegetables are produced, are the natural inheritances that need to be sustainably managed. Furthermore, most of the information on production of aforementioned crops in Northern Mindanao and Bukidnon are on the macro scale. The scarcity of studies on how these crops are actually produced by farmers as well as on the yield quantities at field level have merited the conduct of the study. Soil fertility levels can be calibrated with crop yields by looking into the associations of these two different groups of information.

In developing the SRS for the LandIS, there are parameters that need to be considered to contribute to the pool of information. The following research questions were addressed and the answers are elaborated in the discussion of results:

(i) How do topsoil nutrient levels have indicated the fertility of highland soils? How do the values of parameters differ in terms of location?

(ii) What are the prevalent soil and crop management practices in the highlands? How do these practices affect the topsoil fertility and crop yields of a location?

(iii) How much are the yields of the predominant highland crops? How do yield values differ in locations?

(iv) What are the relationships between topsoil quality and crop yields? How do these two sets of information associate with each other?

3. Objectives of the study

This part of the study had sought to assess and monitor the topsoil fertility by laboratory analyses and measurements of predominant crop yields in the highlands of Bukidnon. Investigation objectives were: (i) to determine the topsoil basic nutrient levels and compare the values in terms of locations within the sub-catchment, (ii) to find out the yields of predominant crops and compare them based on their locations within the sub-catchment, (iii) to identify farmer’s crop management practices and determine how these practices had affected the topsoil fertility levels and crop yields, and (iv) to match the topsoil nutrient levels with crop yields.

4. Study site description

The study site description focuses on the specific locations of the production areas of Miarayon and Bendum. This explains the locations of the plots where topsoil samples were taken and crop yields were measured.

4.1. Miarayon crop production location

Miarayon investigation on topsoil fertility assessment and yield measurements were conducted in the two production locations along the toposequence (Figure IV-1), in Salsalan and Mambuaw. The center of Miarayon which is positioned at about 1,450 m asl, was considered as the reference point of the two compared locations. Salsalan, a *sitio* (hamlet) is located in the intermediate part (1,400-1,600 m asl) of the toposequence, southwest of Miarayon center.

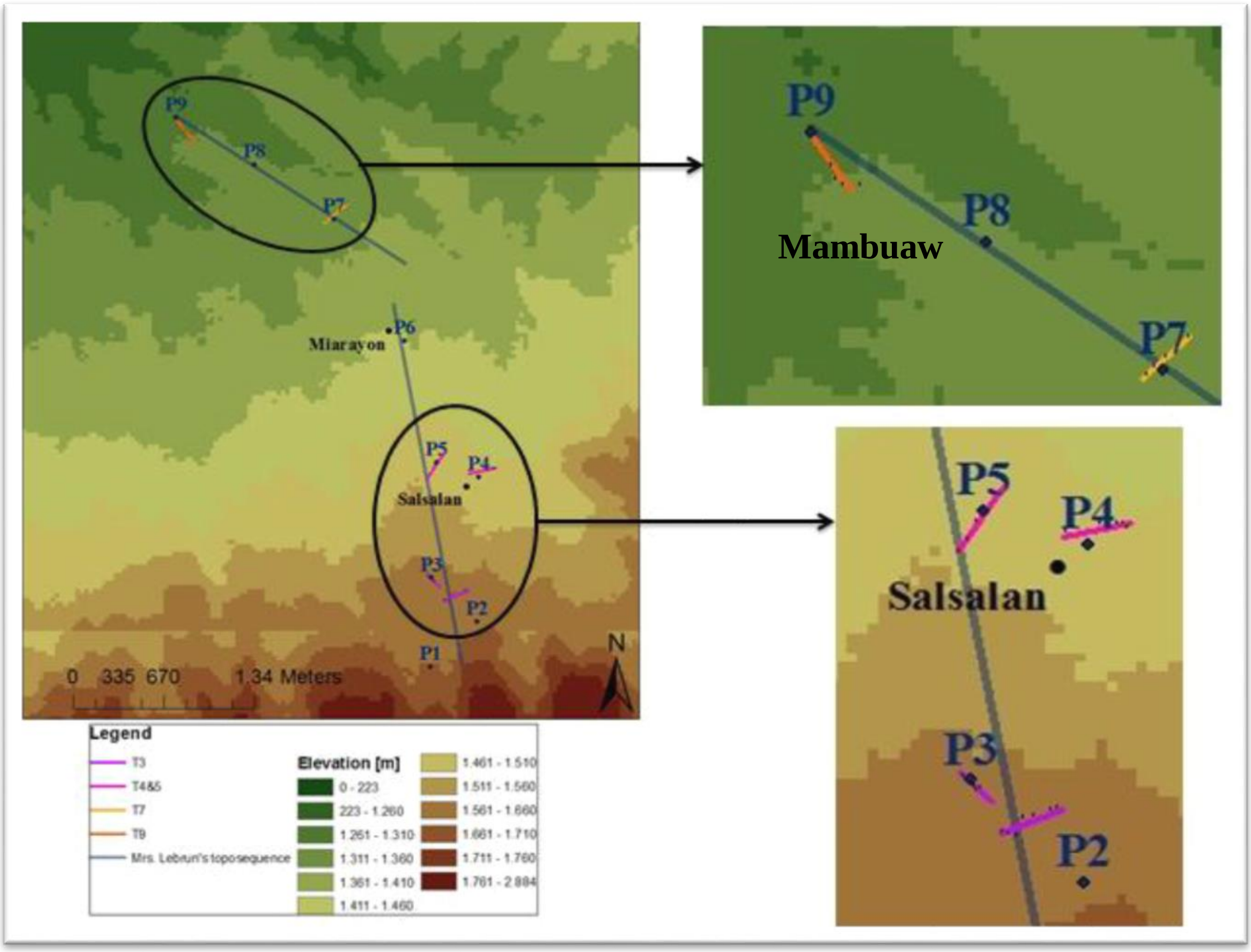


Figure IV-1. Miarayon field yield measurement locations (Barbieux, 2012)

4.1.1. Miarayon crop plot areas

According to the last survey of Miarayon, Salsalan has 121 households and all of them are small farming families. Houses are concentrated in the *sitio* and farmer's production areas are in proximity. Salsalan is a relatively new settlement.

Mambuaw is located at the lower part (1,400-1,300 m asl) of the toposequence, northwest of Miarayon center. According to residents, Mambuaw was once the location of the old Miarayon settlement and was cultivated more than 50 years ago. At present the area is used for crop production only. Cultivators in the area come from different *sitios* of Miarayon and from adjacent *Barangays* Lapok and Lirongan. Farmers whose production areas are located in Mambuaw have to walk few kilometers from their homes to reach their work places.

The dominant crops grown in the village are carrots, corn and potatoes. Other grown high value commercial vegetables are cabbages, cauliflowers, tomatoes, peppers and peas. The vegetables are for cash and the corn is for home consumption. Bulk of the farm produce is directly transported to the Cagayan de Oro City Westbound Terminal where vegetable wholesale and retail activities are conducted. The vegetables are supplied to other points in Mindanao and the Visayas islands.

4.1.2. Miarayon crop plot sizes

Measurements of plot sizes were taken from 75 production plots and 19 fallow fields at elevations between 1,900-1,300 m asl using a global positioning system (GPS) unit (Table IV-1). Most of the production plots were less than 2,500 m^2. Corn had both the smallest and the largest plot sizes. The family is the source of farm labor and the amounts of farm inputs are dependent on the money which is available from the local financiers. These are among the reasons why most of the farmers do not go into bigger plots because these would be difficult for them to maintain.

Table IV-1. Sizes of production and fallow plots in Miarayon.

Land use		Number of plots surveyed		Largest plot (m^2)	Smallest plot (m^2)	Mean plot size (m^2)	Plot modal class (m^2)	Number of plots
All production areas		75		6,386	127	1,621	1,250-1,750	16
	Carrots		28	4,178	409	1,462	750-1,250	9
	Corn		24	6,386	127	1,881	500-1,500	7

	Potatoes		23	3,644	160	1,544	250-750	7
Fallow fields			19	8,672	419	2,042	500-1,500	9
TOTAL			94					

4.1.3. Crop plot production management practices in Miarayon

In 2012, the estimated area in Bukidnon that were devoted to carrots and potatoes were 104 and 550 ha respectively (BAS, 2013). Estimated area for corn production in the Province is 192,100 ha where the yellow corn had occupied 85.7% and the white corn had 14.3% (BAS, 2013). Reported average farm size in Bukidnon is 2.7 ha (PSA, 2004). In Miarayon, the fields are divided and cultivations are done by plots. Thus, in the farmer's production area, carrots, corn and potatoes may all be present at different stages of growth. Farmers were uncertain on the sizes of the plots they were cultivating. Thus when fertilizers and pesticides were applied, the application rates of these could not precisely be determined.

Soil tillage is done by an animal-drawn plow with a furrow slice depth of 20 cm. The cow (*Bos taurus*) is the draft animal for plowing. These animals are appropriate in Miarayon because the fields in the area are dry. Although the land is generally plowed twice in intersecting direction, in the second plowing, farmers do not observe the direction whether it is along or across the contour. In plots located on high slopes, farmers do not attempt to provide soil conservation measures such as retardants for soil erosion. Farmers do not assess the soil fertility before planting. Over or under application of fertilizers can happen because the amount of fertilizers applied would depend on the availability of the farmer's capital.

4.1.3.1. Potato

The seeding rate of potato plot is measured in terms of boxes. Farmers adopt the bed planting method in which mounds of earth are constructed for the laying of tubers. The number of boxes would depend on the size of the plot. The typical distance of rows on center of a double bed planting is 110 cm. The gap between plant hills in a row is estimated using the *dangaw*. The *dangaw* is the distance between the tip of the thumb and the tip of the middle finger when spread. Chicken dung mixed with rice hulls are added as basal application on the furrow. Half of the amount of complete fertilizer (14-

14-14) is applied also as basal fertilizer. For a growing season, there is no definite amount of fertilizers applied because this would depend on the available resources the farmer has. The furrows are left open until after one month. When the leaves of the plant are already growing, the other half of the fertilizer is again applied as side dressing and then the furrows are closed manually using a grab hoe. When furrows are closed, farmers spray pesticides every five days when the weather is good or every three days during rainy periods for two months. The length of the growing period of potato in Miarayon is about three months.

4.1.3.2. Carrot

The seeding rate of carrot is according to the number of cans of seeds that are planted per unit area. Seeds are purchased in the local agricultural shops or these are provided by plot financiers. Direct seeding is practiced in planting carrots using a plastic bottle with a hole punched on its lid that serves as the seed metering device. Planting beds are either single or double with variable widths from 1-1.6 m. During seeding, the number of seeds laid is not controlled. After one month from seeding, thinning is done to control the plant population. Depending on the monetary resources of the farmers, weeding is done once or twice during the cropping period. If the farmer has no money to pay for the laborers, the thinning is the only weeding activity that can be done and the weeds will be left to grow until harvest time. Farmers apply both organic and inorganic fertilizers. However, similar to potato production, there is no definite application rates that are followed. Organic fertilizers are chicken dungs mixed with rice hulls. Inorganic fertilizers mostly are the complete (14-14-14), urea and muriate of potash. Furthermore, application of fertilizers varies because this would again depend on the farmer’s money to buy the inputs. Similar to potatoes, pesticides are applied every five days if the weather is fine and every three days during rainy periods. The growing time length is for 3.5-4 months.

4.1.3.3. Corn

Farmers do not apply any fertilizer on the soil in corn plots. Since corn follows either on potatoes or carrots which are applied with fertilizers, the crop may scavenge the remaining nutrients from fertilizer application. The only maintenance activity for corn is weeding. The plot is kept clean in order to get rid of farm rats that infest in corn areas. Invasion of wild hogs in plantation areas is not a problem in Miarayon. Farmers apply pesticides to control corn stemborers.

4.2. Bendum production areas

There were two specific locations where the fertility assessments were conducted in the production areas of Bendum. The sampling plots chosen were those around BP3 and BP5 along Toposequence 1 and BP9 and BP14 along Toposequence 2 at elevations between 700-800 m asl. Bendum is still identified as forest area. However, many of the areas were already cleared for crop production. Parent rocks around BP3, BP5 and BP9 are ultramafic rocks and around BP14 are pyroclastic deposits. Figure IV-2 shows the sampling locations for the topsoil fertility assessment and field yield measurements in Bendum production areas.

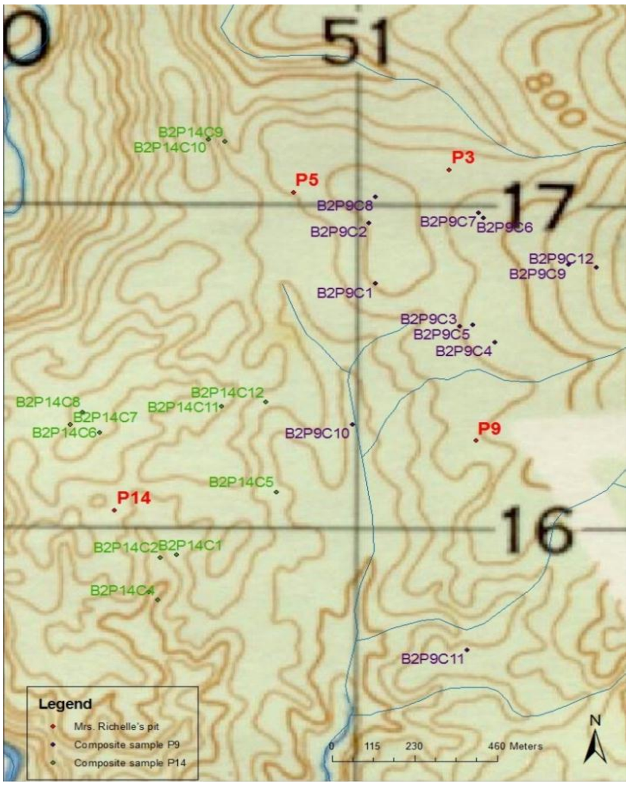


Figure IV-2. Locations of Bendum soil sampling and yield measurement plots (Barbieux, 2012).

4.2.1. Crop production management practices in Bendum

Bendum farmers produce both food crops for home consumption and cash crops. Crops for food are banana, yellow and white corn, lowland rice, sugarcane, root crops and some fruit trees.

Common root crops are cassava, taro (*Colocasia esculenta* (L.) Schott), peanut (*Arachis hypogaea* L.), sweet potato and ginger. Cash crops are rubber, coffee, abaca, ginger and cassava. Soil tillage in Bendum is done by plowing using an animal-drawn plow with a depth of cut of 20 cm. The water buffalo (*Bubalus bubalis*) is used as draft animal because they are suited in wet soil cultivation. The availability of waterlogged areas in Bendum makes it favorable for the water buffaloes because these animals need wallows to cool their bodies and reduce thermal stress.

Figure IV-3. Unmaintained plots or due to lack of labor (a) corn plot and (b) ginger plot in Bendum production areas.

Most of the farmers do not apply fertilizers and pesticides on their crops. They depend on the family members as the source of farm labor. Because of farm area size and with scarcity of labor, plots were usually left unmaintained and weeds were allowed to grow (Figure IV-3). Food plants such as corn and sweet potatoes are hosts of farm rats and wild hogs. Plots which are planted with short term crops are diversified. Cash crops such as rubber and coffee are planted in regular pattern. When rubber and coffee are still young, these are intercropped with corn. Abacas are allowed to grow in succession forests.

Even in small areas, farmers practice crop diversification which is a mixture of short term and long term crops. Young abaca plantation is intercropped with corn and coffee with ginger (Figure IV-4). There were areas in which different species of root crops were present like cassava, taro and sweet

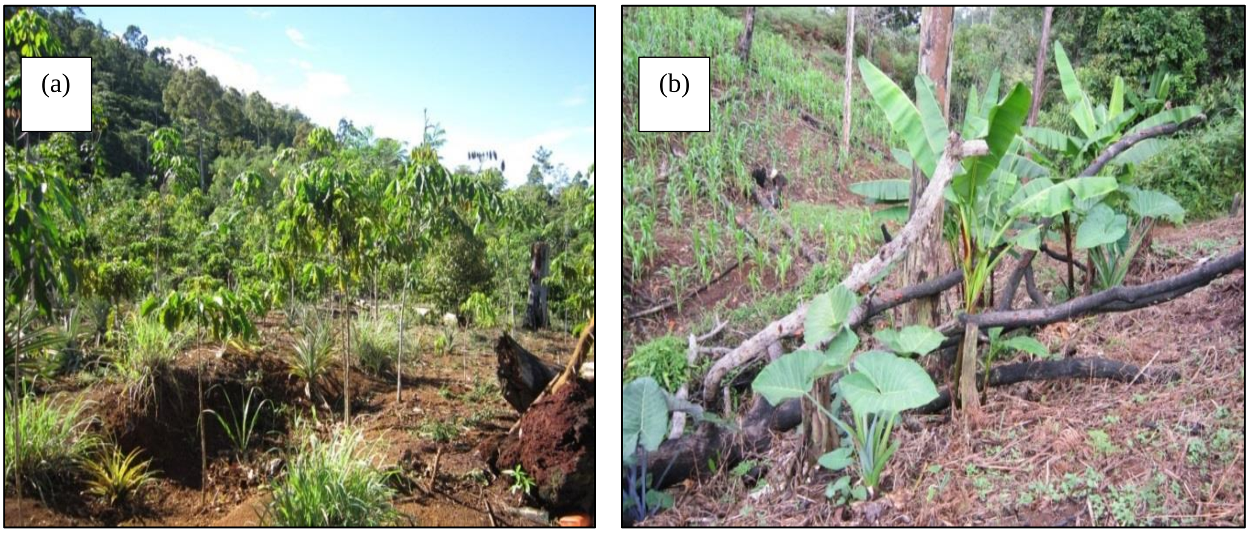


Figure IV-4. Crop diversification in Bendum, (a) coffee, rubber and ginger, (b) corn, abaca and taro.

potato. There were also areas that were fallowed and abaca plants were also grown while the forest is regenerating. However, rice cultivation is already done permanently. For large plants like coffee and rubber, it was also observed that these types of cultivation are sedentary.

4.2.2. Bendum crop plot sizes

Table IV-2 shows the crop plot sizes of Bendum production areas which are planted with corn, ginger and sweet potato, abaca, coffee and rubber. Four plots were measured for each particular land use. Of the 24 plots that were measured for their areas, the mean size is 1,981 m^2. The smallest size is 106 m^2 which was planted with corn and the largest size is 7,449 m^2 which was planted with coffee. Those areas which are planted to rubber and coffee are relatively large. Coffee and rubber are for raw materials, food and non-food respectively. The smallest mean area is ginger although it is a food crop. This is because the crop is not a staple food but it is used as spice. Abaca also is small because in the area, it does not exist as an open plantation but is mixed with forest trees.

Table IV-2. Plot sizes of predominant crops in Bendum cultivation areas.

Plot	Size (m^2)				
	1	2	3	4	Mean
Corn	5,284	3,743	1,506	106	2,660
Ginger	851	406	242	171	418
Sweet potato	2,307	313	146	111	719

Abaca	865	476	401	140	471
Coffee	7,449	4,958	3,150	2,110	4,417
Rubber	4,032	3,823	3,058	1,882	3,200
Mean					1,981
Number of plots surveyed: 24					

5. Methodology

The fieldwork was initiated by the geomorphopedological investigation which was described in Chapter III, and the findings had led to the decisions on the sampling plot selection. Topsoil composite samples were gathered from the chosen plots and crop yields were measured. The laboratory work was done for the topsoil sample analyses and crop yield measurements.

5.1. Miarayon topsoil sampling

After forging the link with the community, the geomorphopedological investigation that was conducted in March to April 2011 had followed (Chapter 3). A total of 94 composite samples were taken at 20 cm depth during the two waves of field work in 2011 and 2012. In the first wave of fieldwork in 2011, 39 samples were taken from plots in the vicinities of the nine (9) pedon locations. In the second wave 55 samples were taken which included the samples from 24 plots within the vicinities of MP4 and MP5, in the intermediate part (Salsalan), and MP7 and MP8, in the lower part (Mambuaw) of the toposequence, where crop yields were measured.

A total of 24 representative crop plots were selected for topsoil composite sampling and yield measurements. Twelve plots were situated around MP4 and MP5 (Salsalan) and the other 12 were located at MP7 and MP8 (Mambuaw). The topsoil sampling was done until December 2012. Composite topsoil samples were taken at 20 cm depth from each plot. The composite sampling followed the zigzag path method and took 20 sub samples using an arable land auger. The samples were put in a single plastic bag and were further mixed thoroughly in the laboratory.

5.2. Bendum topsoil sampling

The study of Richelle (2010) from March to April 2010 was the basis of selecting the locations for the field yield measurements and topsoil sampling within the production areas of

Bendum. The first location was in Toposequence 1 around BP3 and BP5. The second was in Toposequence 2 around BP9 and BP14. Similar to Miarayon, there were two waves of topsoil composite sampling, in 2010 and 2012. A total of 39 plots were tested for topsoil fertility. In the first wave, 13 plots were sampled during the first wave of field work and in the second wave, 26 plots were sampled. For the crop yield measurements and fertility assessment, a total of 12 plots that were devoted to food crops were investigated. These were two corn, two sweet potato and two ginger plots in each toposequence. Corn and sweet potato are food for home consumption and ginger is for the market. Another 12 plots were investigated for fertility assessments which were dedicated with cash crops. These were two rubber, two coffee and two abaca plots from each toposequence. Although coffee can also be classified as food crop, the primary purpose of its cultivation is for the market. The field yield measurements commenced in May 2012 until January 2013. Topsoil composite sampling was done in the last week of March until the first week of April. For the rubber, coffee and abaca plots, two sets of topsoil samples were taken. First was at the base of the plant and second was in the middle of two adjacent plants. The purpose of this was to determine if there were differences in nutrient levels at different sampling distances from the base of the plant. Thus the total number of samples taken from Bendum production areas during the two waves of fieldwork was 51.

5.3. Laboratory work for Miarayon and Bendum topsoils

To find out the topsoil fertility status of the production locations, topsoil samples were taken from each plot and were analyzed. The topsoil composite samples were air dried at Xavier University in Cagayan de Oro City in preparation for their shipment to the Soil Science Unit of ULg-GxABT, Gembloux, Belgium. From the samples, 250 gram weights were taken to Belgium and the remaining samples were left in Xavier University for the soil collections.

The samples were oven dried at 40°C and were totally passed through a 2 mm size sieve before the analyses. Analyses of samples were conducted in the Provincial Laboratory for topsoil analysis and fertilizer advising for farmers at La Hulpe, Belgium. Parameters examined were pH (H_2O and 1N KCl), TOC (Walkley-Black method), TN (Kjeldahl Method), C/N ratio derivations, available

Ca, Mg, K, Na and available P (ammonium acetate-0.5N and EDTA 0.02M at pH 4.65). Measurements for available cations were done by flame atomic absorption (Ca and Mg) or emission (Na and K) measurement and available P by spectrophotocolorimetry.

5.4. Crop yield measurement procedures

The crop yield measurement exercise had run from April 2012 to January 2013. The yield measurement method for carrots, corn and potatoes had adopted the procedure for row crops in Hauser (1973). In the plot, a rectangular harvest frame was established in which three crop-rows were enclosed. The following formula was used to delineate the frame dimensions: **A = XY.** The X, as the reference line, is the width of frame which is three times the crop row distance measured on center in meters. Y is the length of frame, in meters and A is the frame enclosed area which is equal to 10 m^2. The X values depend on the width of the three enclosed beds and the Y values likewise

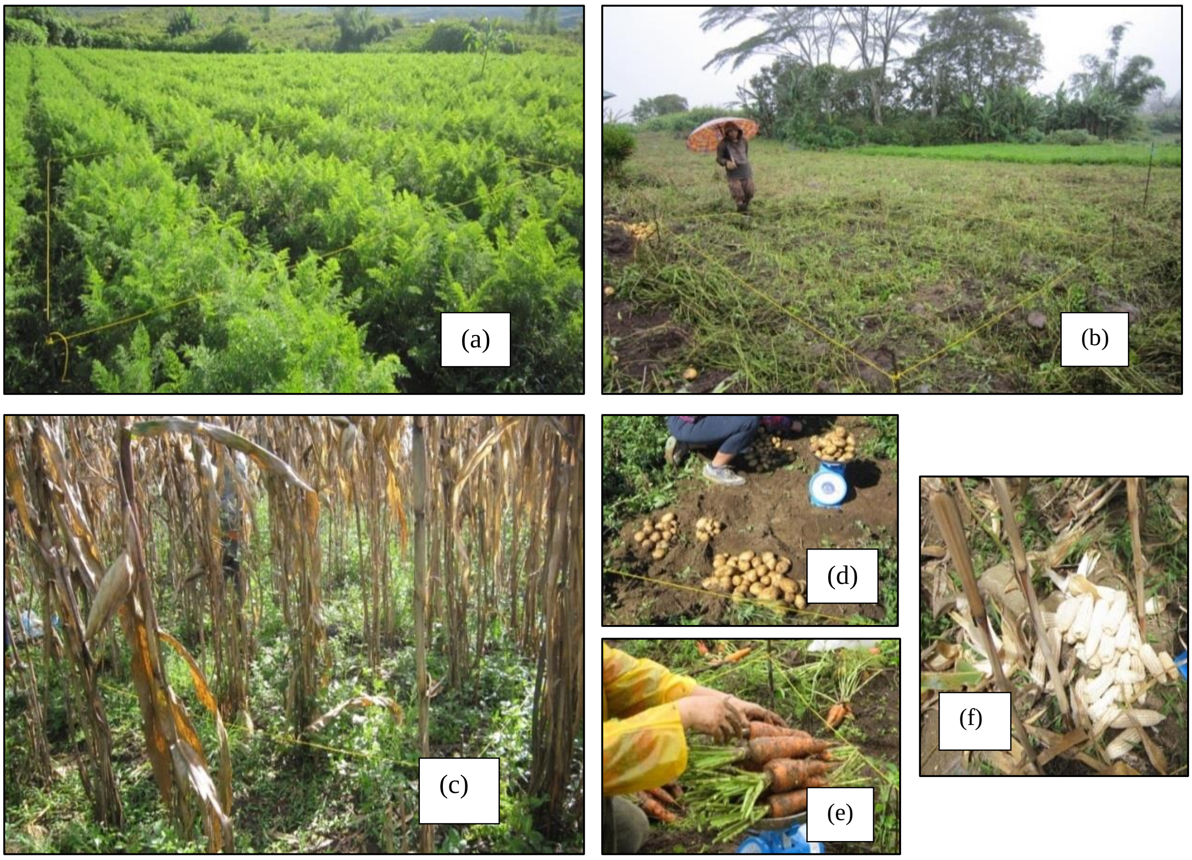


Figure IV-5. Field yield measurements in Miarayon: (1) carrot frame, (2) potato frame, (3) corn frame, (4) potato harvest, (e) carrot harvest, and (f) corn harvest.

correspond to the values of X. Figure IV-5 shows the activities conducted in measuring the yield. The four corners were marked with metal pegs and the enclosed area was cordoned with a nylon rope. The yield of the crops that were enclosed in the frame was taken using a weighing scale. Plant densities were also measured. For carrot, the storage roots were individually counted. For corn, the number of plants inside the frame was counted. For carrots and potatoes, three pieces of the harvested roots which were randomly chosen were brought to the laboratory to determine the soil weight correction. The soil weight correction is the weight of soil that stuck to the roots which should be subtracted to the total weight of harvest to get the weight of the tubers alone. Corn ears were de-husked, dried and shelled. The weights were taken at 12% moisture content which is the safe moisture level at storage (Granados, 2000).

The procedure being used in Miarayon was also used in Bendum for corn only. This was because ginger and sweet potato plots in Bendum did not have definite rows. The yield measurements of ginger and sweet potato had followed the procedure for broadcast crops in Hauser (1973). Equation $A = XY$ was used in delineating the rectangular harvest frame dimensions but setting $X = 2.5$ m and $Y = 4$ m, giving a harvest area of $A = 10\ m^2$. Figure IV-6 shows the yield measurements in Bendum. The corn plant density was measured by counting the individual plant enclosed in the frame. The corn ears were dehusked, dried and shelled and weights of corn kernels were taken at 12% moisture content. For ginger and sweet potato, three pieces were randomly selected to get the weights of the soil that stuck on the tubers.

Figure IV-6. Bendum field yield measurements (a) corn, (b) ginger, (c) sweet potato, (d) ginger crop and (e) sweet potato tubers.

5.5. Applications of statistical methods

The differences in soil nutrient levels between Salsalan and Mambuaw in Miarayon were tested by Two-sample T-test, and in Bendum for comparison between plots in BP9 and BP14 areas. The Paired T-test was used in comparing the nutrient level differences between soil near the base of the plant and mid-way between rows. To detect the associations between existing soil nutrients and fertility levels with crop yields, the Linear Correlations Test (LCT) was applied.

6. Results and discussions

Results and discussions deal with the soil fertility assessment based on the topsoil analyses results of Miarayon and Bendum. Soil analysis results were cross-referenced with the crop yield from respective sampled plots.

6.1. Miarayon soil fertility assessment results

The pedon morphology of the production areas in Salsalan and Mambuaw are presented to provide a view of the nature and properties of the soils in the specific soil sampling and yield measurements locations. This section presents the general view of topsoil fertility of Miarayon, fertility comparison between Salsalan and Mambuaw, and the association between coexisting nutrients in the topsoil.

6.1.1. Morphological characterization of pedons in the specific study areas in Miarayon

As mentioned in Chapter 3, Miarayon soils are either Cambisol or Umbrisol having 'andic' properties. Table IV-3 presents the soil classification and characteristics of Salsalan and Mambuaw pedons where field yield measurements were conducted.

Table IV-3. Soil classifications and characteristics in the two study sites for field yield measurements.

Location	Soil pedon	Main classification	Position	Slope (%)	Elevation (m asl)	Land use
Salsalan (Intermediate part)	MP4	"Andic" Umbrisol	Wavy mesorelief, concave middle part	7	1489	Carrot, corn, potato, fallow
	MP5	"Andic" Cambisol	Wayvy meosorelief, convex middle part	10	1496	Carrot, corn, potato, fallow
Mambuaw (Lower Part)	MP7	"Andic" Cambisol	Rectilinear crest	4	1363	Carrot, corn, potato, fallow
	MP8	"Andic" Cambisol	Divide convex/linear	2	1348	Carrot, corn, potato, fallow

6.1.2. The general view of topsoil fertility in Miarayon

To give the general idea of the topsoil fertility of Miarayon soils, a summary was made on the range of values of soil fertility parameters. The summary in Table IV-4 was derived from the analyses of topsoil samples during the two waves of fieldwork in March to April 2011 and February to March 2012. In the table, the range with category and value suggests the homogeneity or heterogeneity of the soil nutrient levels. In here, category refers to the lowest and highest values of the range of analyses results. Evaluation implies the favorability of soil environmental conditions because extreme values are detrimental to the plants. Table IV-4 presents the summary of soil analyses results for Miarayon topsoil composite samples.

Table IV-4. Summary soil analysis results for Miarayon composite topsoil samples.

Parameter	Range		Evaluation	Pedon location	Toposequence part	Land use
	Category	Value[1]				
pH H_2O	Lowest	4.9	Low (strongly acid)[2]	Around MP8	Intermediate	Potato
	Highest	6.2	Medium (slightly acid)[2]	Around MP5	Intermediate	Corn
	Mean	5.4	Medium (moderately acid)[2]			
TOC (%)	Lowest	4.1	Medium[2]	Around MP7	Intermediate	Corn
	Highest	14.9	High[2]	Around MP5	Intermediate	Corn
	Mean	6.9	Medium[2]			
TN (%)	Lowest	0.30	Medium[2]	Around MP7	Lower	Potato
	Highest	1.29	Very high[2]	Around MP5	Intermediate	Corn
	Mean	0.60	High[2]			
Available P (mg/100g)	Lowest	<1	Low[2]	All pedons		All pedons
	Highest	<1	Low[2]			
	Mean	<1	Low[2]			
Available Ca ($cmol_+kg^{-1}$)	Lowest	1.35	Very low[2]	Around MP7	Upper	Carrot
	Highest	23.13	Very high[2]	Around MP5	Intermediate	Corn
	Mean	4.44	Low[2]			
Available Mg ($cmol_+kg^{-1}$)	Lowest	0.25	Low[2]	Around MP6	Intermediate	Fallow and corn
	Highest	5.10	High[2]	Around MP5	Intermediate	Corn
	Mean	0.79	Medium[2]			
Available K ($cmol_+kg^{-1}$)	Lowest	0.20	Medium[2]	Around MP8	Intermediate	Fallow
	Highest	1.51	Very high[2]	Around MP5	Intermediate	Potato
	Mean	0.67	High[2]			
Available Na ($cmol_+kg^{-1}$)	Lowest	0.00	Very low[2]	Around MP5	Intermediate	Corn and carrot
	Highest	0.13	Low[2]	Around MP5	Intermediate	Potato
	Mean	0.09	Low[2]			
Ca:Mg ratio	Lowest	2.8:1	Acceptable limit but P uptake maybe inhibited (3:1)[3]	Around MP2 and MP8	Upper and Lower	MP2: fallow MP8: 2 fallows, 1 potato
	Highest	10.6:1	Mg gets unavailable (>5:1)[3]	Around MP7	Lower	Carrot
	Mean	6.1:1	Mg gets unavailable (>5:1)[3]			
K:Mg ratio	Lowest	0.3:1	Within the recommended levels for field crops and vegetables[3]	Around MP2	Upper	Fallow
	Highest	2.7:1	Within the recommended levels for field crops and vegetables[3]	Around MP7, MP8 and MP9	Lower	All fallow plots

	Mean	0.1:1	Within the recommended levels of field crops and vegetables[3]	
[1] Lowest and highest values within the range from analyses results of Lebrun (2011), Barbieux (2012) and Calalang's soil samples. [2] Ooms (1992) [3]Landon (1991) N samples = 94				

The table shows that the plots in the lower part of the Miarayon toposequence have lowest values of available nutrients. The lowest values of pH and available K are found in plots around MP8. For the lowest values of TOC, TN and available Ca, these are in plots around MP7. Lowest available Mg is also found near MP6. Although the plot is relatively near MP6 by distance, the plot may have shared more characteristics with plots in MP7 than in MP6. The table shows that MP5 had superior soil fertility among the rest of the pedon locations because it is where the plots with relatively high in pH, TOC, TN, and available bases are found. Correlations between soil properties are explained in the section 6.1.4 of the succeeding pages.

6.1.3. Soil fertility comparison between Salsalan and Mambuaw, Miarayon

Table IV-5 introduces the topsoil nutrient analyses results of 24 plots that were planted with carrot, corn and potato. In naming the plots that were measured for carrot and potato, the first letter is the beginning of the location name, the second letter is the initial letter of the crop name, and the number stands for the plot number. For example; SC1, means the first carrot plot in Salsalan (SC1: S = Salsalan, C = carrot and 1: first plot measured), and MP1 the first potato plot (MP1: M = Mambuaw, P = potato and 1: first plot measured). But for corn, the second is the first two beginning letters. For instance; SCo1 means first corn plot in Salsalan (SCo1, S = Salsalan, Co = corn) or MCo1 means first corn plot in Mambuaw (MCo1, M = Mambuaw, Co = corn and 1: first plot measured).

Table IV-5. Topsoil composite samples analysis results in yield measured carrot, potato and corn plots.

Location	Plot	pH H_2O	TOC	TN	C:N ratio	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	∑
			%			$cmol_{+}kg^{-1}$				
Carrot										
Salsalan (Intermediate part)	SC1	5.4	7.5	0.6	12	4.44	0.33	0.95	0.04	5.76
	SC2	5.4	6.5	0.6	11	3.79	0.25	0.87	0.04	4.95
	SC3	5.9	8.4	0.8	11	9.78	0.66	1.00	0.09	11.53

	SC4	5.1	7.2	0.6	11	2.15	0.16	0.54	0.13	2.98
Mambuaw (Lower Part)	MC1	5.4	4.1	0.3	14	2.10	0.16	0.31	0.04	2.61
	MC2	5.4	7.0	0.5	15	2.40	0.25	0.20	0.04	2.89
	MC3	5.1	8.7	0.6	15	2.64	0.16	0.28	0.09	3.17
	MC4	5.3	6.5	0.4	14	2.5	0.16	0.23	0.09	2.98
Corn										
Salsalan (Intermediate part)	SCo1	5.8	6.7	0.75	11	7.84	0.74	1.13	0.04	9.45
	SCo2	5.8	8.4	0.72	11	7.39	1.15	0.59	0.04	9.17
	SCo3	5.4	8.9	0.57	11	2.30	0.25	0.43	0.09	3.07
	SCo4	5.8	5.9	0.68	8	4.95	0.74	1.05	0.09	6.83
Mambuaw (Lower part)	MCo1	5.0	5.2	0.46	13	1.95	0.41	0.49	0.04	2.89
	MCo2	5.2	5.0	0.39	14	1.90	0.41	0.39	0.09	2.78
	MCo3	5.0	6.8	0.50	15	2.60	0.49	0.43	0.04	2.56
	MCo4	5.1	5.8	0.39	13	11.24	2.14	1.07	0.04	14.49
Potato										
Salsalan (Intermediate part)	SP1	5.8	8.3	0.75	11	7.88	1.48	0.66	0.09	10.80
	SP2	5.4	7.8	0.72	11	7.04	0.90	1.18	0.09	9.21
	SP3	5.4	6.4	0.57	11	3.94	0.49	0.77	0.04	5.24
	SP4	5.5	7.6	0.68	11	6.74	0.74	0.95	0.13	8.56
Mambuaw (Lower part)	MP1	5.2	5.9	0.46	13	3.59	0.58	0.41	0.09	4.67
	MP2	5.1	5.6	0.39	14	2.35	0.82	0.23	0.09	3.49
	MP3	5.5	7.2	0.50	15	2.74	0.58	0.28	0.04	3.64
	MP4	5.1	5.0	0.39	13	3.09	0.49	0.61	0.09	4.28

6.1.3.1. Soil pH

This pH parameter extensively controls the plant nutrient availability and microbial reaction in soils (Brady and Weil, 1999). There are crops that are tolerant to highly acidic soil such as rubber and pineapple (Landon, 1991). In regions where precipitation is high, there is sufficient rainfall that could lixiviate the basic elements (Ca^{2+}, Mg^{2+}, K^+ and Na^+) and the cation exchange capacity will be dominated by Al^{3+} and H^+ ions which will make the soil acidic (Brady and Weil, 1999). This was also true for Miarayon because of the area's high rainfall. Seventy per cent of the 24 plots that were investigated had pH<5.5 with no value that had exceeded 5.9. Of the 12 plots in Mambuaw, except for one plot (MP3), the pH values were less <5.5.

6.1.3.2. TOC, TN and C:N ratio

The mineralization of organic matter substantially affects the accessible N, P and S pools in soils (Baldock and Nelson, 2000). The C:N ratio indicates the degree of humification thus giving the idea of the type of organic matter present (Landon, 1991). Generally, compared to non-volcanic soils, volcanic soils have higher organic matter that may tend to buffer excessive C depletion (Sandoval *et al.*, 2007) which is also observed in Miarayon. It can be posited that high organic matter content in volcanic soils is due to the amorphous elements that fix the organic matter and the low temperature of the locations where Andosols can be found slows down the decomposition process. SOC is negatively related to temperature if keeping other factors such as precipitation and soil organic C chemical structure constant (Baldock and Nelson, 2000). With the influence of climatic factors, organic matter mineralization goes along with the evolution of Andosols into other soil classifications. It should be noted that the total organic matter content in a soil is the sum of all kinds of organic matter which are mineralizing at different rates. For instance in Miarayon, the kind of organic matter that farmers usually apply in their fields are the chicken litters which are mixtures of chicken dungs and rice hulls that have different decomposition rates at the same environmental conditions.

Poultry litters are sources of TOC and TN because the dry matter contains 28-40% C and 1.4-8.4% N (Queensland Department of Agriculture, Fisheries and Forestry, no date). The TOC in soil was medium and TN values were medium to high (Table IV-4). The C:N ratio indicates the degree of organic humification and thus higher values imply abundance of less decomposed organic matter. Therefore, C:N ratios in Salsalan indicated higher degree of humification than in Mambuaw.

6.1.3.3. Available P

Maximum available P occurs in soils which are very slightly acid to very slightly alkaline (Buol, 2008). At low pH (<5.5), phosphate ions combine with Fe and Al to form compounds that make P unavailable to plants, at high pH (>8.0) and with Ca, the phosphate ions will be converted to calcium phosphate [$(Ca_3PO_4)_2$] which reduces P availability to plants and pH>8.5, the presence of Na to soluble sodium phosphate [Na_3PO_4] (Landon, 1991). In volcanic soils, farmers use significant amounts of phosphate fertilizers to obtain suitable yield targets because of high P immobilization (Mejias *et al.*, 2013). It was noted that available P was very low (<1mg $100g^{-1}$). Follow-up analyses were made on selected soil horizon samples from representative plots for organic P (Table IV-6). The P retention ranges from 60-95%. Similar to the findings of Poudel and West (1999), the soil in Miarayon has low available P although farmers apply P and chicken litters as fertilizers. Dry matter of chicken litter has 1.2-2.8% P_2O_5 (Queensland Department of Agriculture, Fisheries and Forestry, no date). With the relatively high total P (presented in Chapter III), it is believed that available P is gradually released during the mineralization process of organic matter along the course of crop's growth before it is sequestered by Al and Fe.

Table IV-6. Phosphorous in Miarayon pit soil samples.

Horizon Sample	Total P (mg/100g)	Mineral P (mg/100g)	Organic P (mg/100g)	P retention (%)
MP1H1	120	48	72	87.0
MP1H3	64	6	58	96.6
MP2H1	66	3	63	95.5
MP2H4	32	3	29	98.2
MP3H1	350	48	302	68.3
MP3H2	263	38	225	75.9
MP5H1	288	40	248	62.5
MP5H4	176	40	136	75.9
MP7H1	82	5	77	91.1
MP7H4	48	4	44	95.3
Mean	149	24	125	84.6

Source: Barbieux (2012)

6.1.3.4. Available Ca

Calcium is important in the processes that preserve the structural and functional integrity of plant membranes, stabilize cell structures, regulate ion transport and selectivity, and control ion-exchange behavior and enzyme activities (Tuna *et al*., 2007). The maximum amount of Ca in soil is at a pH range of slightly acid to medium alkaline (Buol, 2008). Significant amounts of Ca in soils are derived from the addition of limestone, fertilizers (superphosphates with 14-20% Ca) and animal manures (Camberato and Pan, 2000).

Of all the available bases, Ca is predominant in the topsoils of both locations. Miarayon farmers use chicken dungs which are mixed with rice hulls as organic fertilizers and are external source of Ca. Poultry feeds have Ca source in their formula such as mono dicalcium phosphate, ground limestone and oyster shells. Dry matter chicken litter has 1.7-3.7% Ca (Queensland Department of Agriculture, Fisheries and Forestry, no date). Dry hulls have 20% inorganic components with 94% of which is silica and the remaining 6% of which K_2O, CaO, MgO, MnO, Al_2O_3, P_2O_5 and SiO_2 in decreasing concentrations (De Souza *et al*., 2002).

Response of most crops to Ca fertilizers happens when Ca value is <0.2 cmol$_+$kg^{-1} and the high value is 10 cmol$_+$kg^{-1} (Landon, 1991). Of the 24 plots investigated, no value had gone to what is considered as the low level. As cited by Camberato and Pan (2000), a Ca saturation ratio of between 25-30% and an exchangeable Ca of 1 cmol$_+$kg^{-1} in highly weathered soils dominated by kaolinitic clays and Fe/Al oxides are sufficient to supply the Ca requirement of most plants. Table IV-7 presents the Ca saturation ratios of the top horizon soils in pedons where topsoil samples were gathered for fertility assessment. The effective Ca saturation ratios in Salsalan are 63.30 and 71.03%. With 3.57 and 4.12 cmol$_+$kg^{-1} exchangeable Ca, the soil can sufficiently supply the Ca needs of plants. For Mambuaw, the effective Ca saturation ratios are 28.00-41.50%. With 1.83 and 0.93 cmol$_+$kg^{-1}, the exchangeable Ca may not be sufficient to supply the Ca needs of the soils.

Table IV-7. Effective Ca saturation ratios of the top horizons of pedons in areas where composite samples were taken and crop yields were measured.

Pedon	pH H_2O	Ca^{2+}	Mg^{2+}	K^+	Na^+	Exchangeable Acidity	Total	% Effective Ca saturation
		cmol$_+$kg^{-1}						
Salsalan								
MP4-1	5.0	3.57	0.23	0.19	0.01	1.64	5.64	63.30
MP5-1	5.2	4.12	0.28	0.18	0.09	1.13	5.80	71.03
Mambuaw								
MP7-1	4.9	1.83	0.29	0.24	0.01	2.04	4.41	41.50
MP8-1	4.7	0.98	0.05	0.14	0.01	2.32	3.49	28.00

Note: Values of Ca, Mg, K, Na and exchangeable acidity are taken from Lebrun (2011).

6.1.3.5. Available Mg

Magnesium is an essential mineral element which is classified as a macronutrient that activates numerous plant enzymes involving the transfer of phosphate and carboxyl group (Camberato and Pan, 2000). It is also essential to chlorophyll formation and photosynthesis (Buol, 2008). Like Ca, the maximum available amount is within the pH range of slightly acid to medium alkaline (Buol, 2008). Magnesium deficiency occurs when exchangeable level is <0.2 cmol$_+$kg^{-1} but in the tropics 0.5 cmol$_+$kg^{-1} is the limit (Landon, 1991). Similar to Ca, the sources of considerable quantities of Mg in soils are limestone, fertilizers and animal manure (Camberato and Pan, 2000).

Miarayon rocks have 2.3% MgO (Maurissen, 2014) because of its andesitic characteristics. Its soils also receive Mg from chicken litter. Dry matter of chicken litter has 0.35-0.80% Mg (Queensland Department of Agriculture, Fisheries and Forestry, no date). Of the 24 plots, 45% were above the limit, 38% were on the threshold level and 17% were below the limit. In contrast to Ca, Mg values can be attributed to its less likelihood to chemical reaction with the exchange complexes (Camberato and Pan, 2000) of Miarayon soils thereby making this nutrient susceptible to lixiviation. Less absorption of Mg may have also less occurred because of relatively high Ca levels in soil. If Ca:Mg ratio of >5, Mg may progressively be unavailable (Landon, 1991). Of the 24 plots, 83% had ratios >5.

6.1.3.6. Available K

Potassium feldspars (orthoclase and microcline) and micas (biotite and muscovite) are the original K sources in soils (Brady and Weil, 1999). Potassium in available form is K^+ which is attracted to the negatively charged mineral components and organic compound surfaces. Since K^+ is less attracted to these matrices compared to Al^{3+} and H^+, it will easily be displaced and leached in acid or sandy soils. In the Philippines, except in sandy soils, K deficiency is not widespread as those of N and P but problems may be foreseen in the future considering its fast rate of removal by crops (PCARRD, 2006).

Miarayon soils receive K from chicken litters and K fertilizers applied by farmers. Dry matter chicken litter contains 0.9-2.0% K (Queensland Department of Agriculture, Fisheries and Forestry, no date). Available K in Miarayon soils (0.2-1.18 $cmol_+kg^{-1}$) are considered medium to high for tropical soils (Landon, 1991). Magnesium absorption by plants can also be affected by K in soils. At K:Mg ratios >2, Mg uptake is inhibited (Landon, 1991). Only three plots were at these ratios which were all planted with carrot.

6.1.4. Nutrient associations with each other in Miarayon soils

As nutrients in soils coexist, the presence of one can influence the other. Table IV-8 shows the relationships of nutrients with each other.

Table IV-8. Correlations of pH H_2O, TOC, TN, C:N ratio, Ca, Mg, K and Na in Miarayon soils

Parameter	Cell contents	pH H_2O	TOC	TN	C:N ratio	Ca	Mg	K
			%			$cmol_+kg^{-1}$		
%TOC	R value	0.395						
	P value	0.056ns						
%TN	R value	0.672	0.820					
	P value	0.000***	0.000***					
C:N ratio	R value	0.026	0.071	-0.129				
	P value	0.902ns	0.740ns	0.548ns				
Ca	R value	0.546	0.330	0.528	-0.377			
	P value	0.006**	0.115ns	0.008**	0.069ns			
Mg	R value	0.232	0.078	0.271	-0.323	0.801		
	P value	0.276ns	0.717ns	0.307ns	0.123ns	0.000***		
K	R value	0.459	0.557	0.557	-0.536	0.760	0.467	
	P value	0.024*	0.005**	0.005**	0.007**	0.000***	0.021*	

Note: ***very highly significant; **highly significant; *significant; ns not significant

6.1.4.1. On soil pH, TN, TOC and Ca relationships

Total nitrogen is very highly significantly (P=0.000) associated with pH H_20 and %TOC. Soil pH was directly related with TN. Total nitrogen was also directly related with TOC which is normal within certain range of C:N ratio. Most Miarayon farmers use chicken dung that are mixed with rice hulls as organic fertilizers. Chicken dung has relatively high amounts of N. Organic inputs increase potential N mineralization and contribute to plant nutrition (Deenik, 2006). It should be noted that soil pH and TN in soils are signs of fertilization practice in farming. The associations of Ca with pH H_2O and %TN were highly significant ($P<0.01$). Calcium was the most influential base for the soil pH as this is predominant in Miarayon soils. The high significance of Ca to TN can be attributed again to the organic fertilizers which were applied by most farmers. Calcium and TOC relationship is not significant because the range of Ca is larger than the range of TOC. Calcium in Miarayon soils is from either natural or anthropogenic sources which are managed differently. Total organic carbon has no significant relationships with soil pH and C:N ratio. TOC is the total amount of C in an organic compound while pH is a resultant reaction of chemicals in soils.

6.1.4.2. On soil pH and exchangeable bases relationships

Calcium associations with K (P=0.000) is very highly significant and Mg (P=0.021) is significant. The coexistence of Ca and K can be attributed that both elements are found in chicken dungs which are used as organic fertilizers. For Ca and Mg, the elements are related because these two elements have similarity in soil chemical and plant nutritional behavior although Ca has greater affinity than Mg (Camberato and Pan, 2000) in soils with similar characteristics of Miarayon soils. However, in Miarayon rock materials, Ca (CaO, 3.44%) is greater than Mg (MgO, 2.32%). The data presented by Bear and Toth (1945) had shown that Ca has a very significant influence in pH, while Mg has a very significant inverse relationship with soil pH. However, in Miarayon soils, it is only true to Ca and soil pH relationship, but not to Mg and soil pH. This is because, Ca is predominant than Mg in Miarayon topsoils. Lixiviation and crop removal are the two ways that these two mineral elements will be lost in the soil. However, Ca is highly attracted to soils with exchange complexes evolving from organic matter, allophane and oxides of Al and Fe than Mg (Hunsaker and Pratt, 1971 in Camberato and Pan, 2000). The aforementioned soil characteristics are observed in Miarayon soils. The soil pH is directly influenced by K levels in soil.

6.1.5. Soil fertility level comparisons between Salsalan and Mambuaw, Miarayon

Using the Two Sample T-test, differences in soil fertility levels between Salsalan and Mambuaw, where crop yields were measured, are presented in Table IV-9. As previously mentioned, Salsalan is a relatively new production area as it is recently cleared while Mambuaw was the site of the old Miarayon settlement more than 50 years ago. With the time-length difference in using the

Table IV-9. Soil fertility level differences between Salsalan and Mambuaw, Miarayon.

Parameter	P Value	Parameter	P Value
pH water	0.023*	Ca^{++} (cmol$_+$ kg^{-1})	0.013*
TOC (%)	0.003***	Mg^{++} (cmol$_+$ kg^{-1})	0.300^{ns}
TN (%)	0.000***	K^{+} (cmol$_+$ kg^{-1})	0.000***
C:N ratio	0.000***	Na^{+} (cmol$_+$ kg^{-1})	0.178^{ns}
		Sum of bases (cmol$_+$ kg$^{-1)}$	0.013*

Note: ***very highly significant ($P \leq 0.001$); **highly significant ($P \leq 0.01$); *significant ($P \leq 0.05$);
^{ns} not significant ($P > 0.05$)
N samples = 24

land, it was assumed that Salsalan, which still has benefited the soil richness of once forested areas, has higher soil fertility than Mambuaw.

6.1.5.1. TOC, TN and K

According to Rabbi *et al*. (2014), less intensive management practices had resulted to slower turnover of macro-aggregates which allow the development of stable micro-aggregates while more intensive cultivation exposes the SOC into faster rate of decomposition. The differences in TOC, TN and K between the two sites are very highly significant. TOC is the energy source of microorganisms that facilitate the mineralization of substances into plant usable forms. TN and K are essentials for crop growth and productivity. Differences in levels of TOC, TN and K implied that these nutrients were severely affected by long and continuous cultivation. The long term study of the effects of organic matter on Belgian loamy soils by Bock *et al*. (1994) had found out that OM content varied according to land use, soil type under crop and length of time since conversion. Continuous cropping is a slow process of nutrient mining that can exhaust the soil elements. Less or no replenishment of elements runs down the soil capacity to support plants in the long run.

6.1.5.2. Soil pH, available Ca, Mg, Na and exchangeable acidity and Al

Miarayon soils which are derived from volcanic parent materials are acidic. There is significant difference between the soil pH values of Salsalan and Mambuaw. Much lower soil pH in Mambuaw is a sign of soil degradation. As previously mentioned, the imminent danger of Al toxicity occurs when there are high proportions of exchangeable acidity and Al saturation ratio which is gauged with ECEC (Table III-17). Topsoils in Mambuaw has relatively low pH (<5.5) and in this location, high amounts of exchangeable Al in soils were also detected.

Available Ca was significantly higher in Salsalan than in Mambuaw. This may mean that Salsalan has more supply of Ca than in Mambuaw which can also be seen in the chemical analysis of topsoil pedons of MP3, MP4, MP5 and MP6 in Chapter III. Furthermore, this was affirmed by the interviews with farmers that they apply chicken dungs in relatively high amounts when carrots are planted. Similar to Ca, there is significant difference in soil pH between the two production-locations because Ca levels positively affect the soil pH (Bear and Toth, 1948) which is also true in Miarayon soils. Available Mg and Na are not significantly different. The variations of available Mg between the two sites were not detected and therefore, this element is not affected by cultivation duration alone.

6.2. Soil fertility assessment results for Bendum topsoils

Bendum soil properties are presented by their pedon morphology. This section presents the general view of topsoil fertility of Bendum, fertility comparisons between the two sites where ultramafic (BP9) and pyroclastic deposits (BP14) are found which were the actual plot locations of field yield investigations and, the associations between coexisting nutrients in the topsoil.

6.2.1 Morphological characterization of pedons in Bendum specific areas of study

The soil classifications of the four pedon locations in the cultivated areas of Bendum are shown Table III-2. These are Pisoplinthic Acrisol (BP3), Ferralic Nitisol (BP5), Acric Nitisol (BP9) and Haplic Cambisol (BP14). The soil characteristics are likewise presented in Table III-5. Nodules which are believed to be concretions of Fe and Mn were noted in BP3 and BP5. Employing the feel method of soil texture determination, the pedon locations have similarities in terms of soil texture. The top horizons have sandy clay loam soils. It is hypothesized that pseudo sands which are believed to be fine concretions of Fe and Mn are among the components of sandy clay loam. All locations have patches of waterlogged areas. In BP14, the presence of gravels in the top horizon suggests that a relatively recent deposition on pre-existing soils had happened because weathered materials were observed in the deeper part of the soil profile.

6.2.2. The overview of soil fertility status in Bendum

To give the general view of soil fertility status in Bendum, information treated in here was from the topsoil samples specifically taken from the production areas (BP3, BP5, BP9 and BP14) during the two waves of fieldwork conducted in March to April 2010 and late March to early April of

2012. The overview provides the comparison between Miarayon and Bendum soil fertility status. Table IV-10 presents the syntheses of the laboratory analyses results of 43 Bendum topsoil composite samples.

Table IV-10. Summary soil analysis results for topsoils in Bendum cultivation areas.

Parameter	Range		Evaluation	Pedon location	Toposequence	Land use
	Category	Value[1]				
pH H_2O	Lowest	4.7	Strongly acid[2]	Around BP14	2	Young abaca in forest
	Highest	6.1	Slightly acid[2]	Around BP3	1	Coffee and corn
	Mean	5.4	Moderately acid[2]			
TOC (%)	Lowest	1.6	Very low[2]	Around BP3	1	Corn
	Highest	5.8	Medium[2]	Around BP14	2	Corn
	Mean	3.75	Low[2]			
TN (%)	Lowest	0.17	Low[2]	Around BP3	1	Corn and coffee
	Highest	0.41	Medium[2]	Around BP9	2	Corn
	Mean	0.29	Medium[2]			
Available P (mg/100g)	Lowest	<1	Low[2]	All pedon locations		Production plots
	Highest	<1	Low[2]			
	Mean	<1	Low[2]			
Available Ca ($cmol_+kg^{-1}$)	Lowest	0.30	Very low[2]	Around BP9	2	Rubber
	Highest	4.99	Medium[2]	Around BP3	1	Corn and coffee
	Mean	2.65	Low[2]			
Available Mg ($cmol_+kg^{-1}$)	Lowest	0.16	Very low[2]	Around BP5	1	Rubber
	Highest	5.27	High[2]	Around BP14	2	Sweet potato
	Mean	2.72	High[2]			
Available K ($cmol_+kg^{-1}$)	Lowest	0.09	Very low[2]	Around BP9	2	Abaca
	Highest	0.43	Medium[2]	Around BP9	2	Corn
	Mean	0.26	Low[2]			
Available Na ($cmol_+kg^{-1}$)	Lowest	0.04	Very low[2]	9 plots in all pedon locations	1 and 2	Production plots
	Highest	0.09	Very low[2]	22 plots in all pedon locations	1 and 2	Production plots
	Mean	0.07	Very low[2]			
Ca:Mg ratio	Lowest	0.86	Acceptable limit[3]	Around BP5	1	Rubber
	Highest	9.76	Mg gets unavailable[3]	Around BP5	1	Abaca plot
	Mean	5.31	P uptake may be inhibited[3]			
K:Mg ratio	Lowest	0.07	Recommended level[3]	Around BP14	2	Sweet potato
	Highest	0.63	Recommended level[3]	Around BP5	1	Rubber
	Mean	0.35	Recommended level[3]			

[1] Lowest and highest values within the range from analyses results of Richelle (2010) and Barbieux (2012)
[2] Ooms (1992)
[3] Landon (1991)
N samples = 43

The analysis results of Bendum rock samples in Maurissen (2014) elucidated the existence and level of nutrients found in the parent materials. Ultramafic rocks are found in areas where BP3, BP5 and BP9 are located. The soil parent material where BP14 is located is pyroclastic deposits.

Reflection of Ca in soil pH is exhibited in Bendum soils. Highest soil pH is found in BP3 where exchangeable Ca is highest (Table IV-9). Pit locations and correspondingly, the parent rock materials did not show evidence on the influence of soil nutrient levels in Bendum. Instead, land use has profound effects on the levels of nutrients in soils. Areas that are cultivated particularly for corn have relatively high values in TOC, TN and K which are from fertilizers and available Ca from lime applications in the past. Application of aforementioned nutrients are part of the soil management practices in farming.

6.2.2.1. Soil pH of Bendum cultivated areas

The pH of ultramafic rocks is higher than pyroclastic deposits because of the increasing Ca and ferromagnesian minerals content in ultramafics (Grotzinger, 2006). The pyroclastic deposits in Bendum are andesite which has higher amounts of Si and Al. Therefore, the innate soil pH must have come from the parent rock materials. The plot which has the lowest pH is recently planted with abaca and is located around Pedon BP14. The plot was previously planted with coffee after clearing the forest in 1989 and there is no application of any farming input. The parent rock materials of BP14 are pyroclastic deposits which have generally low pH. The plot with the highest pH is planted also to coffee, which is intercropped with corn, at the vicinity of BP5 where the parent rock materials are ultramafic. This plot was opened in 1989 and was primarily planted with coffee and root crops. One hundred bags of lime were applied to this plot in 2000 (Richelle, 2010).

6.2.2.2. TOC and TN in soils of Bendum cultivation areas

The lowest amount of TOC was found in a corn plot in BP3 with no application of farming input. The highest TOC was also in a corn plot intercropped with rubber plot around BP14. The lowest TN level was also in the corn and coffee plot where the pH is highest. The highest TN was also in a corn plot in BP9. According to the plot owner, 100 kg of 14-14-14 fertilizer was applied during the cropping when the soil sample was taken. All plots have very low available P.

6.2.2.3. Available Ca, Mg, K and Na in soils of Bendum cultivation areas

Lowest value of available Ca was found in rubber plot in BP9. Parent rock materials in the area are ultramafic and have low Ca (Maurissen, 2014). Available Ca and pH are highest in the corn and coffee plots in BP3. Aforementioned information given by famers is that the plot was applied with 100 bags of lime in 2000 (Richelle, 2010). Lowest available Mg was in a rubber plot in BP9 and the highest value was in a sweet potato plot in BP14. It should be noted that sweet potato plots have notations of BP14 although they are located closely to BP5 (see Figure IV-2). BP5 is the location where the ultramafic rocks are found.

Lowest available K is observed in an abaca plot and the highest value is in a corn plot around BP9. Lowest and highest values are observed in the same pedon location. Bendum parent rock materials are inherently low in K (Maurissen, 2014). The corn plot where the highest K value was found can be due to the application of K fertilizers. Sodium toxicity is not a constraint in the production plots because concentrations are low to very low. For Ca:Mg ratio, the lowest was in a rubber plot within Pedon BP5 which is within the acceptable limit. The highest ratio, when Mg gets unavailable, is in an abaca plot which is also in Pedon BP5. In this plot, a relatively high amount of Ca is observed compared to Mg. Although the parent rock materials in Pedon BP5 have high percentage of MgO, the levels of Mg in this plot may have been overtaken by Ca levels due to the decrease of Mg levels because of weathering process and limestone ($CaCO_3$) application by farmers. For all plots in the production areas, the K:Mg ratio is still at the recommended levels.

6.2.3. Nutrient associations with each other in Bendum topsoils

Analyses of nutrient occurrences and their associations were based from the results of 43 topsoil composite samples taken from Bendum cultivated areas in 2010 and 2012. Table IV-11 shows the relationships between coexisting nutrients.

Table IV-11. Correlations of pH H_2O, TOC, TN, C:N ratio, Ca, Mg, K and Na in Bendum soils

Parameter	Cell content	pH H_2O	TOC	TN	C:N ratio	Ca	Mg	K
			%			$cmol_+kg^{-1}$		
%TOC	R value	-0.494						
	P value	0.004**						
%TN	R value	-0.449	0.823					
	P value	0.01**	0.000***					
C:N ratio	R value	-0.183	0.513	-0.055				
	P value	0.316ns	0.003**	0.765ns				
Ca	R value	0.697	-0.326	-0.057	-0.488			
	P value	0.000***	0.069ns	0.755ns	0.005**			
Mg	R value	0.603	-0.251	-0.060	-0.342	0.631		
	P value	0.000***	0.166	0.745ns	0.056ns	0.000***		
K	R value	-0.243	-0.463	-0.624	-0.130	0.147	0.044	
	P value	0.180ns	0.008*	0.000***	0.478ns	0.423ns	0.811s	
Na	R value	0.033	-0.063	-0.182	0.180	-0.130	0.032	-0.216
	P value	0.859ns	0.731	0.318ns	0.325ns	0.478ns	0.861ns	0.236ns

Note: ***very highly significant; **highly significant; *significant; ns not significant
N samples = 43

6.2.3.1. Relationships of soil pH with TOC, TN and C:N ratio

The pH H_2O is inversely related to %TOC and %TN and at a highly significant level at P=0.004 and 0.01 respectively. It was also observed that the plot that has the lowest value in TN has also the lowest value in soil pH (Table IV-10). This may mean that additions of TOC and TN which come from crop residues and nitrogen fertilizers have strong effects in lowering the soil pH. Slow decomposition of humus releases ammonium (NH_4^+) ions which are subsequently oxidized to form nitrite (NO^{2-}) and nitrate (NO^{3-}) and are taken in by plants (Landon, 1991). Nitrification is freeing protons into the soil and if there is no Ca^{2+}, the buffering capacity of the soil is overwhelmed and the pH decreases. The release of H^+ from the plant root systems will acidify the surrounding soil. In this condition, organic matter with high amounts of N acidifies the soil. Furthermore, TOC and TN were closely and positively related to each other. When high TOC exists, high TN also prevailed. The C:N ratio is significantly affected by TOC content and quality. Although, the soil pH and TN do not significantly affect the C:N ratio, their associations tend to be inversely related. Therefore, the associations of the soil pH with TOC and TN have to do with the quantity and quality of SOM.

6.2.4. Soils in abaca, coffee and rubber plots in Bendum cultivation areas

Two sets of topsoil composite samples were gathered from each abaca, coffee and rubber plots. One set was taken at the base of the plant while the other was at midway between two adjacent plant rows. The total number of samples gathered was 24. The Two Sample T-test was used to determine the differences in the levels of nutrients between the two distances from the plant base in terms of pH H_2O, %TOC, %TN, available Ca, Mg, K, and Na.

It was noted that in most of the comparisons, the results at two different sampling points within the plot were not significantly different. This means that whether the soil sample was taken near to or distant from the plant, there is no difference in soil quality. However, there was a striking point in coffee plots where the TOC levels in soils near the plant where highly significantly greater ($P<0.01$) than in soils which were taken midway between plant hills. This confirms that farmers apply organic matter in coffee plots at the base of the plant. It was noted that most of the coffee plants at the time of sampling were young. To assist the young plant in establishing its growth, it is the usual practice of farmers to put organic matter as basal application before the seedlings are transplanted. This practice is not done only in tree crops but also in planting large tree species. Therefore the idea of taking samples between trees was premature because the plants are still very young. Another is the K levels in rubber plots. The K levels in soil at the base of the rubber plant are significantly higher ($P<0.05$) than at farther distance. The application of K rich fertilizers is evident in these plots. It was also noted that rubber trees in most plots are well established.

6.2.5. Soil fertility differences between two cultivation areas in Bendum

A total of 36 plots in the production areas in Toposequences 1 and 2 were chosen as sampling locations for the fertility assessment. These plots were into abaca, coffee, rubber, corn, ginger and sweet potato. The Two Sample T-test was used to check the significant differences between two production areas in terms of soil fertility level. Table IV-12 introduces the statistical summary of the two areas. Parent rock materials around Pedon BP9 are ultramafic containing relatively high amounts of Mg and Fe. Those around Pedon BP14 are pyroclastic deposits with relatively high CaO content (11.93%) compared to the rock samples of BP9 (0.46% and 3.25%).

Table IV-12. Differences between soil fertility levels of BP9 and BP14.

Parameter	P Values	
	BP9 - BP14 $\neq$ 0	BP9 > BP14
pH water	0.000***	0.000***
TOC (%)	0.000***	1.000ns
TN (%)	0.000***	1.000ns
C:N ratio	0.0765ns	0.681ns
Available Ca ($cmol_+kg^{-1}$)	0.525ns	0.263ns
Available Mg ($cmol_+kg^{-1}$)	0.403ns	0.798ns
Available K ($cmol_+kg^{-1}$)	0.190ns	0.905ns
Available Na ($cmol_+kg^{-1}$)	0.493ns	0.246ns

Note: ***very highly significantly different (P=0.000); **highly significantly different (P<0.01); *significantly different (P<0.05); ns not significant (P>0.05)
N samples = 36 (from the 2012 field work)

Dissimilarities of soil nutrient levels were only in pH water, TOC and TN. The soil pH values in BP9 plots were very significantly higher (P=0.000) than in BP14. This can be attributed to the high amount of Mg that is in the rocks around BP9. Soil pH is very significantly related to the topsoil available Mg contents (Tables IV-10). The TOC and TN in BP9 plots were very significantly lower (P=0.000) than in BP14 plots. Likewise, TOC and TN had positive associations with each other. Contrasts between the two sampling locations on the rest of the parameters were not significant.

6.3. Miarayon crop yield measurements and soil fertility assessments

This section presents the crop yields of the three predominant crops in Miarayon carrots, corn and potatoes. This further presents the relationships of yield and the soil nutrients and to find out if soil fertility can be a bench mark for estimating crop yields.

6.3.1. Yields of carrot, corn and potato in Miarayon

Table IV-13 presents the crop yields of carrot, corn and potato. This further shows the plant densities of carrots and corn in the plot. Miarayon farmers practice direct seeding when planting carrots and corn. Thinning comes after one month to control the plant population in a plot. Carrot plant densities were obtained by counting the storage roots individually. For corn, each individual stalk inside the harvest frame was reckoned.

Mean yield of carrot in Salsalan was less than in Mambuaw by 2.39 tha^{-1}. However, mean yield in the two locations was higher than the average yield of Bukidnon Province (BAS, 2013).

Table IV-13. Crop yields and plant densities of carrot, corn and potato plots in Miarayon.

Crop	Location	Plot	Yield tha^{-1}	Mean yield t/ha^{-1}	Yield difference			Plant density plants/10m^2
					tha^{-1}	%	P value	
Carrot	Salsalan	SC1	36.78	18.41	-2.39	-13.0	0.734ns	238
		SC2	8.02					104
		SC3	18.51					279
		SC4	10.32					86
	Mambuaw	MC1	18.19	20.80				198
		MC2	19.66					288
		MC3	24.15					288
		MC4	21.02					214
Corn	Salsalan	SCo1	3.68	3.75	0.29	8.4	0.711ns	48
		SCo2	4.47					51
		SCo3	3.03					43
		SCo4	3.82					50
	Mambuaw	MCo1	2.77	3.46				37
		MCo2	2.14					29
		MCo3	3.58					48
		MCo4	5.34					59
Potato	Salsalan	SP1	29.09	28.99	8.98	31.0	0.001***	
		SP2	30.11					
		SP3	27.00					
		SP4	29.77					
	Mambuaw	MP1	18.65	20.01				
		MP2	19.91					
		MP3	23.24					
		MP4	18.24					

***very highly significant
ns not significant

Miarayon farmers plant the white corn variety because this is for home consumption. Mean yield of corn in the two sites differ only by 0.29 tha^{-1} which is not significant. Miarayon yield was almost twice as much as the yield of white corn in Bukidnon (BAS, 2013) although farmers do not apply fertilizers when corn is planted. Corn may have benefited the slow release of nutrients applied in the previous cropping. There are farmers in Miarayon that use relay cropping system (*lapat)* particularly on potato plots. The farmers seed the corn while the potato plants were still growing. Thus the corn plant can benefit the applied inputs while the potato is growing.

Mean yield of potato in Salsalan is higher than in Mambuaw by 8.98 tha^{-1}. Potato adaptation trial results by Tatoy *et al*. (2001) in Miarayon, Lirongan and San Miguel had yields of 26.16, 23.19 and 25.63 tha^{-1} respectively. Potato yields in Salsalan are similar to the Miarayon region yields 13 years ago. Therefore the present potato productivity of Salsalan which is relatively recently opened is as good as the state of Miarayon soil productivity when the potato adaptation trials conducted about 12 years ago.

6.3.2. Crop yield calibration with soil fertility levels in Miarayon

Table IV-14 presents the statistical analysis results for yields with soil nutrient levels. In this study, there was no relationship detected between carrot yields and soil nutrients. However, some observations were drawn from the crop's behavior in response to the topsoil quality.

Table IV-14. Correlations between crop yields and soil fertility levels of Miarayon soils.

Crop	Value	pH H_2O	TOC	TN	Ca^{2+}	Mg^{2+}	K^+	Na^+
			%		cmol$_+$kg^{-1}			
Carrot	R	0.047	0.253	0.042	0.095	0.130	0.066	-0.297
	P	0.911ns	0.545ns	0.921ns	0.823ns	0.785ns	0.876ns	0.476ns
Corn	R	0.173	0.222	0.274	0.896	0.894	0.642	-0.503
	P	0.682ns	0.598ns	0.512ns	0.003**	0.003**	0.086ns	0.204ns
Potato	R	0.784	0.887	0.950	0.849	0.515	0.761	0.196
	P	0.021*	0.003**	0.000***	0.008**	0.192ns	0.028*	0.676ns

***very highly significant ($P\leq0.001$); **highly significant ($P\leq0.01$); *significant ($P\leq0.05$), ns not significant ($P>0.05$)

6.3.2.1. Relationships between carrot yield and topsoil nutrients

The prerequisite optimum soil pH for carrots is 6.0 (Rubatzky *et al*., 1999) and all carrot plots fell below the required condition. Carrot yields in these areas were higher than the provincial yield value (BAS, 2013). In Mambuaw, the plot with the highest yield (MC3) has the highest TOC (8.7%), TN (0.6%) and sum of available bases (3.17 cmol$_+$kg^{-1}). The crop with the lowest yield (MC1) has also the lowest TOC (4.1%), TN (0.3%) and sum of available bases (2.61 cmol$_+$kg^{-1}).

For Salsalan, SC2 and SC4 plots have low yield values, having K:Mg ratio of >2 (3.5:1 and 3.4:1 respectively). At these values, K may inhibit the uptake of Mg (Landon, 1991). Moreover, according to farmers these plots were affected by long dry days at the early stage of planting. Carrots like a uniform water supply throughout the growing season (Fritz *et al*., 2013) and hot sunny days can kill the young plants. Miarayon crops are rain-fed. Plant densities of these two plots were 104 and 84 plants per 10 m^2 only and these were less than half of the average modal carrot plant densities. The plot with the highest yield (SC1), had the crop which was harvested the latest. In Miarayon, there are farmers cannot decide as to when the crops shall be harvested. The financiers who watch the product marketing trends dictate the schedules of harvests. Carrots are planted continuously regardless of the time of the year or season. Plant density shows that the sizes of the carrots in this plot were much bigger than the average size. Compared to the three groups of crop plots, carrot plots have low available Mg.

6.3.2.2. Relationships between potato yield and topsoil nutrients

Figure IV-7 presents the scatter plots of the correlations between potato yield and TOC, TN, soil pH, Ca and K. Potato yield has high positive correlations ($P \leq 0.01$) with both TOC and TN which would mean that the crop is a good indicator of TOC and TN levels that are in soils.

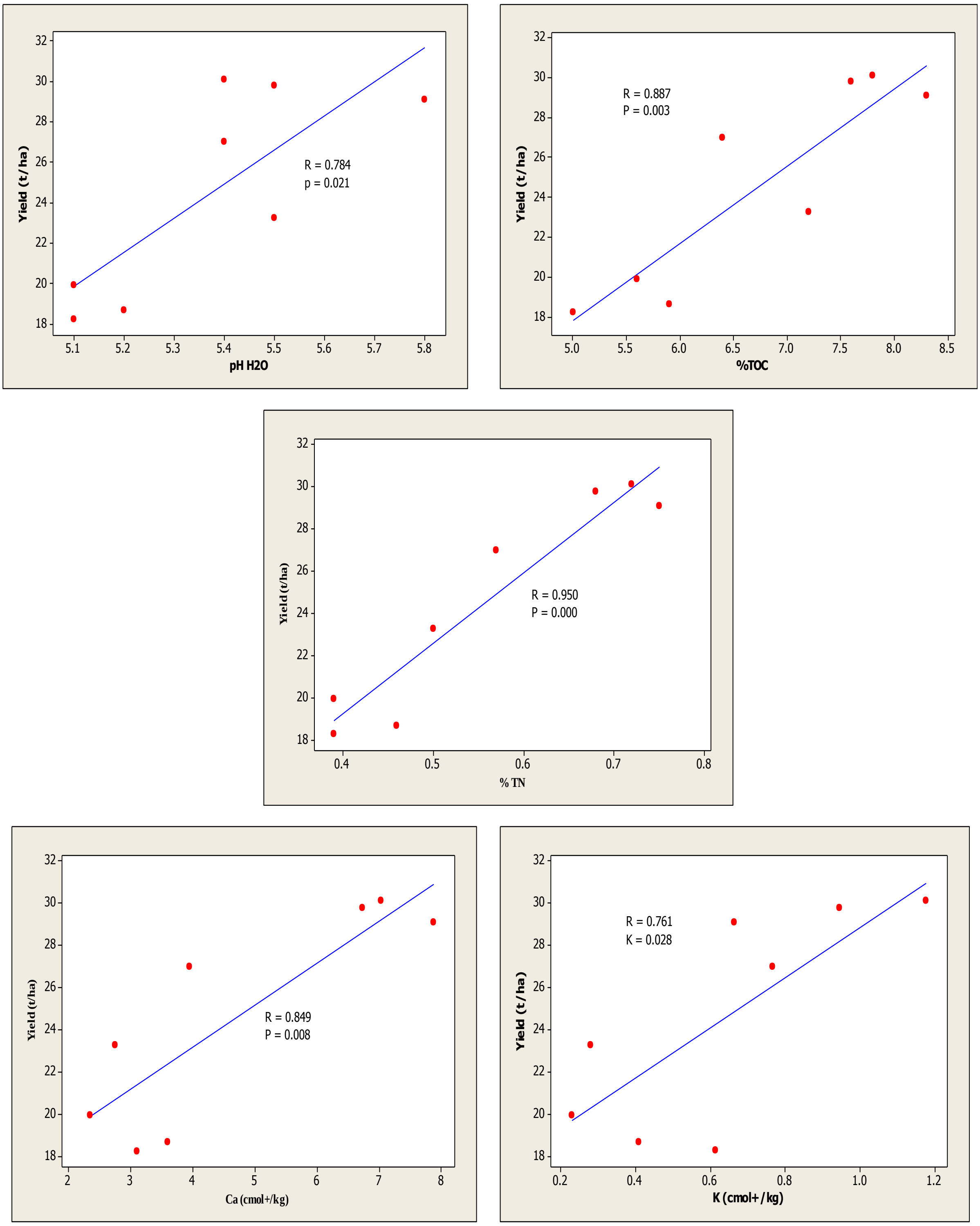


Figure IV-7. Correlation graphs between potato yield and soil pH, TOC, TN, available Ca and K in Miarayon.

6.3.2.3 Relationships between corn yield and topsoil nutrients

Figure IV-8 shows the scatter plots of the correlations between corn yield and available Ca and Mg. Corn apparently responds to different levels of these two available bases. In this study, there was no sign of relationship on yields with soil pH, TOC, TN, available K and Na. The soil pH range of tolerance for satisfactory corn yield is 5.0-8.0 (Landon, 1991) and in Miarayon corn plots, the range of soil pH values is narrow (5.1- 5.8). Therefore, the effects of soil pH on corn yield may not be striking because the values of this parameter are not highly varied. According to Landon (1991), the N specific requirement for corn is high (0.5-1.0%). Miarayon corn plots have medium to high TN values (Table IV-4). As N is the most important nutrient for corn, the crop in Miarayon grows sufficiently. The aforementioned findings can be the reasons why the soil pH and TN in Miarayon soils do not affect the yield of corn. This is because, generally, the values are within the range of the specified requirements.

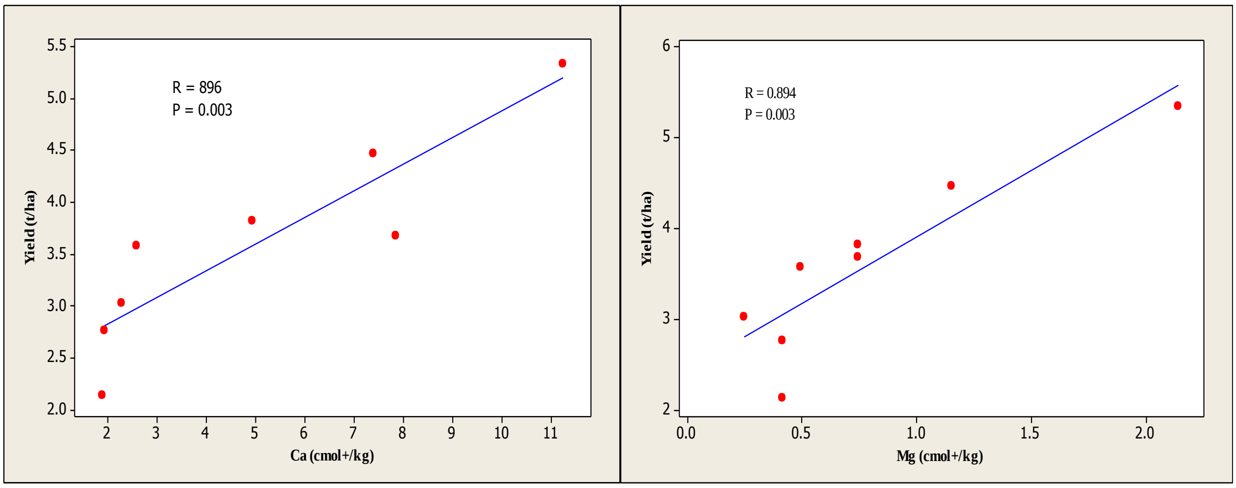


Figure IV-8. Correlation graphs between corn yield and available Ca and Mg in Miarayon topsoils.

The K:Mg ratio had ranged from 0.5 to 1.7 which were below the threshold of >2 (Landon, 1991). Therefore, Mg uptake in corn plants may not be affected by the presence of K in soils. There is no relationship detected between potato yields and Na because of its low quantity and it is not a critical element for the crop unless its concentration in soil is beyond the tolerance limit of the plant's threshold level.

6.4. Bendum crop yield measurement results

Results presented as follows are the crop yields of the three predominant crops in Miarayon namely, corn, sweet potato and ginger. This also further presents the determining nutrients in crop yields.

6.4.1. Crop yields and topsoil fertility in Bendum cultivation areas

Table IV-15 presents the results of crop yield measurements of corn, ginger and sweet potato in Bendum production areas. The highest yield of corn was in BP14Co1 plot which was planted with yellow corn variety. Furthermore, when the topsoil samples were taken, the plot was relatively recently opened, about three years ago. Plot BP9Co1 was also with the yellow corn variety. Comparing with the 2012 Bukidnon yield for yellow corn, the yields of BP14Co1 and BP9Co1 were much lower. The yields from BP9Co2 and BP14Co2 were for the white corn variety. The yield values were also lower than the provincial yield. Because of the lack of farm resources, Bendum farmers generally do not or under apply fertilizer to the plot.

Table IV-15. Yield measurement results of corn, ginger and sweet potato plots in Bendum cultivation areas.

Crop	Location	Plot	Yield	Mean yield	Mean yield difference	2012 Bukidnon yield[1]
			t/ha			
Corn	Around BP9	BP9Co1	2.15	1.71	-0.4	4.74 (yellow) 2.37 (white)
		BP9Co2	1.27			
	Around BP14	BP14Co1	3.66	2.11		
		BP14Co2	0.56			
Ginger	Around BP9	BP9G1	8.37	5.31	4.43	8.64
		BP9G2	2.24			
	Around B14	BP14G1	2.32	3.56		
		BP14G2	4.80			
Sweet potato	Around BP9	BP9SP1	1.28	3.34	1.76	19.74
		BP9SP2	5.41			
	Around BP14	BP14SP1	0.99	1.58		
		BP14SP2	2.16			

[1]Source: BAS (2013)

For the ginger, BP9G1 had the highest yield which was comparable to the 2012 Bukidnon yield (BAS, 2013). The plot is located at the remotest part of the production area in which to the extent has invaded the forest. Although a newly opened plot, the farmer had applied 50 kg of 16-20-0 fertilizers and did a relatively good maintenance (Figure IV-9). The rest of the ginger yields in other plots are way below the Bukidnon yield values (BAS, 2013).

Sweet potato was poorly growing in Bendum. The lowest yield is from the plot which is situated on a very steep slope. If their yields shall be compared with the Bukidnon values, these were far more inferior. Farmers shall look into the sweet potato cultivation management and practices. With the physical characteristics of Bendum soil, particularly in texture and aggregation, there is need to thoroughly prepared the land for the root crops to grow well. Farmers have to look into the suitability of sweet potato in Bendum. As sweet potato is a staple food but does not grow well in the area, the farmers should find other kinds of root crops that would fit into the soil environment.

Table IV-16 shows the plot yields with their respective soil nutrient levels. The low yield values of corn (BP9Co2 and BP14Co2) in both locations had high C:N ratios (14 and 15). The C:N ratio denotes the degree of humification of organic matter (Landon, 1991). Granting a constant value of TOC in a soil, low N content increases the C:N ratio. Therefore, the C:N ratio is dependent on the kind of organic matter and in its own C and N proportions. It should be noted that N is an essential nutrient for corn and for many crops (Landon, 1991). The high yield values of ginger plots around BP9 and BP14 have the highest amounts of Mg (both having 0.82 $\mathrm{cmol_{+}kg^{-1}}$) and K in both plots (0.18 $\mathrm{cmol_{+}kg^{-1}}$).

Figure IV-9. Ginger yield of Plot BP9G1.

Table IV-16. Plots with crop yields and their respective soil nutrient levels in Miarayon.

Crop	Plot	Yield tha^{-1}	pH H_2O	TOC	TN	C:N	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	∑ available bases
							$cmol_{+}kg^{-1}$				
Corn	B9Co1	2.15	5.1	1.2	0.20	6.0	2.10	1.56	0.15	0.04	3.05
	B9Co2	1.27	4.9	5.8	0.41	14.1	2.99	1.10	0.87	0.04	5.00
	B14Co1	3.66	4.8	3.7	0.30	12.3	1.30	0.87	0.36	0.09	2.62
	B14Co2	0.56	5.0	5.9	0.39	15.1	1.90	0.91	0.31	0.04	3.16
Ginger	B9G1	8.37	5.6	3.3	0.20	16.5	1.95	0.82	0.18	0.09	3.04
	B9G2	2.24	5.6	2.5	0.20	12.5	3.09	0.33	0.13	0.09	3.64
	B14G1	2.32	4.9	3.6	0.30	18.0	0.90	0.33	0.08	0.09	1.40
	B14G2	4.80	5.3	4.2	0.30	14.0	3.49	0.82	0.18	0.09	4.58
Sweet potato	B9SP1	1.28	5.3	3.6	0.20	18.00	0.80	0.66	0.20	0.09	1.75
	B9SP2	5.41	5.3	2.2	0.20	11.00	2.35	1.89	0.10	0.04	4.38
	BP14SP1	0.99	5.4	3.4	0.30	11.33	3.74	5.27	0.30	0.04	9.35
	BP14SP2	2.16	4.9	3.4	0.30	11.33	0.60	0.66	0.10	0.09	1.45

For sweet potato, the low yield values around BP9 had the highest C/N ratio and the lowest sum of bases (1.75 $cmol_{+}kg^{-1}$). Magnesium removal by sweet potato is 16 kg-Mg/ha (Camberato and Pan, 2000). If sweet potato is continuously planted, Mg depletion may occur as the only nutrient source is the rock materials. Sweet potato field in Bendum is continuously planted because the plot is considered as storage of sweet potato tubers. As the sweet potato is for home use, farmers will harvest the tubers which are enough for certain period of consumption. Magnesium is the dominant base in Bendum, its depletion in this plot may be due to the sweet potato which is planted continuously. Asio *et al*. (2009) cited that continuous planting of corn and sweet potato had depleted the Mg content of highland soils in Leyte Island.

7. Chapter conclusion

The questions raised in this particular part of the PhD research study which were articulated in the significance of the study, were on the nutrient levels, their differences and indications on soil fertility; the prevalent soil management practices in the highland's and their effects on the soil quality; the quantity of yields of predominant crops and the differences between locations; and the relationships between crops yields and soil nutrient levels in order to assess if these crops can be used as indicators of soil fertility levels.

7.1. Topsoil fertility comparison and soil management practices in crop production

The soil pH range in Miarayon is narrower (1.3 units, slightly acid to moderately acid) compared to Bendum (2.6, slightly acid to slightly alkaline). Miarayon soils are derived from more homogenous parent materials compared to Bendum. Although soil pH can also be anthropogenic induced, it can be shown in the data that in Bendum, there were extremely high values of total Mg. The relatively high total Ca in soils was detected at the pedon locations where the soil pH is highest. Both sites have the same mean soil pH values of 5.4 (moderately acid). The highest value of TOC in Miarayon was more than twice as much as in Bendum. The lowest value in Miarayon soils was four times than that of Bendum soils. The high TOC values in Miarayon soils can be due to the properties which are inherent in volcanic soils that fix organic matter thus delaying the mineralization of carbon. Furthermore, farmers apply organic matter when carrots and potatoes were planted thus the soil has constant supply of organic matter which would tend to build up in Miarayon soils. The C:N ratio of both sites are relatively similar. The TN range in Miarayon was from medium to very high. This can be explained by the Miarayon farming practice which adds external inputs as basal application before the seeding of carrots and potatoes and during maintenance as well. Organic fertilizers are nitrogen rich which come from animal wastes (chicken dung). The Bendum TN range was from low to medium. The plot with the medium TN level was planted with corn and this shows that N fertilizers were applied. Available P in both sites was undetected.

For the exchangeable bases in soils, the highest exchangeable Ca in Miarayon was twice than that of what Bendum has, although the rock samples in Bendum which are pyroclastic deposit has higher percentage of CaO that in Miarayon rocks (11.65% and 3.44% respectively). The constant application of chicken dung in Miarayon plausibly has increased the Ca concentration in soils. As explained in Chapter 3, Miarayon soils have the characteristics of high Ca affinity, thus these keep the Ca from lixiviation. The exchangeable Mg range in Bendum was extreme from very low to very high. For exchangeable K, the range in Miarayon was from low to high while in Bendum was from very low to low. Bendum rocks are low in K compared to Miarayon. Furthermore, Miarayon farmers apply K fertilizers while the Bendum farmers, only few are applying. Exchangeable Na was not a constraint in both sites. The sums of the bases of the two sites were almost at par with each other. Calcium dominates the bases in Miarayon while in Bendum, Mg is foremost.

7.2. Crop yields of Miarayon and Bendum

The indicator crops in Miarayon were carrot, corn and potato. The yields of these crops were much higher than the Bukidnon province average yields. Carrot and potato are root crops which are suitable to the kind of soils that Miarayon has. For corn, farmers did not even apply fertilizers in its cultivation but the yields are better than in other places in Bukidnon province. As rotational crop, corn follows right after either carrot or potato. The response of corn yields in Miarayon to the availability of Ca and Mg was highly significant and to K was significant. Carrots do not have a general trend in responding to the soil fertility. This was because the plant can be affected not only by the soil fertility status but also by other environmental conditions and its crop management. However, looking into the crop affinity to soil nutrients, it responds to the TOC, TN and sum of bases. The response of potato to TN was very highly significant, to TOC and to Ca were highly significant, and to soil pH and C:N ratio were significant. The conditions of Miarayon soils were favorable to crops because of its high TN content and its hydraulic conductivity although its soil pH is generally low.

The Bendum yields of corn, ginger and sweet potato were much lower than the Bukidnon province yield values. However, there was one ginger plot which can compete with the provincial yield. It can be noted that the C:N ratio is a factor that seemed to affect the yields of corn and sweet potato. Nitrogen is an important nutrient for corn but this nutrient was found to be low in Bendum. This is because farmers generally do not or under apply fertilizers on their fields because of farm resource availability constraints. Furthermore, Bendum plots are under maintained and weeds are allowed to compete with the crops due to the farmer’s scarcity of resources. Therefore, there is a need to look into the crop cultivation management and practices in Bendum.

7.3. General appreciation

This part of the study had grasped the topsoil fertility and how this can be affected by long cultivation. This further had determined the link of topsoil fertility to the field yields of predominant crops. The field measurement was done in actual setting of agricultural practices of farmers and there were no agricultural inputs which were provided by the researcher. The strong and positive relationships of potato yields for most of the soil nutrient levels and for corn on Ca and Mg, although at a minimal number of observations can be a good way of calibrating soil fertility levels with associated crops.

For Miarayon soils, long and continuous cultivation had already affected the soil fertility levels and this shall be the signpost for succeeding soil management and conservation initiatives. Furthermore, the yields of carrots, corn and potatoes are higher than the provincial values and therefore, it can be posited that Miarayon soils are still competitive in terms of soil fertility. The physico-chemical properties of the soil are also most fitting for the three crops (carrot, corn and potato). However, the issue of available P needs to be addressed. For Bendum, there are soils which still have strikingly high total Mg which can be attributed to the parent materials. However, most of the total elements that are essential to plant growth are already low. Better crop yields for Bendum farmers may be achieved if farming systems such as soil management and crop maintenance shall be improved. To determine the soil's capacity to release nutrients, the nutrients absorbed by a test plant has to be examined. This is the subject of the succeeding chapter (Chapter V) in which the pot experiment is used as the strategy in calibrating soil fertility.

Chapter V

Soil fertility assessment and monitoring through pot experiment for Bukidnon agricultural highland soils, Northern Mindanao, Philippines

1. Chapter overview

At a given climatic condition and management scheme, plants assimilate nutrients from the soil and therefore their appearance, growth and yield performance are indicators of the quality of this environmental matrix where their sustenance come from. The quantity and quality of plant biomass are yardsticks in understanding the soil health status. Visual symptoms in plants can be used to qualitatively diagnose the nutrient deficiencies in soils. Poor crop growth and consequent low yields are the outcomes of low nutrient availability (PCARRD, 2006). In this study, plant responses to soil fertility were quantified in two ways: (1) by field observation and (2) by laboratory investigation. The field observation was done through crop yield measurements and cross-referencing the results with the soil chemical properties. This is one of the subjects of Chapter IV. The laboratory investigation was to reckon a test plant response in a controlled environment by pot experiment and calibrated the results with soil chemical properties. This is the focus of this chapter.

The pot experiment is a simple test to determine the response of a plant to particular soil conditions and treatments. This method has been used in many applications such as testing of plant response to different soil treatment and fertilization scheme, soil resource mobility, food safety and bioavailability evaluations (Kang *et al.*, 2014; Su *et al.*, 2014; Vos *et al.*, 2014; Wilberts *et al*., 2013; Stephen and Waid, 1963).

A pot experiment was conducted at the Manresa Experimental Research Station of the College of Agriculture, Xavier University, Cagayan de Oro City, Philippines. Because of its adaptability to the Philippine condition, Signal grass *(Brachiaria decumbens* var. *Basilisk)* was used as the test plant in the study. Discussions in this chapter are the differences in the biomass weights of Signal grass with respect to the different soil types, the assimilation rates of soil nutrients by the test plant, the relationships of the nutrient levels that are found in the plant and the elements that are in the soil media, and the relationships between absorbed elements by the test plant.

2. Significance of the study

Understanding the inherent soil quality and the relationships with nutrient elements and how these affect plant growth are salient information in formulating strategies for soil fertility management. To establish the relevant information for the SRS, the following research questions were raised and answers are discussed in the presentation of results:

(i) Are there differences in biomass yields between different soil types?

(ii) What are the soil nutrients in different soil types that are absorbed by the test plant? Are there differences in the concentration levels?

(iii) How does each assimilated elements has apparently influenced the absorption levels of other elements?

(iv) How do locations and soil types affect the assimilation rates of nutrients by the test plant?

3. Objectives of the study

Differences in the biomass yields tell the effects of different soil types and their inherent nutrients in the growth of a test plant. Interactions between absorbed nutrients illustrate the affinity of individual elements to one another. This part of the study had aimed to assess and monitor the soil fertility by pot experiment using a test plant. Investigations conducted were: (i) to determine the difference in biomass yields of a test plant in different soil types, (ii) to find out the soil nutrient assimilated by a test plant and their differences in absorption levels, (iii) to find out the interactions between nutrient levels absorbed by a test plant, and (iv) to find the influence of locations and soil types in a test plant’s assimilation of nutrient elements.

4. Methodology

The methodology describes the procedure of soil media gathering, setting up of the pot experiment, the laboratory analyses on plant samples and statistical method application.

4.1. Soil media gathering and preparation

The soil media for the pot experiment were gathered around the pit locations. After scraping the vegetation and trash on the top soil, 20 cm depth of core composite soil samples were taken using an Eidelman auger. Each sampling point is 10 m distance from each other and a total of 20 augers were made. The 20 augered core soil samples were mixed in the laboratory and were air-dried (Figure V-1).

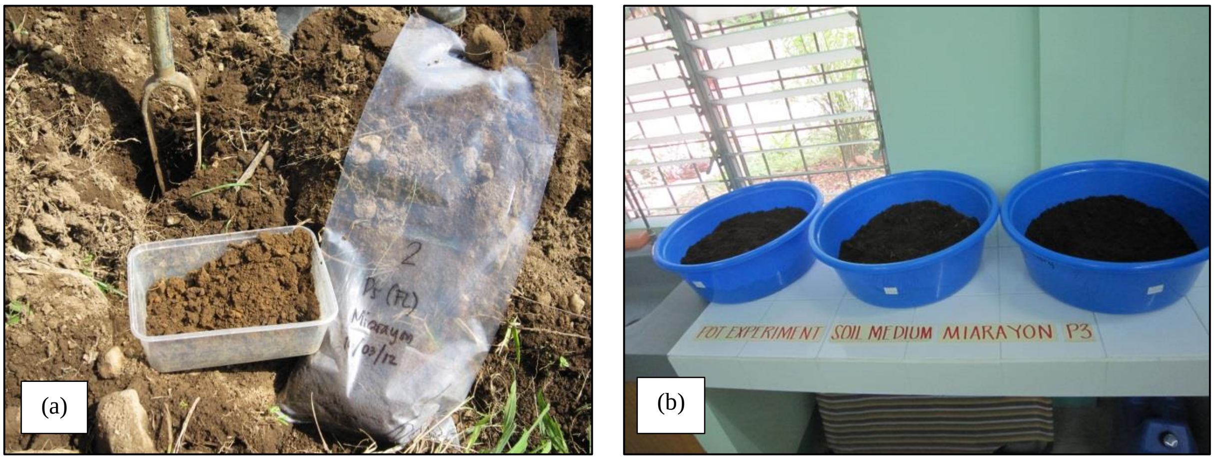


Figure V-1. Soil media for pot experiment (a) gathering using an Eidelman auger and (b) air drying in the soil laboratory.

4.2. The experiment

This part of the methodology explains the details of the test plant used, the shed construction, the soil media preparation, the growing process and the biomass harvesting. The pot experiment was conducted at Manresa Experimental Research Station of Xavier University College of Agriculture, Cagayan de Oro City, Philippines. Illustrations are found in Figure V-2.

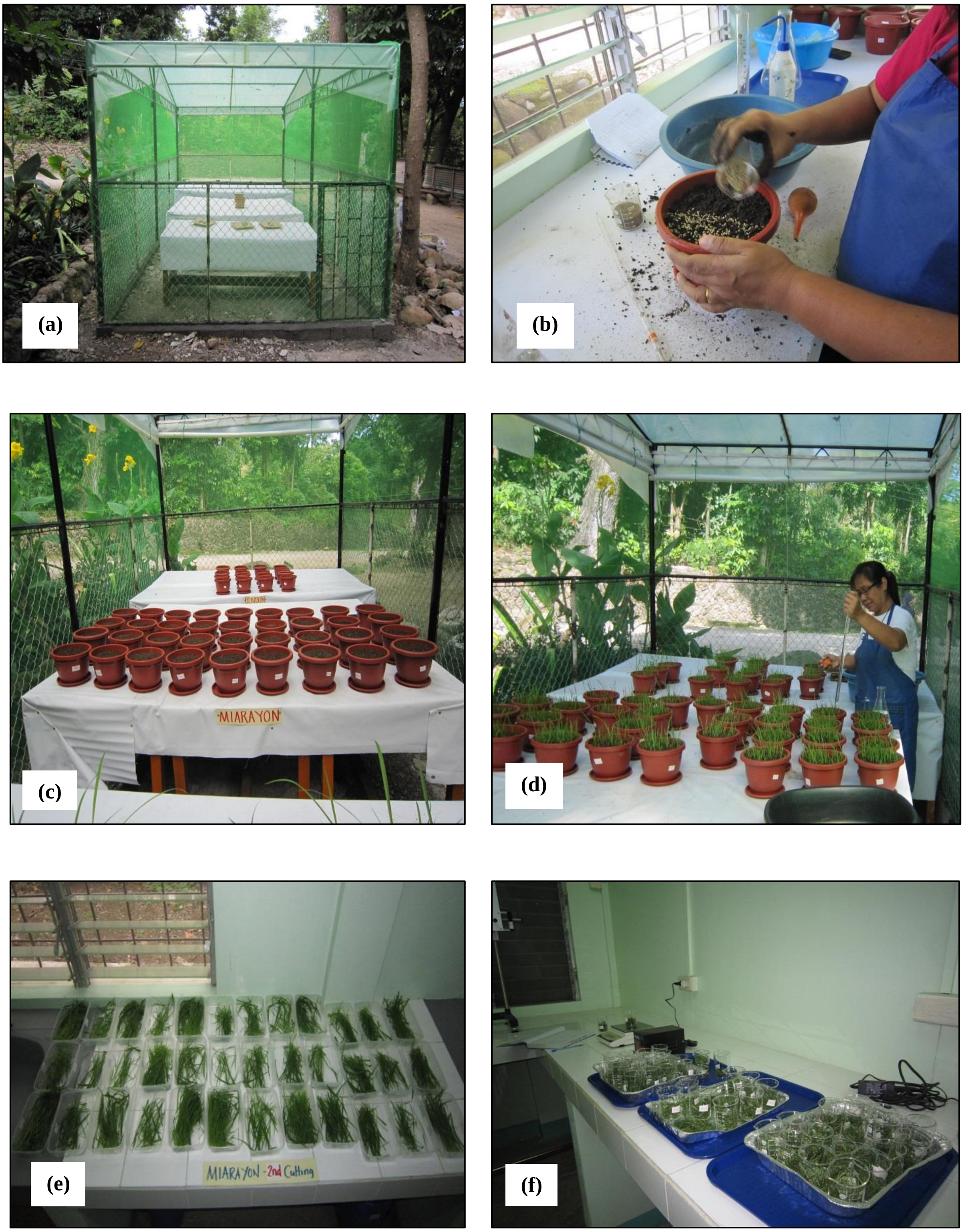


Figure V-2. Pot experiment procedures (a) the shed, (b) soil preparation, (c) experimental set-up, (d) water application, (e) biomass harvest and (f) taking the biomass fresh weights.

4.2.1. The test plant

In this experiment, one of the criteria for the test plant to be used should have small seeds of grass particularly. First, the use of small seeds in pot experiment enables the procedure to standardize the quantity of plants in the pot and the seeds can be spread evenly on the soil in the pot. Second, the small seed has minute quantities of initially stored nutrients to sustain the plants upon establishment. Therefore, the quantities of nutrients assimilated by plants (upon analysis) when they are established would come from the soil media where these are planted. In here, a grass is used because it has small seeds and, the vegetative parts regenerate after each cutting which is a requirement of this experiment. The grass should adapt to the locality where the experiment would be conducted. For temperate conditions, Rye grass *(Lolium perenne,* L.*)* is used as test plant for soil fertility assessment and fertilizer application (Stephen and Waid, 1963). The test plant used in this experiment was Signal grass *(Brachiaria decumbens var Basilisk)*. The Basilisk variety is adapted to a wide range of soils and climates, will persist on infertile and acid soils and is well suited to wet or dry tropics (Horne and Stur, 1999). Another also is that the variety is adapted to tropical conditions and therefore should thrive in Manresa conditions.

If Rye grass is used in the experiment, the weight of seeds is 3 g or approximately 1,000 seeds to fully occupy the soil surface in the pot. By determining the weight of individually counted 100 Signal grass seeds in four replications, it was estimated that the weight of 1,000 seeds was 4.4 g. For this experiment, the weight of the Signal grass seeds that was used in the study was 4.4 g which is approximately 1,000 seeds since the Signal grass seeds are bigger and therefore heavier than Rye grass seeds. Prior to the conduct of the proper experiment, a test was conducted to check if the Signal grass seeds would germinate and the plant can survive in the Manresa Experimental Research Station environmental conditions.

4.2.2. Conduct of the pot experiment

The duration of the study from preparations to proper execution of the experiment was from 21 October 2012 until 12 February 2013. For Miarayon soils, a total of 36 pots were prepared for nine soil types at four replications. Bendum soils had 16 pots for four soil types which were also replicated four times. One kilogram of air-dried soil was used in each 1.5L plastic pot. Cutting of biomass was done four times. The first cutting was done three weeks after the seeds had sprouted and every three weeks thereafter until the fourth cut. The cutting schedules were as follows:

First cut – 10 December 2012
Second cut – 31 December 2012
Third cut – 21 January 2013
Fourth cut – 11 February 2013

4.2.3. Soil analyses

The sources of soil data were from Lebrun (2011) for Miarayon soil and Barbieux (2012) and Richelle (2010) for Bendum soils which are found in Tables V-1 and V-2. These data were from the first horizon samples from the soil pits of both study sites. Soil laboratory analyses methods are reflected in Chapter III. There are differences in the soil chemical parameters that were analyzed for Miarayon and Bendum soil samples. For Miarayon, first horizon soil samples were analyzed for soil pH, TOC, exchangeable Ca, Mg, K and Na, total element contents of P, Ca, Mg, K, Na, Al, Fe, Mn, Cu and Zn. For Bendum, the soil samples were only analyzed with total element contents only on TOC, P, Ca, Mg, K, Na, Al, Fe and Mn. Moreover, for Bendum, the soil pH analysis was done in the field.

4.2.4. Plant analyses

The fresh weights of the cut biomass from both sites were taken and these were oven dried at 80 °C for 24 hours. The oven dried biomasses were analyzed at the Geopedology Unit of ULg-GxABT, Gembloux, Belgium. Plant samples were analyzed for Ca, Mg, K, Na, P, Al, Fe, Mn, Cu and Zn by HNO_3 and $HClO_4$ extraction. Except for total P, the measurements of total elements were conducted by atomic absorption spectrometry. Total P was determined by spectrophotocolorimetry.

Table V-1. Soil chemical properties of the first horizons of the soil pedons in Miarayon.

Pedon	Soil Classification	Soil chemical properties															
		pH H_2O	TOC	Exchangeable bases				Total element content									
			%	Ca	Mg	K	Na	P	Ca	Mg	K	Na	Al	Fe	Mn	Cu	Zn
				cmol₊/kg				mg/100g					%		ppm		
MP1	‘Andic’ Cambisol	5.2	11.6	1.62	0.25	0.29	0.14	120	463	337	153	350	6.56	8.23	299	148	48
MP2	‘Andic’ Cambisol	5.2	6.9	2.23	0.88	0.22	0.01	66	288	220	69	238	11.24	9.39	231	104	48
MP3	‘Andic’ Umbrisol	5.5	10.0	11.05	1.49	0.28	0.00	350	952	685	430	610	7.76	6.16	1506	143	93
MP4	‘Andic’ Umbrisol	5.0	8.3	3.57	0.23	0.19	0.01	277	594	575	311	514	9.32	6.63	1254	116	102
MP5	‘Andic’ Cambisol	5.2	6.0	4.12	0.28	0.18	0.09	288	984	819	923	1080	6.57	7.30	930	168	82
MP6	‘Andic’ Umbrisol	5.0	11.2	3.73	0.41	0.22	0.15	338	582	616	151	488	6.86	5.44	588	78	55
MP7	‘Andic’Cambisol	4.9	5.7	1.83	0.29	0.24	0.01	82	183	180	32	160	7.36	6.89	302	104	52
MP8	‘Andic’ Cambisol	4.7	5.7	0.98	0.05	0.14	0.01	147	248	223	58	205	10.73	7.68	698	64	56
MP9	‘Andic’ Umbrisol	4.8	5.3	4.29	0.89	0.26	0.00	170	346	205	119	258	11.50	9.33	2109	122	273

Source: Lebrun (2011)

Table V-2. Soil chemical properties of the first horizons of the soils in Bendum production areas.

Pedon Soil classification		Soil chemical properties									
		pH H_2O	TOC	Total element content							
				P	Ca	Mg	K	Na	Al	Fe	Mn
			%	mg/100g					%		ppm
BP3	Pisoplinthic Acrisol	5.5	2.0	27	174	1211	98	63	6.79	25.88	235
BP5	Ferralic Nitisol	5.0	2.4	51	164	872	101	119	9.70	23.13	186
BP9	Acric Nitisol	5.5	3.5	32	133	578	114	60	9.47	25.11	111
BP14	Vitric Cambisol	4.5	2.9	48	104	69	63	67	15.08	11.44	31

Source: Barbieux (2012) and Richelle (2010)

4.2.5. Statistical analysis methods

Data were treated using the Minitab 16 software. Statistical analyses used were the Two Sample T – test and linear correlations test (LCT). In this chapter, separate discussions for Miarayon and Bendum test plant and soil interactions are presented because of two reasons. First, Miarayon soils are much different from Bendum. Second, there are differences in soil parameters analyzed for both sites. For nutrient assimilation by the test plant, the Miarayon and Bendum results were dealt together employing the LCT, Principal Component Analysis (PCA) and Analysis of Variance using the General Linear Model (ANOVA-GLM).

5. Miarayon results and discussions for soil and test plant relationships

This section communicates the soil and test plant relationships of the pot experiment conducted for Miarayon soils. This presents the biomass weights of Signal grass harvests for the soil in each location and describes their relationships with the total elements in topsoil. This further explains the plant assimilation rates of nutrients from soil.

5.1. Biomass fresh weights of harvested Signal grass in the Miarayon study

Table V-3 shows the Signal grass biomass weights from nine soil types in four harvests from Miarayon soils. Biomass weights were highest in the soils from MP3 and MP9 which were on toeslopes and were Umbrisols. The lowest yield was from MP5, which is a Cambisol on open, convex position. The highest biomass yield was generally attained in the second cut and after then, the yield had declined. Using the Two sample T-test, the fresh weights of the biomass harvests from 'Andic' Umbrisols were significantly higher (P=0.018) than that from 'Andic' Cambisols.

Table V-3. Biomass yields of Signal grass planted on Miarayon soils (g).

Pedon	Soil Type	First harvest	Second harvest	Third harvest	Fourth harvest	Total harvest
MP1	'Andic' Cambisol	8.70	15.90	11.24	7.52	43.36
MP2	'Andic' Cambisol	7.50	19.21	9.75	5.24	41.70
MP3	'Andic' Umbrisol	21.88	41.72	26.29	15.94	105.83
MP4	'Andic' Umbrisol	15.96	14.91	13.78	7.73	52.38
MP5	'Andic' Cambisol	12.01	7.17	8.77	7.06	35.01

MP6	‘Andic’ Umbrisol	14.22	12.60	10.18	12.00	49.00
MP7	‘Andic’ Cambisol	12.36	16.26	10.66	8.61	47.89
MP8	‘Andic’ Cambisol	7.61	15.33	14.04	4.64	41.62
MP9	‘Andic’ Umbrisol	23.28	33.71	20.89	13.17	91.05

5.2. Biomass fresh weights in relation to the properties of Miarayon topsoils.

Table V-4 presents relationships of the biomass fresh weights and the soil chemical properties of pedon topsoils. Significant relationships between the test plant fresh weights and some soil nutrients are illustrated in Figure V-3. It is expected that the more nutrient elements in soil, the better is the performance of the plant. However, in this experiment the fresh weights of biomass were only directly associated with exchangeable Ca (R=0.813; P=0.008), exchangeable Mg (R=0.824; P=0.006), the total Mn (R=0.814; P=0.013) and almost for Zn (R=0.628; P=0.070). There was no apparent trend on the relationships between test plant yield and the rest of the total element contents in Miarayon topsoils.

Table V-4. Biomass fresh weights and soil properties correlations of Miarayon soils.

Soil property	R/P values	Soil property	R/P values	Soil property	R/P values
Soil pH	R = 0.274	Total P	R = 0.368	Total Fe	R= -0.055
	P = 0.476^{ns}		P = 0.330^{ns}		P = 0.887^{ns}
TOC	R = 0.094	Total Ca	R = 0.272	Total Mn	R = 0.779
	P = 0.810^{ns}		P = 0.479^{ns}		P = 0.013*
Exch Ca	R = 0.813	Total Mg	R = 0.084	Total Cu	R = 0.203
	P = 0.008**		P = 0.831^{ns}		P = 0.600^{ns}
Exch Mg	R = 0.824	Total K	R = -0.017	Total Zn	R = 0.628
	P = 0.006**		P = 0.966^{ns}		P = 0.070^{ns}
Exch K	R = 0.562	Total Na	R = -0.040		
	P =0.115^{ns}		P = 0.920^{ns}		
Exch Na	R = -0.431	Total Al	R = 0.195		
	P = 0.247^{ns}		P = 0.616^{ns}		

Note: ** highly significant, * significant, ^{ns} not significant

Potassium is highly absorbed by the plants because it is a macronutrient. In this number of observations, there is a positive relationship between the nutrient and the biomass fresh weights, although not significant (R=0.562; P=0.115). For Na, even though there is no significant relationship with biomass yield, the seemingly inverse relationship between them can cause unfavorable plant conditions. Sodium would have negative effects on plant biomass weights if conditions would allow more of its intake. The results of correlations test using exchangeable Mg, Ca, total Mn and Zn in soils are the possible factors to be considered in order to increase the plant biomass

Table V-5 indicates the total elements assimilated by the plants and the total elements in the topsoil. Plant total elements were expressed in terms of milligrams of analyzed dry biomass weights. Soil total elements were also expressed in terms of milligrams in a kilogram of soil in the pot. The mean weights of nutrient which were mostly absorbed by the test plant biomass were K (μ=33.38 mg), Mg (μ=4.33 mg) Ca (μ=3.52 mg) and P (μ=1.7 mg). The higher percentage of nutrient absorption by the test plant relative to the levels of nutrients in topsoils were those of K (μ=3.44%) and P (μ=1.3%). Bear and Toth (1948) pointed out that of the three basic cations, K dominates in the plant. This is because K is an integral part of the plant metabolism, to form and transport carbohydrates and proteins, thus the nutrient is required in large amounts (Buol, 2008). The second

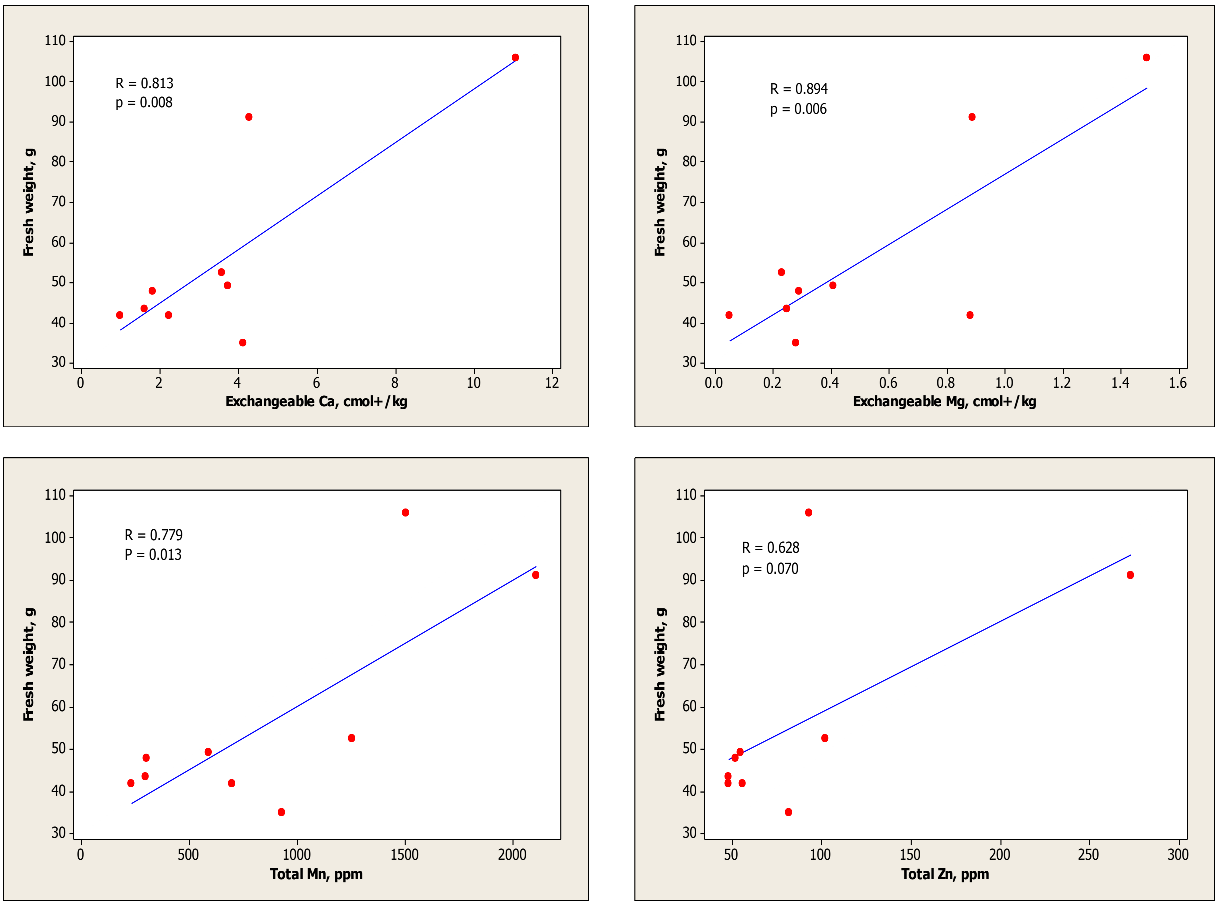


Figure V-3. Correlation graphs of biomass fresh weights and exchangeable Ca, exchangeable Mg, total Mn and total Zn in Miarayon soils.

mostly absorbed element was Mg. Removal of Mg from soil by vegetation depends on the species (Camberato and Pan, 2000). Opfergelt *et al.* (2013) had used Mg isotopes to trace the soil to plant transfer to identify the source of Mg. As cited by Camberato and Pan (2000), Mg removal by white potatoes and sweet potatoes are 8 and 16 kg Mg/ha.

Table V.5. Total elements assimilated by the Signal grass and total element contents of soil in pots from Miarayon.

Pedon	Total Ca (mg/100g)			Total Mg (mg/100g)			Total K (mg/100g)			Total Na (mg/100g)		
	Test plant	Top horizon	%	Test plant	Top horizon	%	Test plant	Top horizon	%	Test plant	Top horizon	%
MP1	3.05	4,630	0.07	4.43	3,370	0.13	33.79	1,530	2.21	0.40	3,500	0.01
MP2	3.32	2,880	0.12	5.75	2,200	0.26	32.19	690	4.67	0.44	2,380	0.02
MP3	3.18	9,520	0.03	4.24	6,850	0.06	29.44	4,300	0.68	0.30	6,100	0.00
MP4	3.75	5,940	0.06	4.74	5,750	0.08	34.04	3,110	1.09	0.50	5,140	0.01
MP5	3.72	9,840	0.04	4.17	8,190	0.05	39.13	9,230	1.26	0.45	10,800	0.00
MP6	3.72	5,820	0.06	4.61	6,160	0.07	31.07	1,510	2.06	0.42	4,880	0.01
MP7	3.60	1,830	0.20	4.65	1,800	0.26	32.89	320	10.28	0.46	1,600	0.03
MP8	3.44	2,480	0.14	4.32	2,230	0.19	34.61	580	5.97	0.45	2,050	0.02
MP9	3.92	3,450	0.11	4.75	2,050	0.23	33.23	1,190	2.79	0.40	2,580	0.02
µ	3.52		0.09	4.63		0.15	33.38		3.45	0.42		0.01

Pedon	Total P (mg/100g)			Total Al (mg/100g)			Total Fe (mg/100g)		
	Test plant	Top horizon	%	Test plant	Top horizon	%	Test plant	Top horizon	%
MP1	1.74	120	1.45	0.294	65,600	0.00	0.252	82,300	0.00
MP2	1.81	66	2.4	0.329	112,400	0.00	0.265	93,900	0.00
MP3	2.13	350	0.61	0.168	77,600	0.00	0.195	61,600	0.00
MP4	1.99	277	0.72	0.287	93,200	0.00	0.216	66,300	0.00
MP5	2.17	288	0.75	0.198	65,700	0.00	0.209	73,000	0.00
MP6	2.14	338	0.63	0.307	68,600	0.00	0.236	54,400	0.00
MP7	1.97	82	2.40	0.702	73,600	0.00	0.417	68,900	0.00
MP8	1.87	147	1.27	0.454	107,300	0.00	0.356	76,800	0.00
MP9	1.92	170	1.13	0.317	110,500	0.00	0.265	93,300	0.00
µ	1.97		1.26	0.335		0.00	0.268		0.00

Pedon	Total Mn (mg/100g)			Total Zn (mg/100g)			Total Cu (mg/100g)		
	Test plant	Top horizon	%	Test plant	Top horizon	%	Test plant	Top horizon	%
MP1	0.088	299	0.03	0.020	48	0.04	0.011	148	0.01
MP2	0.097	231	0.04	0.022	48	0.05	0.011	104	0.01
MP3	0.204	1,506	0.14	0.030	93	0.03	0.010	143	0.01
MP4	0.144	1,254	0.01	0.028	102	0.03	0.012	116	0.01
MP5	0.108	930	0.01	0.027	82	0.03	0.011	168	0.01
MP6	0.107	588	0.02	0.031	55	0.06	0.011	78	0.01
MP7	0.125	302	0.33	0.024	52	0.05	0.011	104	0.01
MP8	0.131	698	0.02	0.029	56	0.05	0.011	64	0.01
MP9	0.171	2109	0.01	0.031	273	0.01	0.011	122	0.02
µ	0.131		0.07	0.027		0.04	0.011		0.01

Note: Total element in soils is of the first horizon (Lebrun, 2011)
Total element in test plant is the mean of values of four replications

Phosphorous is also needed because this is used in the metabolic function and a component of the cell nuclei. Soil analysis conducted yielded very low available P (<1 mg/100g) results. However, P is fourth in terms of nutrient absorption by the test plant. In this situation P is not detected as available nutrient. This is worth checking to find out the gaps in P availability in soils. It can be further shown in Table V-5 that the pedon locations where the highest ratios on element absorbed versus the total elements in a kilogram of soil were: K (MP7=10.28%), P (MP2=2.74%), Mn (MP7=0.33%), Mg (MP2 and MP7=0.26%), Ca (MP7=0.20%), and were in 'Andic' Cambisol. This is because the least amounts of aforementioned elements or if not relatively lower concentrations but absorption of these elements in the test plant is relatively higher are in Cambisols. It was noted that relatively high values of assimilated K were observed from soils in MP7 (10.28%), MP8 (5.97%) and MP2 (4.67%). These three soil media were 'Andic' Cambisol. It is noted that when these soil pedons were examined in 2011, these were under fallow.

The pedon locations where the test plant had high P assimilation are also 'Andic' Cambisol: MP2 (2.74%), MP7 (2.40%) and MP1 (1.45%). Moreover, when the soil media were taken around their respective pedon in 2012, the locations were still under fallow. Compared to other macro nutrient elements, the relatively high assimilation percentage of K and P (>1%) shows that these nutrients are needed by plants in large quantities but the soil has only relatively less K and P reserves. Aluminum and iron were the most abundant elements in the soil media but the percentages of elements assimilated were nearing zero and only minute quantities were absorbed by the test plant. This is because Al is not needed in building the plant tissues and Fe is a micronutrient.

6. Bendum results and discussions

This section communicates the results and discussions of the Bendum pot experiment study. This section presents the weights of Signal grass biomass harvests from each soil type. This describes their relationships with the total elements present in the topsoil.

6.1. Biomass fresh weights of harvested Signal grass and their relationships with Bendum topsoils

Table V-6 presents the fresh weights of the Signal grass harvested from the Bendum pot experiment. Acrisol (BP3) yielded the most. The general pattern of the biomass growth was that the highest weights of harvest were during the first 21 days of growth and had followed a declining trend except for BP14 which had picked up in the second harvest after the next 21 days.

Table V-6. Fresh biomass yields of Signal grass on topsoils of Bendum production areas (g).

Pedon	Soil type	First cut	Second cut	Third cut	Fourth cut	Total
BP3	Pisoplinthic Acrisol	19.52	16.30	12.26	11.97	60.05
BP5	Ferralic Nitisol	22.37	19.24	9.15	5.87	56.63
BP9	Acric Nitisol	17.74	9.71	9.13	7.44	44.02
BP14	Haplic Cambisol	12.55	24.84	9.75	5.49	52.63

Table V-7 shows the biomass fresh weights and the total elements of Bendum topsoils. The highest yield was in BP3 which had the highest total element Ca, Mg and Mn. There was no apparent relationship between the nutrients assimilated by Signal grass and the Bendum topsoil total element content.

Table V-7. Signal grass biomass fresh weights and total element contents of Bendum topsoils.

Pedon	Fresh weight	Topsoil total element*[1]						
		P	Ca	Mg	K	Al	Fe	Mn
	g	mg/100g				%		ppm
BP3	60.05	27	174	1211	98	6.79	25.88	235
BP5	56.63	51	164	872	101	9.70	23.13	186
BP9	44.02	32	133	578	114	9.47	25.11	111
BP14	52.63	48	104	69	63	15.08	10.82	31

Note: *From Barbieux (2012)

Table V-8 shows the average values of four replications of the total elements assimilated by the test plant and the total elements in topsoil horizons of Bendum production areas which are assumed to be contained in the pot. Similar to the nutrients analyzed in Miarayon plants, K had the highest concentration (µ=24.57 mg), followed by Mg (µ=6.71 mg), Ca (µ=4.65 mg) and then P (µ=1.72 mg). Basing from the element concentration in the test plant and the corresponding total element in the soil contained in the pot, the absorption rate of K (2.34-3.27%) was the highest compared to the rest of the elements analyzed followed by P (0.32-0.65%) and then Ca (0.23-0.48%).

The highest per cent K (3.27%) and Ca (0.48%) assimilation were in the Cambisol with reasons similar to Miarayon. However, the highest percent Mg (0.10%) assimilation were both in Nitisols. The lowest per cent assimilation for Mg (0.05%) was in Acrisol because of very high total Mg in soils. Per cent assimilation of both Al and Fe are nearing zero even though these two elements are abundant in Bendum soils. Between the two elements, the concentration of Fe (μ=0.72 mg) in plants was higher than Al (μ=0.31 mg) because Fe is a micronutrient and Al is not needed by plants. Furthermore, Fe content in Bendum topsoil is two to three times higher than Al particularly in pedon locations where ultramafic rocks are found. Absorption of Na and Mn were in relatively small quantities.

Table V-8. Total elements assimilated by the Signal grass and total element contents of soils in pots from Bendum.

Pedon	Total Ca (mg/100g)			Total Mg (mg/100g)			Total K (mg/100g)			Total Na (mg/100g)		
	Test plant	Top horizon	%	Test plant	Top horizon	%	Test plant	Top horizon	%	Test plant	Top horizon	%
BP3	4.08	1,740	0.23	6.60	12,110	0.05	26.10	980	2.66	0.66	630	0.10
BP5	5.70	1,640	0.35	7.73	8,720	0.09	23.67	1,010	2.34	0.71	1,190	0.06
BP9	3.81	1,330	0.29	5.67	5,780	0.10	27.92	1,140	2.45	0.64	600	0.11
BP14	5.00	1,040	0.48	6.85	6,900	0.10	20.60	630	3.27	1.12	670	0.17
μ	4.65		0.35	6.71		0.06	24.57		2.68	0.78		0.11
Pedon	Total P (mg/100g)			Total Al (%)			Total Fe (%)			Total Mn (ppm)		
	Test plant	Top horizon	%	Test plant	Top horizon	%	Test plant	Top horizon	%	Test plant	Top horizon	%
BP3	1.75	270	0.65	0.273	67,900	0.00	0.755	258,800	0.00	0.106	2,350	0.00
BP5	1.64	510	0.32	0.449	97,000	0.00	1.521	231,300	0.00	0.120	1,860	0.01
BP9	1.66	320	0.52	0.134	94,700	0.00	0.230	251,100	0.00	0.077	1,110	0.01
BP14	1.81	480	0.38	0.394	150,800	0.00	0.382	114,400	0.00	0.168	310	0.05
μ	1.72		0.47	0.312		0.00	0.722		0.00	0.118		0.02

Note: Total element in soils is of the first horizon (Barbieux, 2012)
Total element in test plant is the mean of values of four replications

7. Analyses of nutrients assimilated by the test plant in Miarayon and Bendum soils

This section presents the relationships between nutrients assimilated by the test plant. This also presents the differences between the degrees of nutrient assimilation of the test plants in the soils coming from the two sites.

7.1. Relationships between nutrients assimilated by the test plant

Table V-9 presents the correlation test results of nutrients assimilated by the test plant. Figures V-4, V-5, V-6 and V-7 show the significant relationships between nutrients absorbed. The direct relationships between assimilated nutrients possibly mean that each element caters the absorption of another, thus potentially contributing to the assimilation of certain nutrients to plants. The inverse relationships between them probably mean that one inhibits the absorption of the other and therefore may cause deficiency of certain elements in plants.

Table V-9. Correlations between total element absorbed by Signal grass in Miarayon and Bendum soils.

Nutrient	Cell content	Total Ca content	Total Mg content	Total K content	Total Na content	Total P content	Total Fe content	Total Al content	Total Mn content	Total Cu Content
Mg	R value	0.697								
	P value	0.000***								
K	R value	-0.655	-0.699							
	P value	0.000***	0.000***							
Na	R value	-0.543	0.697	-0.522						
	P value	0.000***	0.265***	0.000***						
P	R value	-0.177	-0.619	0.399	-0.337					
	P value	0.209^{ns}	0.000***	0.003**	0.006**					
Fe	R value	0.427	0.513	-0.214	0.293	-0.332				
	P value	0.002**	0.000***	0.127^{ns}	0.035*	0.016*				
Al	R value	0.053	0.037	0.067	0.118	-0.054	0.556			
	P value	0.710^{ns}	0.979^{ns}	0.638^{ns}	0.404^{ns}	0.702^{ns}	0.000***			
Mn	R value	0.270	-0.248	-0.054	-0.233	0.479	-0.080	0.102		
	P value	0.053^{ns}	0.072^{ns}	0.134^{ns}	0.096^{ns}	0.000***	0.572^{ns}	0.932^{ns}		
Cu	R value	-0.172	-0.331	0.354	0.109	0.414	-0.214	0.284	-0.028	
	P value	0.224^{ns}	0.017*	0.01*	0.444^{ns}	0.002**	0.086^{ns}	0.042*	0.844^{ns}	
Zn	R value	0.147	-0.273	-0.063	-0.149	0.607	-0.099	-0.052	0.653	-0.000
	P value	0.297^{ns}	0.051^{ns}	0.659^{ns}	0.293^{ns}	0.000***	0.484^{ns}	0.716^{ns}	0.000***	1.000^{ns}

Note: ***very highly significant ($P \leq 0.001$); **highly significant ($P \leq 0.01$); *significant ($P \leq 0.05$); ^{ns} not significant

Assimilated Ca was very highly associated with Mg, Na and Fe but its presence apparently constrains the absorption of K (Figure V-4). Magnesium is also very highly correlated with Na and Fe but is inversely related to K and P (Figures V-4 and V-5). Magnesium absorption by plants can also be affected by K in soils, at K:Mg ratios >2, Mg uptake is inhibited (Landon, 1991).The presence of Ca and Mg may indicate the deterrence of K absorption by the plants. Potassium is highly linked with P and Cu but seemed to be constrained by Na (Figures V-5 and V-6). Phosphorous is very highly linked with Mn, Cu and Zn but inversely related to Fe and shows that tendency with Al (Figures V-6 and V-7). Aluminum is strongly associated with Fe and Cu (Figure V-7). Manganese is also very significantly correlated with Zn (Figure V-7).

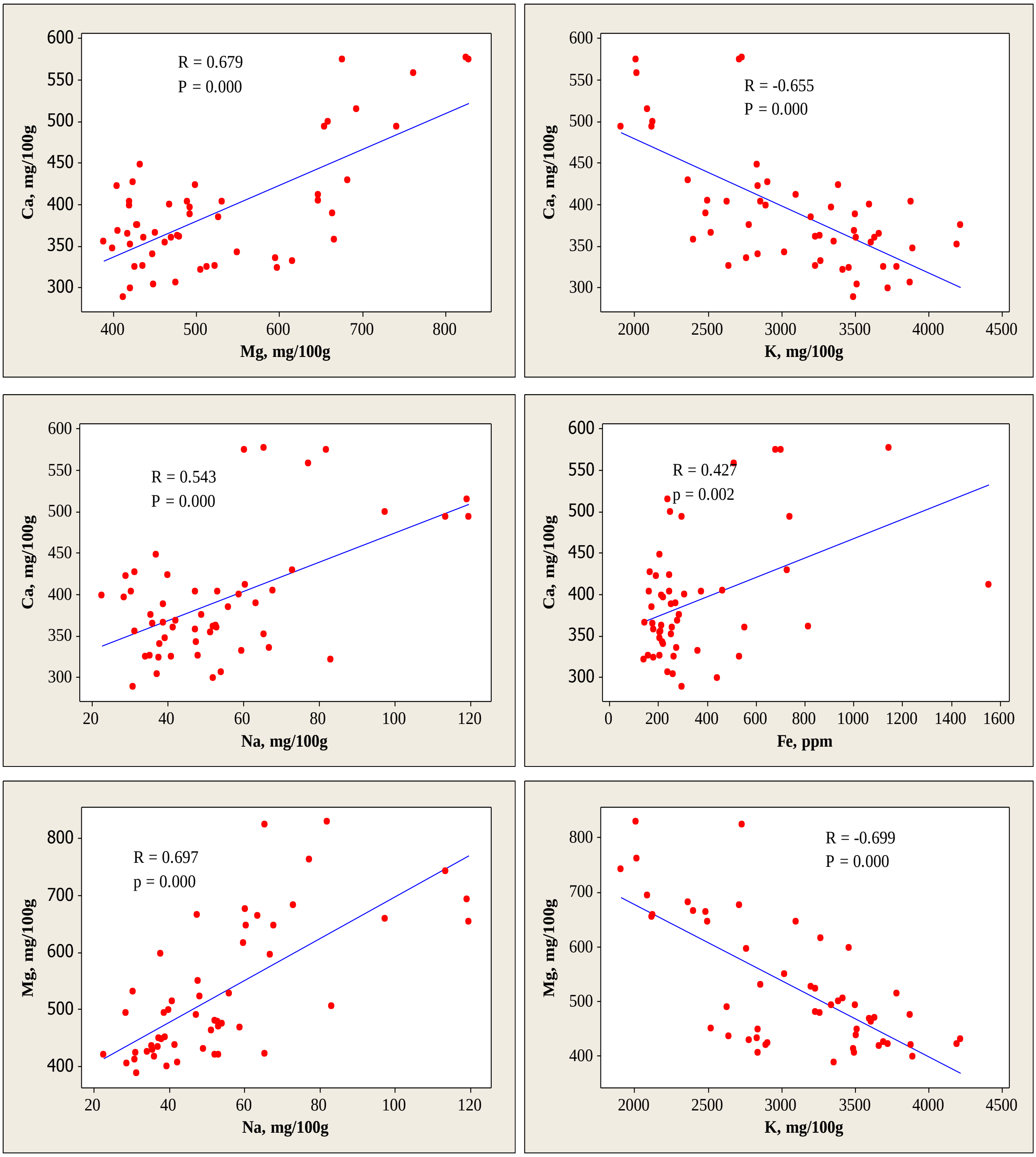


Figure V-4. Correlations between assimilated total Ca with Mg, K, Na and Fe and total Mg with Na and K of Miarayon and Bendum pot experiments.

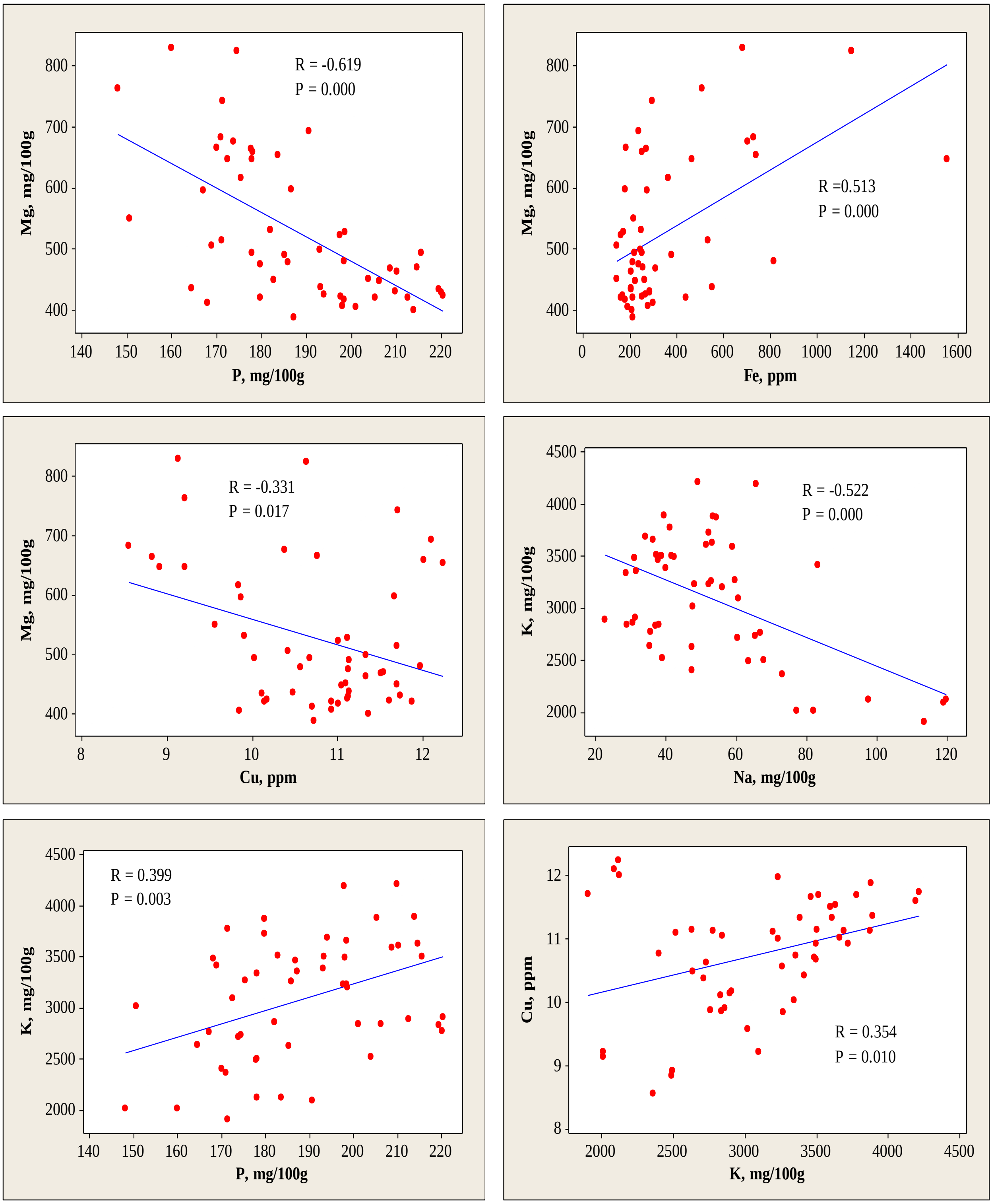


Figure V-5. Correlations between assimilated total Mg with total P, Fe and Cu and total K with total Na, P and Cu of Miarayon and Bendum pot experiments.

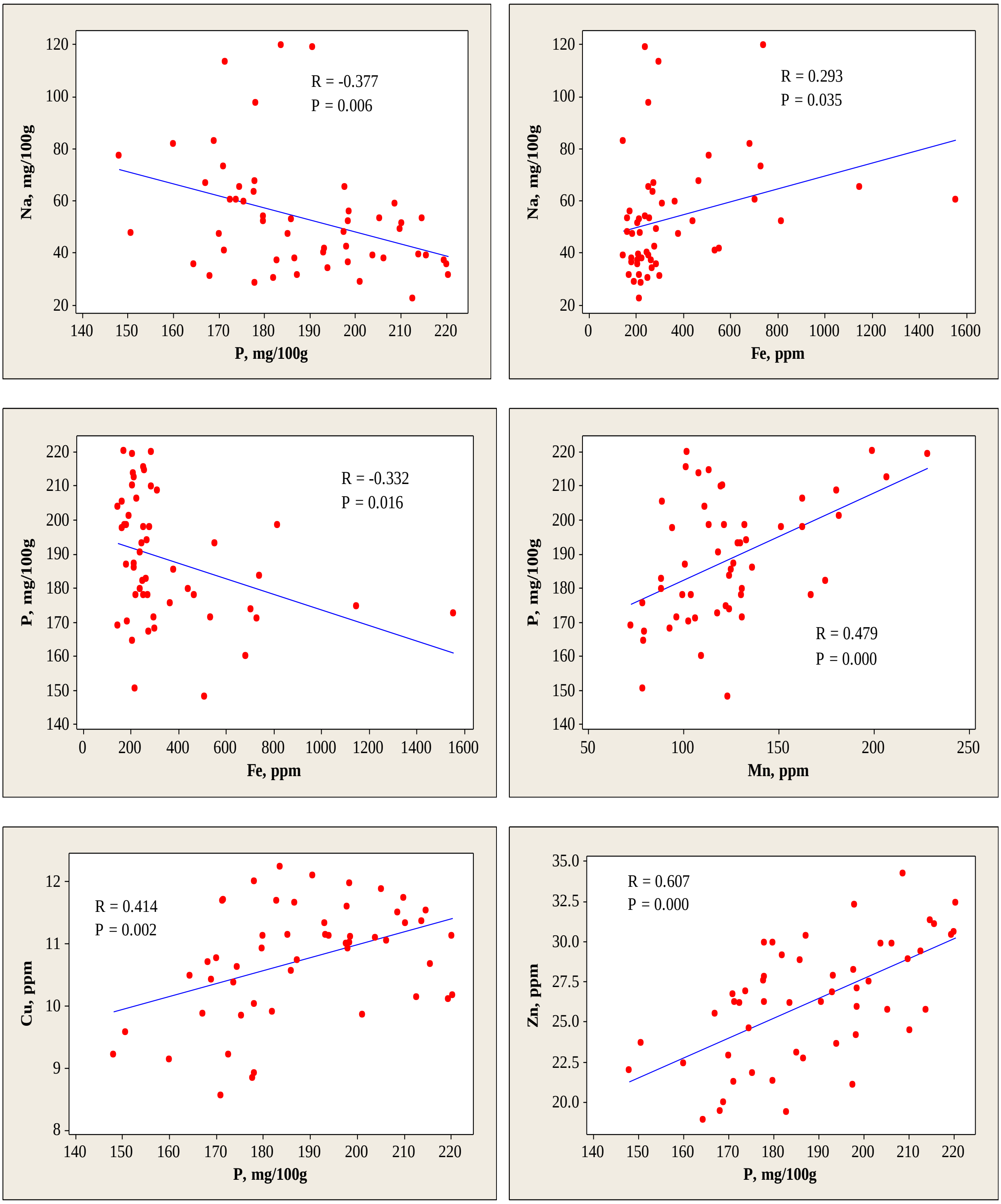


Figure V-6. Correlations between assimilated total Na with total P and Fe and total P with total Fe, Mn, Cu and Zn of Miarayon and Bendum pot experiments.

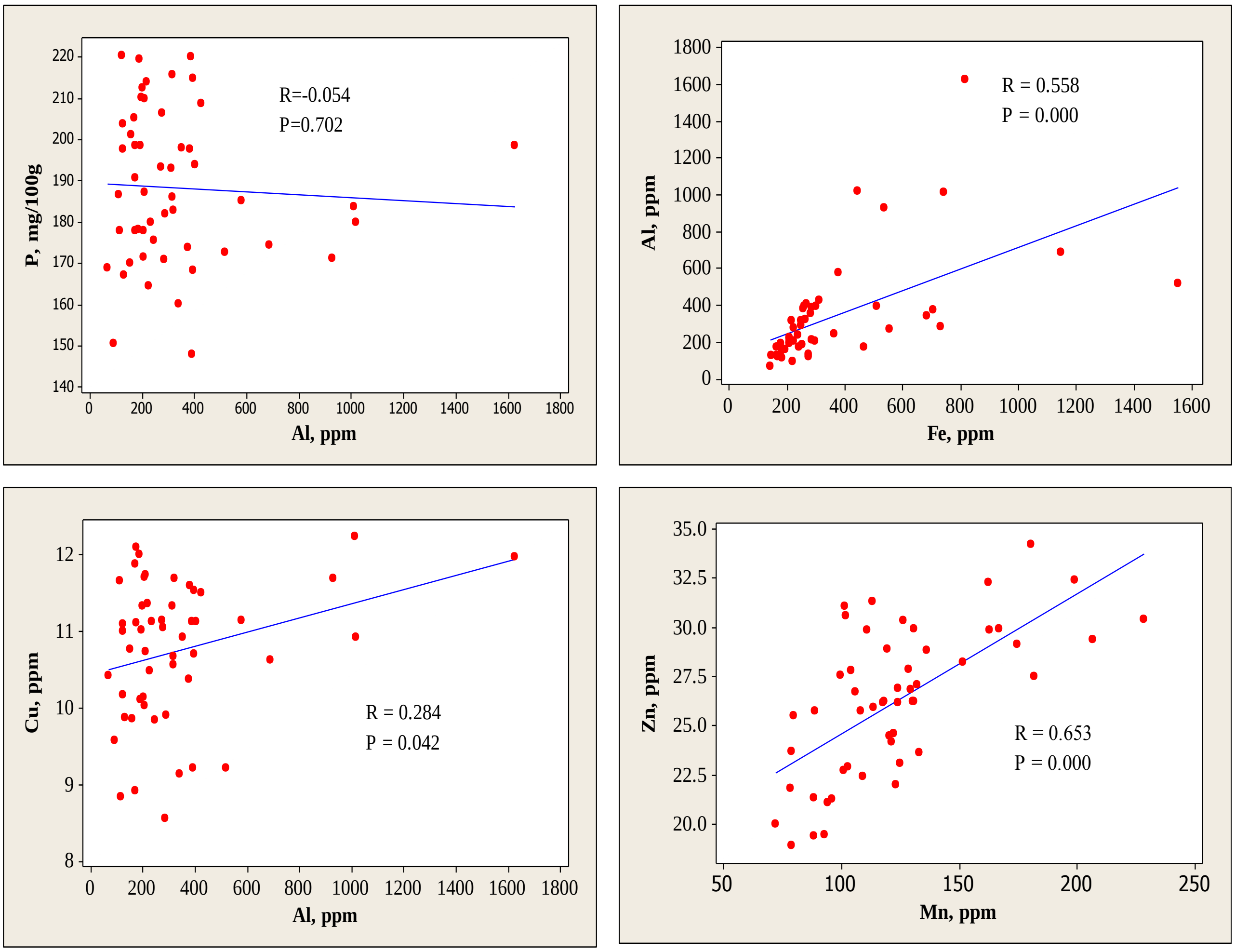


Figure V-7. Correlations with assimilated total Al with total Fe and Cu and total Zn with Mn of Miarayon and Bendum pot experiments.

In this experiment, there is no significant relationship of the assimilated nutrients between Ca with P, Al, Mn, Cu and Zn, although the tendency of Ca to negatively affect P and Cu is apparent. Magnesium is not significantly related to Al, Mn and Zn. However, there is a perceived negative affinity of Magnesium to Mn and Zn. Potassium seems not significantly connected with Fe, Al, Mn and Zn. Sodium has no significant association with Al, Mn, Cu and Zn. As mentioned, P can be fixed by Al and Fe (Landon, 1991). In this experiment, P is negatively affected by Fe but with Al, the relative effects are not significant although the tendency for P to be negatively affected by Al is observed. The relationships between Fe and Mn, Cu and Zn are not significant although the tendency for inverse relationships of Fe to exist with the aforementioned micronutrients is shown. Manganese has no significant relationships with Al, Cu and Zn.

7. 2. Correlations of plant assimilated nutrients by Principal Component Analysis (PCA)

The PCA illustrates the relationships between elements which were assimilated by plants. Figures V-8 shows the PCA loading and score plots. The figures show that the total proportion of the variability of assimilated nutrients is 58%. Calcium and Mg have large positive loadings in the first component while P has large negative loadings in the second component. The least represented nutrients are Al, Cu, Fe and Na. The first component shows the opposition of Ca, Mg, Na and Fe versus K, P and Cu. The second component is a gradient of P, Zn and Mn. It can be noted that the test plant in Bendum apparently have assimilated more Ca and Mg from the soils compared to those that were planted in Miarayon soils.

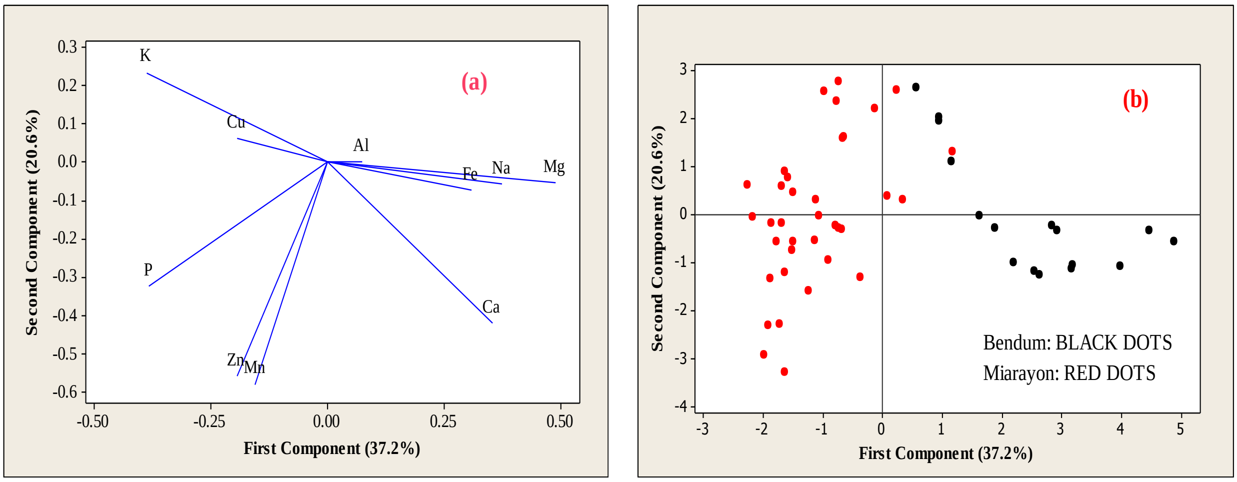


Figure V-8. The PCA graphs for the element contents in test plant from Miarayon and Bendum pot experiments (a) the loading plot and (b) the score plot.

7.3. Differences between plant element contents which were assimilated from Miarayon and Bendum soils

To determine the differences between total element contents of Signal grass planted in both Miarayon and Bendum soils, the GLM-ANOVA was used. The first factor is the site and the second factor is the soils which are also considered as the random sample. Table V-10 shows the significant differences of total element contents in the test plant from soils of the two locations. Analyses were conducted using the test plant dry matter.

Table V-10. Analysis of variance of element contents in the test plant from Miarayon and Bendum.

Total element content	Site	Order	Soil	Order	R^{2adj}
	P value		P value		
Ca	0.036*	Bendum>Miarayon	0.000***	Figure V-10 (a)	91.7
Mg	0.000***	Bendum>Miarayon	0.000***	Figure V-10 (b)	87.1
K	0.002**	Miarayon>Bendum	0.008**	Figure V-10 (c)	55.4
Na	0.001**	Bendum>Miarayon	0.000***	Figure V-10 (d)	80.4
P	0.008*	Miarayon>Bendum	0.000***	Figure V-10 (e)	73.8
Fe	0.012**	Miarayon>Bendum	0.067ns	Figure V-10 (f)	33.9
Al	0.075ns	No difference	0.290ns	Figure V-11 (a)	3.5
Mn	0.281ns	No difference	0.000***	Figure V-11 (b)	92.5
Cu	0.103ns	No difference	0.000***	Figure V-11 (c)	76.9
Zn	0.422ns	No difference	0.000***	Figure V-11 (d)	83.9

Plant biomass analyses revealed that in Bendum test plant assimilated significantly higher Ca, Mg and Na than in Miarayon. Although Miarayon top horizons (Table V-5) have higher amounts of Ca and Na than Bendum top horizons (Table V-8), results may also indicate that Miarayon soils slowly release Ca and Na to be available for the plants than Bendum soils. It can be posited that the volcanic characteristics of Miarayon soils are the reasons of the delay in nutrient assimilation by the test plants. It is further assumed that the higher total Mg absorbed by the plant from Bendum than from Miarayon is due to the fact that Bendum soils have inherently high amounts of total Mg (Table V-8) and the volcanic characteristics of Miarayon soils may also have lessen the Mg assimilation of the test plant for Miarayon soils. Test plants from Miarayon soils take up more K and P than from Bendum soils. Site location does not significantly affect the assimilation of the test plants on Al, Mn, Cu and Zn. Thus, it is theorized that absorption of micronutrients by the test plants are not affected with differences in locations.

Variations of nutrient element absorptions of test plants from different soils within the site are shown in the succeeding figures. Analysis results showed that there were significant differences in Ca, Mg, K, Na and P assimilations from different soil types within each location (Figure V-9). Calcium and Mg in Bendum are highly variable but for Miarayon, variations are only in some soils. Highest amounts of Ca absorbed in Bendum was from the soils in BP5. For Miarayon soils, it is in MP3. The highest Mg absorbed in Bendum was again in BP5 and for Miarayon soils, the highest amount of Mg absorbed was in MP2 which is a little more than the lowest amount absorbed in BP9 of Bendum.

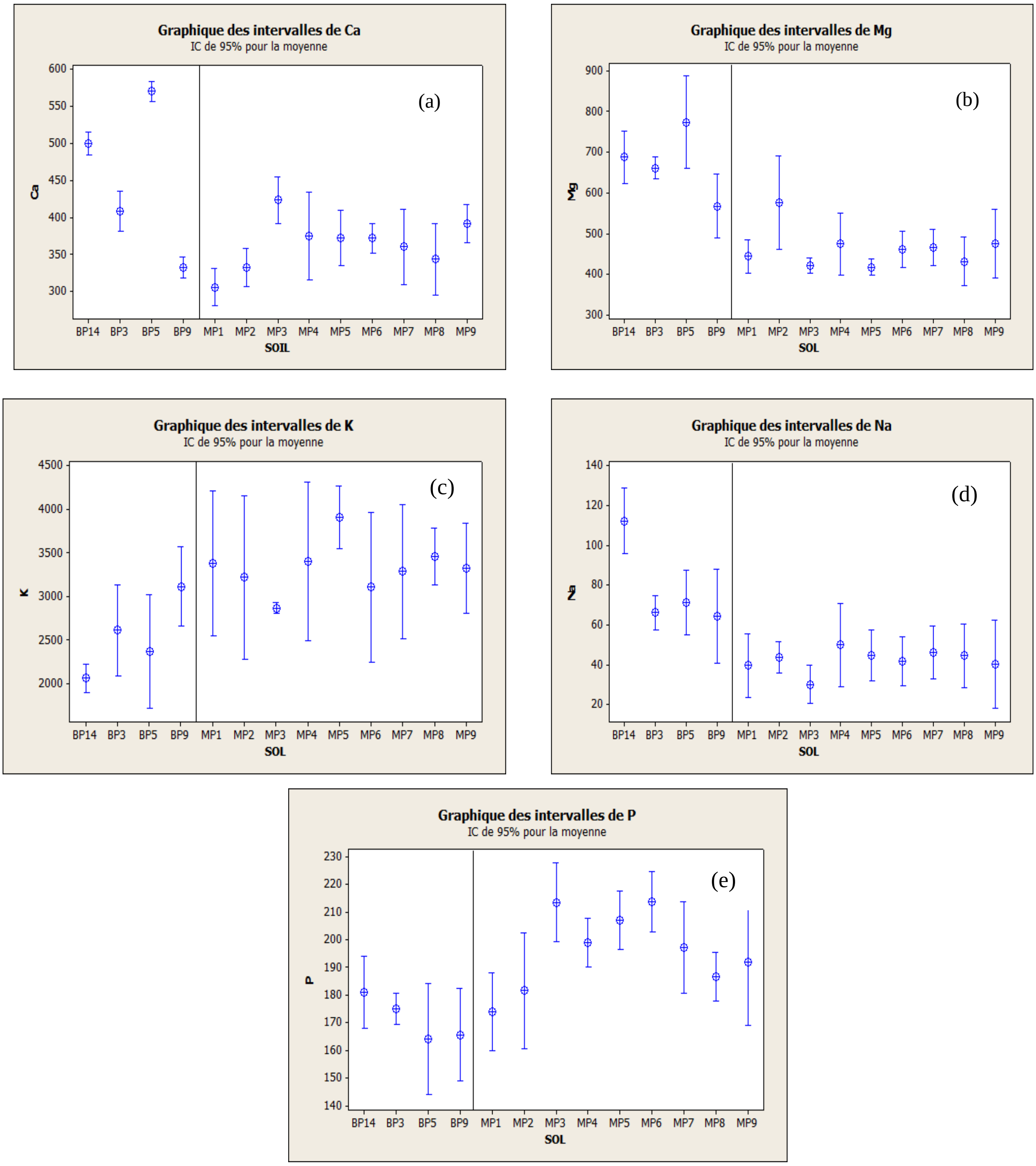


Figure V-9. Variations of test plant assimilated nutrients from Miarayon and Bendum soils: (a) Ca (b) Mg, (c) K, (d) Na and (e) P

Potassium absorption is also highly variable in both sites. Generally, the test plant absorbed K much higher from Miarayon soils than from Bendum soils. It should be noted that Miarayon soils are used for cash crops and farmers apply K fertilizers for crop maintenance. For Na absorption, it is only variable in the plants of Bendum soils with the highest assimilation in BP14, where the pyroclastic rock samples were taken. But for Miarayon soils, it is almost the same in all pedon locations. Phosphorous absorption in Miarayon is higher in soils that are in the intermediate part of the toposequence (MP3, MP4, MP5 and MP6). At the time of sampling, these pit locations are under cultivation.

Figure V-10 shows the variations of test plant assimilated nutrients for Fe, Al, Mn, Cu and Zn from Miarayon and Bendum soils. Soil types do not significantly influence the amount of Fe and Al that are assimilated by the test plant. Thus no matter what the soil is, the mean values of Fe and Al are the same. For Mn, Cu and Zn, soil types had significantly affect the absorption of these nutrients but with the site, they are not significantly different. In Miarayon, the highest amount of Mn is absorbed by the test plant in soils from MP3 but for Cu, absorption level is the lowest. Relatively high amounts of Zn are absorbed from the soil media which come from the toeslopes of Miarayon toposequence (MP3, MP6 and MP9).

8. Chapter conclusion

Pot experiment is a simple method to identify the dynamics of nutrients within the soil and how they are absorbed by plants. The findings of this study had shown that at certain situations, the locations and soil conditions could affect the plant biomass yield.

8.1. The test plant biomass and the soil nutrients

The biomass growth rate of the test plant in Miarayon attained its peak after six weeks of seed sprouting which was during the second cutting of the foliage and receded after until the last cutting. In Bendum soils, the highest yield started in the first three weeks, was maintained after six weeks and receded after until the last cutting of the foliage. In Miarayon, the test plant on ‘Andic’ Umbrisol had high biomass fresh weights while in Bendum is on Pisoplinthic Acrisol.

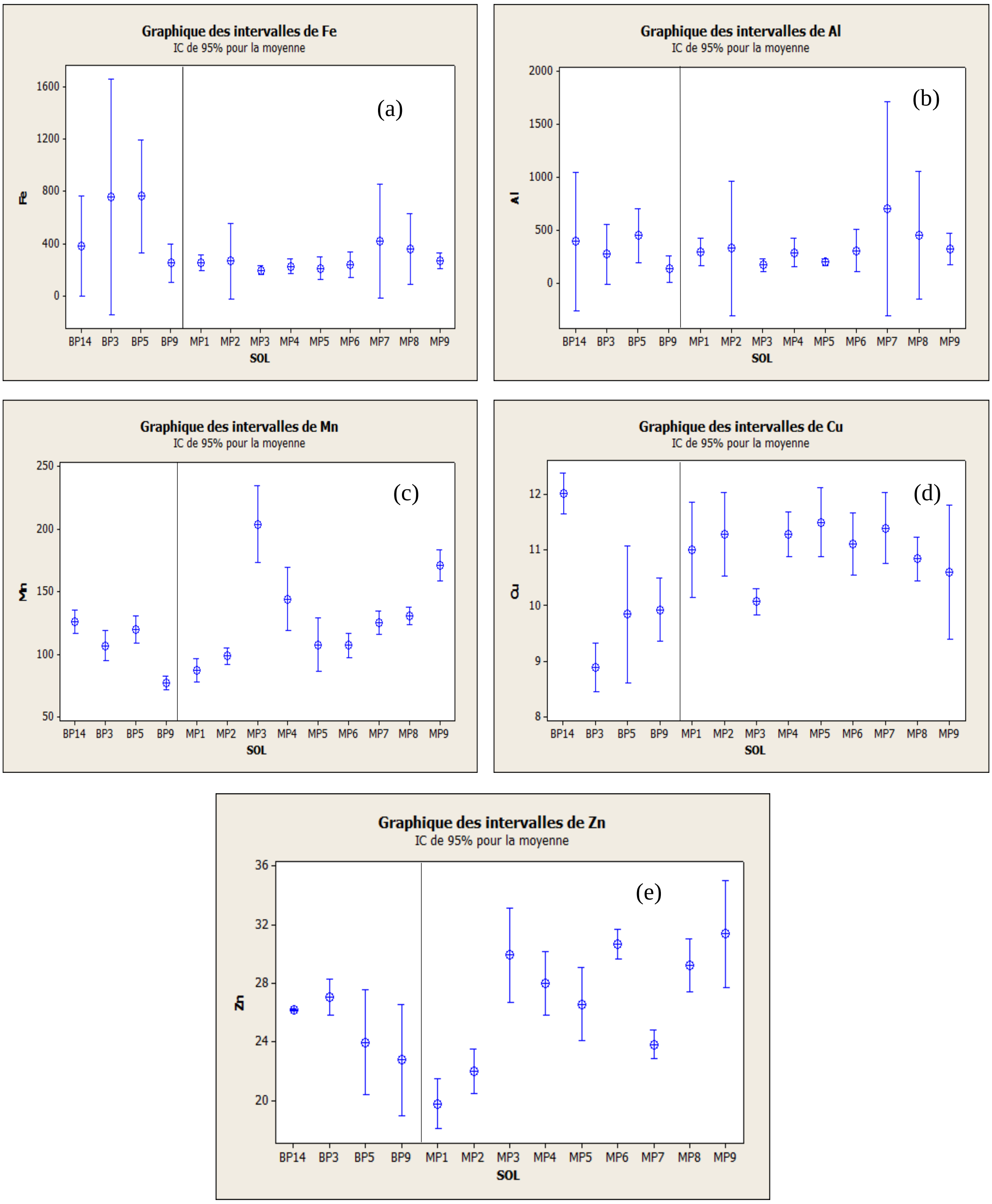


Figure V-10. Variations of test plant assimilated nutrients from Miarayon and Bendum soils: (a) Fe (b) Al, (c) Mn, (d) Cu and (e) Zn

8.2. Assimilated nutrients from Miarayon and Bendum soils

The highly assimilated nutrients by the test plant from Miarayon and Bendum soils which were identified in order are K, Mg and Ca. The values of each assimilated nutrient differ in each site. Comparing the K absorption in both sites, ingestion levels of the test plant in Miarayon soils were higher than in Bendum which can be attributed to the relatively high K reserve in Miarayon soils. The test plant in Bendum soils had higher Mg assimilation than in Miarayon which can be credited to the high Mg content of Bendum soils. Test plants in Bendum soils have also significantly higher assimilation rates in Ca and Na compared to the test plants in Miarayon soils. The lower assimilation rates of Ca and Na in Miarayon soils is due to the less availability of Ca and Na in soils. This can also be attributed to the soil volcanic characteristics of Miarayon soils.

8.3. The relationships between assimilated nutrients in test plant from Miarayon and Bendum

Calcium had highly significant relationship with Mg, Na, and Fe but is inversely related with K. This information may mean that Ca apparently caters the absorption of Mg, Na and Fe but had the tendency to inhibit K absorption. Phosphorous was significantly associated with K but was inversely related with Mg, Na and Fe. Iron was directly associated with Ca, Mg, and Na but seemingly indirectly related to P. Aluminum had no influence with respect to all other nutrients except to Fe and Cu. Copper is the micronutrient that seemed to have direct influences with other nutrients such as K, P and Al and inversely related with Mg. The direct influence of Mn is only on P and Zn while for Zn, it is only on Mn.

8.4. The effects of site and soil factors on nutrient assimilation rates

Site effects on nutrient absorption are significant for Mg, K, Na, P, Ca and Fe. This would connote that the test plant in Bendum soils takes up more Ca, Mg, and Na and less in K and P compared to those in Miarayon soils. For Al, Mn, Cu and Zn, test plants have similar amounts absorbed from Miarayon and Bendum soils. Variability of nutrient assimilation rates were observed within the soils. Nutrient levels absorptions were all different in Bendum. For Miarayon, the differences were only exhibited in some soils.

Chapter VI

The SRS for Bukidnon highlands, Northern Mindanao, Philippines: Soil information integration and the prospects of soil analyses in the region

1. Chapter overview

Bukidnon highlands, like in any other highland areas in the Philippines and countries in the tropics, are intensively and extensively used for food production. To sustainably use these resources and address the food security demands of the populace, adequate and quality land and soil information are crucial. The evolution of a swidden farm to a permanent, intensive crop production plot necessitates suitable land conservation and management. However, sustainable soil management in these intensively cultivated lands cannot be achieved unless scientific reference on soils which offers sound bases when deciding for its use is available. Highland soils need conservation and management to reduce the pressure created by land development for any purpose, be for agriculture, forestry, tourism or infrastructures to protect the most vulnerable part particularly in steep slopes.

Soils have different capabilities and therefore can be utilized for different purposes. Since it is necessary to answer the land development demands, prudent decisions are essential in using the land and in identifying the better option it can offer. For a comprehensive Land Information System (LandIS), geological, geomorphopedological, agropedological, soil and crop management systems and crop yield data have to be included in the Soil Reference System (SRS) for agricultural highlands. Because information of soil sampling locations and crop yield measurements are georeferenced, the SRS is a better guide in determining which parts within the agricultural highlands in the region that have better soil quality and yield. Locations that have inferior soil quality and low crop yield can be identified and interventions can be made through soil improvement and crop management measures.

This chapter is about the integration of all information in the series of data gathering to build a SRS for the two investigated sub catchments, Miarayon and Bendum. This specifically deals with the importance of integrated information that can be used as reference for land use planning and management at the local level, the methodology rundown in gathering the data, discussions on data integration, and the prospects of the Near Infrared Reflectance Spectroscopy (NIRS) technology for soil analysis. The quality of information and the cost of obtaining the desired data are crucial in developing the SRS. This makes the soil analysis task obligatory in designing the framework for building the system. A section of this chapter briefly discusses the prospects of how soil analysis can be done better to serve the need in developing an SRS.

2. Significance of integrated soil information

The importance of knowing the soil characteristics and quality, its capability and suitability has been recognized in sustainable land use and management, its contribution to effective land assessment and evaluation (Rushemuka *et al.,* 2014; Sonneveld *et al.*, 2010; Sanchez, *et al*., 1982). In the Philippines, soil information are available however, the scale of investigation, the associated data density and the integration of all types of information shall be looked into in order to get the holistic idea about the soil.

The PhD research has established a regional Soil Reference System (SRS) that contributes to developing a generic protocol for LandIS in the agricultural highlands of Mindanao, Philippines. The work is an adaptation of the framework by Bock (1994) which is a combination of geomorphopedology and agropedology that closely links instruction and research in Soil Science. An application of the work was the case study in Southeast China (Bock *et al.*, 2010) which had aimed to gather full information on biophysical situation to assess the diversity, the representativeness and provide databases for inferences in the event that changes in the use of the land in a catchment will happen.

There are two primary benefits which were derived from this research. The first is the established regional SRS for agricultural highlands which is a valuable tool that provides scientific reference and therefore quality information is necessary when making decisions in changing the use of the land. Since data collection adheres to scientific research methods, the information are sound inputs for extension work and follow-up research on soil and crop management at the local level.

The second is the adopted methodology has addressed a series of queries on rock, relief, soil, land cover and crop plot management with farmers' participation through meetings and field level sharing of experiences. The study had adopted an intra-disciplinary approach, which was the combination of geology, geomorphology, pedology, agronomy and socio-economics applied to and synthesized for small agricultural highland catchments in Mindanao, Philippines. The developed methodology will serve as template for instruction and research on soil studies for the region. As it is desired that the SRS shall be tailor-made for a location, it can always be considered as a “work-in-progress” because new essential information can be added which are dependent on the local environmental situation where the framework shall be applied.

3. Objectives of information integration

The soil information integration had established a SRS for the agricultural highlands in the upper catchments of Cagayan de Oro and Pulangui Rivers, the two primary watersheds of Bukidnon, Philippines. This had aimed to address the issue of fragmented and stand-alone facts, and the scarcity of information about the soil in undifferentiated areas which are already used for agriculture in the region. In this chapter, the integration of soft science in hard science is demonstrated. Soft science is any of the specialized fields which deal with human behavior in which it may be difficult to form accurate quantifiable standards. The soft science in the study is the identification of the sociological and behavioral standpoints to determine the anthropological factors in soil development. Hard science is one of the natural or physical sciences where data and conclusions are backed by unbiased criteria. Geopedology, geomorphopedology, agropedology and hydropedology are the hard sciences in this study.

The SRS should continue to seek improvement in designing the system. One of the aspects that should be looked into is the method of soil analyses to be used in the system which is precise, cost effective and environment friendly to fit into intensified soil data gathering. This Chapter further presents the possibility of using NIRS in soil analysis.

4. Methodology

The study employed a multidisciplinary approach in order to get the relevant information on rock, relief forms and associated soil types, land use and crop management, response to soil nutrient fertility through plant biomass and crop yield assessment. This had involved the aforementioned aspects.

4.1. Geological aspects

Understanding the elements that can be present in soils was first traced from the parent rock materials. Rocks in Miarayon are pyroclastic deposits of andesitic composition. A rock sample from Miarayon was taken for elemental analysis. Bendum rocks are diverse. Three representative rock samples from Bendum production areas (two ultramafic rocks within the vicinity of BP3, BP5 and BP9, and a basaltic andesite pyroclastic deposit from BP14) were taken for analysis (Maurissen, 2014). To match the information on elements in rocks and minerals with the soil elements of concern, analyses results on Al_2O_3, CaO, Fe_3O_2, K_2O, MgO, MnO, Na_2O, P_2O_5, SiO_2 and TiO_2 were included in the SRS. Information on Al_2O_3, SiO_2 and TiO_2 tells about the type of igneous rocks the parent materials are. Mineralogical analyses were conducted on soil horizon samples from profiles of both sites to identify primary and secondary minerals to better assess the degree of weathering the rocks had undergone (Barbieux, 2012 and Maurissen, 2014).

4.2. Geomorphological aspects

The geomorphological approach was used to define the topsequence(s) which helped in identifying the locations of characterized soil pedons. In Miarayon, a major longitudinal toposequence, four transversal toposequences, four lands units and nine soil pedon locations were ascertained (Lebrun, 2011). In Bendum, there were two toposequences defined, each having three land units, and 13 pedon locations that were marked out (Richelle, 2010). However, as this PhD research limits only in the cultivated areas, the four pedon locations of Bendum cultivated areas were given due importance.

4.3. Pedological aspects

Full report of soil pedons has come up with descriptions of all horizons in terms of soil horizon depths and boundaries, porosity, biological activity within the profile, presence of roots, stone/rock fragments soil texture, color, mottling, soil pH, consistency and clay skins/coatings. Soil-water relationships were also investigated that generated information on bulk density, hydraulic conductivity, field capacity and soil-water retention capacity (Van Daele, 2012).

Soil horizon samples from all pedons of Miarayon were analyzed with allophanes and TOC, acidity (pH water and KCl, exchangeable acidity and Al), exchangeable bases (Ca, Mg, K, Na), total element content (Ca, Mg, K, Na, P, Al, Fe, Cu, Mn and Zn). Furthermore, selected horizon samples were analyzed with inorganic P, organic P, and sesquioxides (Al_{ox} and Fe_{ox}). Selected soil horizons samples from the four pedons in the production areas of Bendum were analyzed for their total element content (Ca, Mg, K, Na, Al, Fe and Mn), total P, inorganic and organic P. Findings had led to classifying the soils in both catchments.

4.4. Edaphological aspects

For Miarayon, a total of 93 composite samples at 20 cm depth from carrot, corn, potato and fallow plots were gathered and were analyzed for soil pH, TOC, TN, available Ca, Mg, K, Na and P. Twenty four plots were measured for their crop yields which were eight carrot, eight corn and eight potato plots. Topsoil from nine pedon locations replicated four times was used as media for pot experiments. A total of 36 experimental units were observed and plant biomasses were taken for their fresh weights. These were analyzed for total Ca, Mg, K, Na, P, Al, Fe, Mn, Cu and Zn in plant tissues of the grass test plant.

For Bendum, a total of 43 composite samples were gathered at 20 cm depth from production areas. Most of the samples were gathered from BP3, BP5, BP9 and BP14 which are Bendum's production locations. The production plots where yields were measured were on corn, ginger, sweet potato, abaca, rubber and coffee. In each crop, four plots were taken and the composite samples from each were analyzed for soil pH, TOC, TN, available Ca, Mg, K, Na and P. For corn, ginger and sweet potato, one composite sample was taken from each plot. For abaca, coffee and rubber, two sets of composite samples were taken, one at the base of the plant, another midway between two plant hills in order to compare the differences in fertility of soils near or far from the plant. Crop yield measurements were only done in corn, ginger and sweet potato with 12 observations. The soil media from the four soil pedons in the production area were taken and replicated four times. A total of 16 experimental units were taken for biomass fresh weights and these were analyzed for total Ca, Mg, K, Na, P, Al, Fe, Mn, Cu and Zn.

4.5. Socio-economic aspects

Owners of investigated plots were interviewed. Information gathered were on crop varieties, soil tillage practices, crop management practices such as fertilization rates and kinds of fertilizers, pesticide application rates and kinds of pesticides, weeding schedules, crop rotation, planting and harvest dates, crop yields and other cultural practices.

5. Results and discussions

Integration of soil information for both sub catchments depicted their different soil signatures which can be gleaned from parent rock materials, the geomorphological setting, and the influence of farming and crop management. This section devotes the discussions on the syntheses of Miarayon and Bendum soils and the comparisons of their general conditions. Moreover, a section is devoted to the discussion of the results of NIRS analysis of Miarayon and Bendum soils. The prospects and benefits of this technology on soil analysis for Mindanao soils are taken up.

5.1. Miarayon and Bendum soils

The section is allocated to features and differences of Miarayon and Bendum soils, their potentialities and constraints and the reasons why these soils had attained their respective characteristics.

5.1.1. Miarayon soil features

Table VI-1 shows the integrated soil information for Miarayon sub catchment. Miarayon soils are formed from homogenous volcanic parent materials in the Pleistocene period (Bukidnon Provincial Development Staff, 1985). The volcanic origin of the soil is confirmed by the presence of allophanes in the soil profile samples, low bulk densities and the analysis results of 2% for Al_{ox}+

$½Fe_{ox}^2$ on representative horizon samples. Miarayon rocks are intermediate igneous rocks (trachyandesites) because of the SiO_2 content of 54.87% (Maurissen, 2014).

A natural factor in soil formation and development, the relief, has contributed to the prevalence of particular soil characteristics and therefore distinguishing classifications are found. Soils in linear slopes and on convex positions have thin topsoils because the nature of its surface positions is relatively vulnerable to soil erosion. Incipient evolution is evident because the soils are regularly affected by soil erosion and thus they are classified as Cambisols. Soils in concave positions and in toe slopes are developed from colluvial deposits. In this position within the relief, erosional deposits of topsoils that contain nutrients and organic matter are concentrated. Moreover, the soils in concave positions are moister because water tends to concentrate in depressions.

Miarayon soils are dark. The topsoils are generally brownish black and the subsoils are dark brown although parent rock materials are relatively light colored. The high amounts of organic matter (5.3-11.6% TOC) had influenced the dark coloration of the soil. The presence of relatively higher concentration of organic matter and the high moisture content cause the darkening of the soil color thus the soils in this position are classified as Umbrisols.

The effects of soil management in Miarayon soils are evident by the concentrations of organic carbon and Ca in the soil profile. High amounts of TOC and Ca are present in topsoils compared to the subsoils and the occurrence of high TN values in composite samples. Farmers confirmed that they often apply organic fertilizers which are composed of chicken dung mixed with rice hulls (litter floors in poultry houses). Furthermore, soils of better quality are found particularly in the intermediate part of the toposequence. Soils have very high CEC but low in base saturation (dystric) when calculated at pH 7. If the base saturation is based on the ECEC and the buffering capacity is lower than what can be calculated from CEC, the available elements that can be estimated in soil is relatively higher.

Humans have influence in soil quality. In Miarayon, the length of farming had affected the topsoil qualities which were exemplified by the differences between the intermediate (Salsalan) and lower part (Mambuaw) of the toposequence. Plots in Mambuaw have inferior soil fertility as this location was once the seat of early settlement in the catchment more than 50 years ago. It was also shown that the yields of carrot, corn and potato, i.e. the yield of investigated primary crops in Salsalan, where recent cultivation plots are located, are higher than those plots situated in Mambuaw.

Table VI-1. Soil information integration for Miarayon sub-catchment, Talakag, Bukidnon, Philippines

Land Unit	Reference Pedon	Minerals	Depth	Physical parameters				Acidity				
				Stoniness	Color	Texture	Residual humidity	pH H_2O	pH KCl	ΔpH	Ex Acidity	Ex Al
				%			%				$cmol_+kg^{-1}$	
1	MP1, MP2	Ho, G, A, C,	Topsoil	6.0 to7.0	10YR2/3 to 3/3	SaCL to SaC	4.4 to 5.9	5.2	4.6 to 4.7	(-)0.5 to (-)0.6	0.96 to 1.53	0.56 to 1.17
		P, Ha, He	Subsoil	2 to(14) to 9	10YR4/4 to 5YR4/4	SaCL to SiCL	3.4 to 4.4	4.8 to 5.1	4.0	(-)0.8 to (-)1.1	4.23 to 5.63	3.70 to 5.62
2	MP3, MP4, MP5, MP6	A, An, C, G,	Topsoil	1.0 to 20.0	10YR2/3 to 3/2	CL to SaL	4.9 to 7.3	5.0 to 5.5	4.5 to 5.7	(-)0.4 to (-)0.6	0.61 to 1.64	0.17 to 1.27
		He, Ha, Ho L, P, T(low)	Subsoil	2 to54	10YR4/4 to 5/6	SaCL to SiCL	5.1 to 5.4	5.6 to 6.3	4.6 to 5.7	(-)0.2 to (-)1.7	0.29 to 0.43	0.10 to 0.13
3	MP7, MP8	A, C, G, Ha,	Topsoil	0 to10	10YR3/2	SaCL	4.6 to 5.1	4.7 to 4.9	4.3 to 4.5	(-)0.3 to (-)0.4	2.04 to 2.32	1.59 to 1.81
		P	Subsoil	1 to10	10YR3/4 to 5/6	SiC	4.2	4.8 to 5.0	5.4 to 5.7	0.6 to 0.7	0.26 to 0.41	0.08 to 0.14
4	MP9	Ho, G, A,	Topsoil	30	10YR2/2	SaCL	4.6	4.8	4.4	(-)0.4	1.54	1.08
		Ha	Subsoil	6	10YR3/4	SiCL	4.0	5.5	5.2	(-)0.3	0.43	0.2

LEGEND:

A: Albite
An: Anorthite
C: Clinipyroxene

G: Gibbsite
Ha: Halloysite
He: Hematite

Ho: Hornblende
L: Labradorite
P: Plagioclase

T: Tridymite
SaCL: Sandy clayloam
SaC: Sandy clay

SiCL: Silty clayloam

Table VI-1. Continuation..

Land Unit	Reference Pedon	Depth	TOC	Allophane[a]	Exchangeable bases							
			%		Ca	Mg	K	∑ bases	CEC	ECEC	BS	Eff BS
					cmol$_+$/kg						%	
1	MP1, MP2	Topsoil	6.9 to 11.6	7 to 8	1.62 to 2.23	0.25 to 0.88	0.22 to 0.29	2.30 to 3.34	38.3 to 62.1	3.83 to 4.32	3.7 to 8.7	60.1 to 77.4
		Subsoil	0.2 to 0.5	6 to 7	0.24 to 1.03	0.67 to 0.71	0.21	1.08 to 2.10	22.7 to 40.2	***	3.9 to 5.2	***
2	MP3, MP4,	Topsoil	6.0 to 11.2	7 to 8	3.57 to 11.05	0.23 to 1.48	0.18 to 0.28	4.00 to 12.81	56.6 to 82.0	5.64 to 13.42	5.5 to 17.6	71.0 to 95.4
	MP5, MP6	Subsoil	2.2 to 2.9	7	2.18 to 7.27	0.27 to 0.32	0.06 to 0.08	3.23 to 7.91	44.4 to 52.5	***	7.3 to 15.1	***
3	MP7, MP8	Topsoil	5.7	7 to 8	0.98 to 1.83	0.05 to 0.28	0.14 to 0.24	1.17 to 2.37	38.9 to 42.0	3.49 to 4.41	3.0 to 5.7	33.5 to 53.8
		Subsoil	06 to 0.8	7	0.26 to 0.28	0.02 to 0.06	***	0.27 to 0.37	20.2 to 22.6	***	1.3 to 1.6	***
4	MP9	Topsoil	5.3	1	4.29	0.83	0.26	5.45	43.6	6.99	12.5	78
		Subsoil	2.2	7	2.60	0.86	0.17	3.63	33.2	***	10.9	***

[a]Interpretation according to the Fieldes and Perrot (1966) and our scale of 1 (weak reaction) to 8 (strong reaction).

Land Unit	Reference Pedon	Depth	Total element content									
			Ca	Mg	K	Na	TRB	Al	Fe	Mn	Cu	Zn
			mg/100 g				cmol$_+$/kg	(%)		ppm		
1	MP1, MP2	Topsoil	288 to 463	220 to 337	69 to 153	239 to 350	44.3 to 69.6	6.36 to 11.24	8.23 to 9.39	231 to 299	104 to 148	48
		Subsoil	35 to 62	113 to 116	10 to 11	75 to 79	14.6 to 20.2	8.08 to 10.54	4.05 to 9.19	5.24 to 8.09	65 to 115	356 to 600
2	MP3, MP4,	Topsoil	582 to 984	575 to 819	151 to 923	488 to 1090	104.4 to 186.2	6.57 to 9.32	5.44 to 7.30	588 to 1506	78 to 163	55.93
	MP5, MP6	Subsoil	288 to1063	287 to 973	210 to 739	246 to 657	53.4 to 190.1	7.66 to 11.60	3.89 to 7.72	274 to 997	97 to 354	66 to 104
3	MP7, MP8	Topsoil	183 to 246	180 to 223	32 to 58	160 to 205	31.5 to 40.9	7.36 to 10.73	6.89 to 7.68	302 to 698	64 to 104	52 to 56
		Subsoil	38.45	57 to 82	6 to13	80 to 99	11.4 to 12.5	9.77 to 13.68	4.66 to 8.42	265 to 500	62 to 73	45 to 61
4	MP9	Topsoil	346	205	119	258	48	11.5	9.33	2109	122	273
		Subsoil	202	215	32	149	34.9	11.25	8.76	1836	147	106

Table VI-1. Continuation

Land Unit	Reference Pedon	Depth	Topsoil fertility (20 cm depth)								Yields		
			pH H_2O	TOC	TN	C:N ratio	Available elements				Carrot	Corn	Potato
							Ca	Mg	K	Na	t/ha		
				%			cmol_+/kg						
1	MP1, MP2	Topsoil	5.1 to 5.6	6.6 to 8.0	0.45 to 0.70	10.90 to 15.53	1.45 to 4.49	0.41 to 1.56	0.36 to 0.79	0.04 to 0.09	No info	No info	No info
2	MP3, MP4, MP5, MP6	Topsoil	4.9 to 6.2	4.1 to 14.9	0.38 to 1.28	10.0 to 15.15	1.35 to 23.15	0.25 to 5.10	0.09 to 1.23	0.04 to 0.13	8.02 to 36.78	3.03 to 4.47	27.00 to 30.11
3	MP7, MP8	Topsoil	5.0 to 5.6	4.1 to 8.7	0.30 to 0.62	10.65 to 16.50	1.35 to 11.23	0.33 to 1.32	0.20 to 1.10	0.00 to 0.17	18.19 to 24.15	2.14 to 5.34	18.24 to 23.24
4	MP9	Topsoil	4.9 to 5.4	5.3 to 7.0	0.40 to 0.43	12.33 to 16.50	2.40 to 5.49	0.49 to 1.32	0.20 to 0.84	0.04 to 0.09	No info	No info	No info

Table VI-1. Continuation

Land Unit	Reference Pedon	Depth	Phosphorous					
			Total P (mg/100g)	Mineral P (mg/100g)	Organic P (mg/100g)	P organic in total P (%)	P retention (%)	Available P (mg/100g)
1	MP1, MP2	Topsoil	66 to 120	3 to 48	63 to 72	60 to 91	87 to 96	* to 0.22
		Subsoil	32 to 110	3 to 6	29 to 58	91 to 95	97 to 98	
2	MP3, MP4, MP5, MP6	Topsoil	277 to 350	40 to 48	248 to 302	86	63 to 68	< 1
		Subsoil	96 to 287	38 to 40	136 to 225	77 to 86	69 to 76	
3	MP7, MP8	Topsoil	82 to 147	5	77	94	91	< 1
		Subsoil	48 to 69	4	44	92	95	
4	MP9	Topsoil	170	No info	No info	No info	No info	< 1
		Subsoil	128					

5.1.2. Bendum soil features

Table VI-2 presents the integrated information for the soils of Bendum production areas. Bendum soils are formed from various parent rock materials from the periods of Upper Cretaceous-Paleogene and Oligocene-Lower Miocene, which are relatively earlier than that of Miarayon, (Bukidnon Provincial Development Staff, 1985). There are two main types of igneous rocks found in Bendum, the ultramafic rocks and pyroclastic deposits. The ultramafic rocks have SiO_2 content of 40.22 to 43.67% and MgO content of 33.65 to 42.9% (Maurissen, 2014). The relatively high total element of Mg in Bendum soils particularly in BP3, BP5 and BP9 can be attributed to the ultrabasic parent rock materials. The pyroclastic deposits had SiO_2 content of 48.42% and low MgO content of 5.4% (Maurissen, 2014). These pyroclastic deposits are composed of various clasts having vacuoles and the mineralogy is composed of 50% plagioclase, 5% serpentine, 20% clinopyroxene, less than 5% orthopyroxene, 5% olivine and 3% opaque.

Soils in BP3, BP5 and BP9 are brown to reddish brown. Soil in BP14 is bright brown to brown. Bendum soils have high total Fe particularly in BP3, BP5, and BP9 where ultramafic rocks are found. Farmers' management is a crucial factor in attaining the desired soil productivity. It is evident that in general, Bendum farmers do not apply agricultural inputs in the soil to avoid further loses in farming because they believe that the soil is already degraded. Compared to Miarayon, soils in the Bendum production areas have very low TOC. Almost all of the farmers do not apply fertilizer. However, a corn plot around BP14 had medium TN because the farmer applied urea at unknown quantity to ensure his harvest although the area was opened two years earlier from the time of investigation. Yields of corn, sweet potato and ginger which are important food and cash crops in Bendum were far lower than the Bukidnon provincial yield values. An exception on a ginger plot having a yield comparable to the provincial value in which the farmer had applied fertilizers. This plot was relatively newly opened, i.e. three years before the investigation was conducted.

Table VI-2. Soil information integration for Bendum sub catchment, Malaybalay, Bukidnon, Philippines

Topo-sequence	Geomorpho-logical Unit	Reference Pedon	Minerals	Depth	Physical parameters			Acidity	Organic Matter
					Stoniness %	Color	Texture	pH H_2O	TOC %
1	2. Cultivated flat surface	BP3, BP5	F, G, Go He, Q	Topsoil	0 to 3	7.5YR4/4 to 10YR3/3	SaCL	4.5	2.0 to 2.4
				Subsoil	3 to 10	2.5YR4/6 to 7.5YR5/8	SaL, CL, L	4.0 to 6.0	0.4 to 0.7
2	2. Cultivated flat surface	BP9	He, Q G, K	Topsoil	none	7.5YR4/5	SaL	5.5	3.4
				Subsoil		2.5YR4/6 to 5YR4/6	SaL, SiC, L	6.5 to 7.0	0.1 to 0.5
		BP14	An, G	Topsoil	none	7.5YR4/4	SaCL	4.5	2.9
				Subsoil	none	7.5YR5/4 to 5/8	SiC to SaCL	4.0 to 4.5	2.8

Table VI-2. Continuation..

Topo-sequence	Geomorpho-logical Unit	Lithology	Reference Pedon	Depth	Total elements				
					Ca	Mg	K	Na	TRB
					mg/100 g				$cmol_+$/kg
1	2. Cultivated flat surface	Ultra mafic	BP3, BP5	Topsoil	164 to 174	872 to 1211	98 to 101	63 to 119	88.6 to 114.9
				Subsoil	57 to 142	854 to1461	92 to 190	61 to 78	80.4 to 134.6
2	2. Cultivated flat surface	Ultra mafic	BP9	Topsoil	133	578	114	60	60.3
				Subsoil	44 to 47	338 to 370	82 to 104	72 to 382	36.3 to 49.8
		Pyroclastic deposit	BP14	Topsoil	104	69	63	67	15.4
				Subsoil	43	70	81	79	13.5

LEGEND: An: Anorthite, F: Feldspar, G: Gibbsite, Go: Goethite, He: Hematite, SaCL: Sandy clayloam, SaL: Sandy loam, CL: Clay loam, SiC: Silty clay, L: Loam.

Table VI-2. Continuation

Topo sequence	Geomorpho-logical unit	Lithology	Reference Pedon	Depth	Total elements			Phosphorous				
					Al	Fe	Mn	Total P	Mineral P	Organic P	Organic P in Total P	Available P
					(%)		ppm	mg/100g			%	mg/100g
1	2. cultivated flat surface	Ultramafic	BP3, BP5	Topsoil	6.8 to 9.7	23.1 to 25.9	186 to 235	27 to 51	2 to 4	25 to 48	93	<1
				Subsoil	7.8 to 9.9	26.0 to 27.3	55 to 318	9 to 13	1	8 to 12	89 to 90	
2	2. cultivated flat surface	Ultramafic	BP9	Topsoil	9.5	9.5	111	32	2	30	93	< 1
				Subsoil	9.0 to 12.2	9.0 to 12.2	325 to 374	4 to 6	1	3 to 5	78	
		pyroclastic deposits	BP14	Topsoil	15.4	11.4	31	48	4	4	91	< 1
				Subsoil	13.6	10.8	28	47	3	5	92	

Table VI-2. Continuation

Topo sequence	Geomorpho-logical unit	Lithology	Reference Pedon			Topsoil fertility (20 cm depth)					
				pH H_2O	TOC	TN	C:N ratio	Ca	Mg	K	Na
					%			cmol$_+$kg^{-1}			
1	2. Cultivated flat surface	Ultramafic	BP3, BP5	4.9 to 6.1	1.6 to 5.2	0.17 to 0.30	8 to 23	0.30 to 4.99	0.16 to 2.06	0.20 to 0.28	0.04 to 0.09
2	2. Cultivated flat surface	Ultramafic	BP9	4.9 to 5.8	2.2 to 5.8	0.20 to 0.41	11 to 20	0.50 to 3.49	0.54 to 1.97	0.09 to 0.43	0.04 to 0.09
		Pyroclastic	BP14	4.7 to 5.4	3.2 to 5.9	0.20 to 0.39	11 to 18	0.50 to 3.74	0.33 to 5.27	0.13 to 0.36	0.04 to 0.09

5.1.3. Soil potentialities of the two sub-catchments

Potentialities are physical and chemical attributes which are natural or human induced for the soil to produce more. Table VI-3 summarizes the potentialities of the two sub-catchments. Miarayon soils are medium-textured but Bendum soils are relatively heavier. Both locations have low soil bulk densities, rapid hydraulic conductivities and high field capacities. Chemical potentialities in Miarayon are different from Bendum. Miarayon has high organic matter and CEC compared to Bendum. Large part of CEC is due to organic matter. For the reason that soil parent materials were products of relatively recent volcanic rock formation, Miarayon soils have higher values in total reserve bases especially in the intermediate part of the toposequence than in Bendum. For Bendum, the total reserve bases are dominated by Mg because of the ultramafic rocks that are present in most production areas. Total P and organic P which are relatively high in Miarayon soils are future supply of available P for crops to use. Because of human interventions Miarayon soils have high TOC and TN compared to Bendum soils. Miarayon soils further have high Ca although this element is relatively lower than in Bendum rocks. Miarayon farmers apply organic matter while Bendum farmers generally do not.

5.1.4. Soil constraints of the two sub-catchments

Table VI-3 further encapsulates the constraints of the two sub-catchments. Both sub-catchments have steep land slopes that are cultivated making the topsoil vulnerable to soil erosion. The land formations in both sub catchments are wavy which can cause difficulty in tillage and uneven distribution of applied soil nutrients and moisture. There were areas which had shown water stagnation. In Miarayon, rockiness especially in the intermediate part is distinct. Rock formations in Miarayon were younger compared to Bendum and their degree of weathering is less than in Bendum rocks. Profile investigations showed that in Miarayon, rocks and stones were present in horizons while in Bendum, the soils in production areas have very few and weathered stones. In Miarayon, rock outcrops, especially in the intermediate part of the toposequence, occupy a large part of the surface area. For chemical constraints, the low soil pH and low P availability are highlighted in both sub catchments. By measurement, available P is low. It is a challenge to know the timing of release of P into the soil solution for the element to be utilized by the crops. Because of the kind of parent rock, Bendum soils have more total Fe than Miarayon soils have. In Miarayon there are some areas that had shown high proportions of Al.

Table VI-3. Potentialities and constraints of Miarayon and Bendum soils

Catchment	Land Unit	Reference Pedon	Potentialities		Constraints	
			Physical	Chemical	Physical	Chemical
M I A R A Y O N	1	MP1, MP2	↑ T: medium BD: low HC: high FC: high ↓	Top OC: high, C:N ratio, right CEC: high-very high, P organic: high	S: steep AW: medium-low	pH: low, BS: low, Available P: low, P retention: high, Exch Al proportions: high
	2	MP3, MP4, MP5, MP6		Top OC: high, C:N ratio, right CEC: high-very high ∑B: high, TRB: high P organic: high	S: steep, AW: medium-low R/S: high, LF: wavy	pH: low, BS: low, Available P: low, P retention: high
	3	MP7, MP8		Top OC: high, C:N ratio, right CEC: high-very high P organic: high	AW: medium-low R/S: moderate LF: wavy	pH: low, BS: low, Available P: low, P retention: high, Exch Al proportions: high
	4	MP9		Top OC: high, CN ratio: right CEC: high-very high, P organic: high Exch Mg: high	AW: medium-low R/S: high, LF: wavy Water logging	pH: low, BS: low, Available P: low, P retention: high

	Topo-sequence	Reference Pedon	Potentialities		Constraints	
			Physical	Chemical	Physical	Chemical
B E N D U M	1	BP3, BP5	T:light-moderate BD: low-medium FC: high, R/S: none	Total Mg: high TRB: high (due to Mg) Total Mg: high, P organic: high	S: steep, AW: medium HC: low in some parts (water stagnation)	pH: low, Total Fe: high, TOC: low Available P: low, P retention: high
	2	BP9	T:light-moderate BD: low R/S: none	pH: slightly acid-neutral P organic: high	S: steep, AW: medium-low HC: low in some parts (water stagnation	Total Fe: high, TOC: low, Available P: low P retention: high
		BP14	T:light-moderate BD:low-medium FC: high, HC: rapid, R/S: none	P organic: high	AW: medium-low	pH: low, Total Fe: high, TOC: low, Available P: low P retention: high, TRB: low

LEGEND
T: Texture
BD: Bulk density
HC: Hydraulic conductivity
FC: Field capacity
AW: Available water
R/S: Rockiness/stoniness
LF: Land surface formation
OC: organic carbon
CEC: Cation exchange capacity
TRB: Total reserve bases

5.2. Application of NIRS to the soils of Miarayon and Bendum

Soil analysis is obligatory in knowing about the soils; be in instruction, research, extension and in crop production. Results of analysis are quantifications of the soil physico-chemical conditions. Choosing the appropriate method for a particular soil, while looking into its effective cost and convenience is important. Intensifying the soil data collection would need numerous soil analyses to fill in the need. The NIRS has been tested for its applicability in soil analyses. Applications of NIRS in soil analyses were in organic matter, elements in minerals, texture, plant nutrients, water, pH and heavy metals (Stenberg *et al*., 2010). Genot *et al*. (2011) used the NIRS in estimating TOC, TN, clay content and CEC for soils in Wallonia, Belgium and had shown accurate results.

The technology was applied to the analyses of all topsoil samples taken from Miarayon and Bendum. It was tested for pH (water and KCl), TOC, TN, CEC, total bases (Ca, Mg, K, Na), total Al and Fe, exchangeable bases (Ca, Mg, K, Na) and acidity. The results had shown good relationships between actual soil laboratory analysis results and the predicted values using the NIRS on TOC, TN CEC, available Ca, available Mg, exchangeable acidity, exchangeable Al and total Fe (Table VI-4). Figures VI-1 and VI-2 show the correlation graphs of significant relationships between the actual and the predicted values of Miarayon and Bendum soil chemical properties. The actual values are the analyses results from the soil laboratory while the predicted values are the results using the NIRS.

Table VI-4. Correlations between actual and predicted values of some parameters for Miarayon and Bendum soils.

Parameter	SEC	SEC-V	R-Sq	1-VR
TOC	0.373	0.657	0.997	0.940
TN	0.380	0.518	0.963	0.938
CEC	5.373	6.236	0.912	0.866
Exchangeable acidity	0.283	0.746	0.898	0.477
Exchangeable Al	0.283	0.738	0.904	0.515
Available Ca	1.742	2.562	0.961	0.899
Available Mg	138.884	163.752	0.801	0.701
Total Fe	110.216	147.746	0.881	0.751

Analyses conducted by Dr. Valerie Genot of the Provincial Agriculture Laboratory, Liege, Belgium

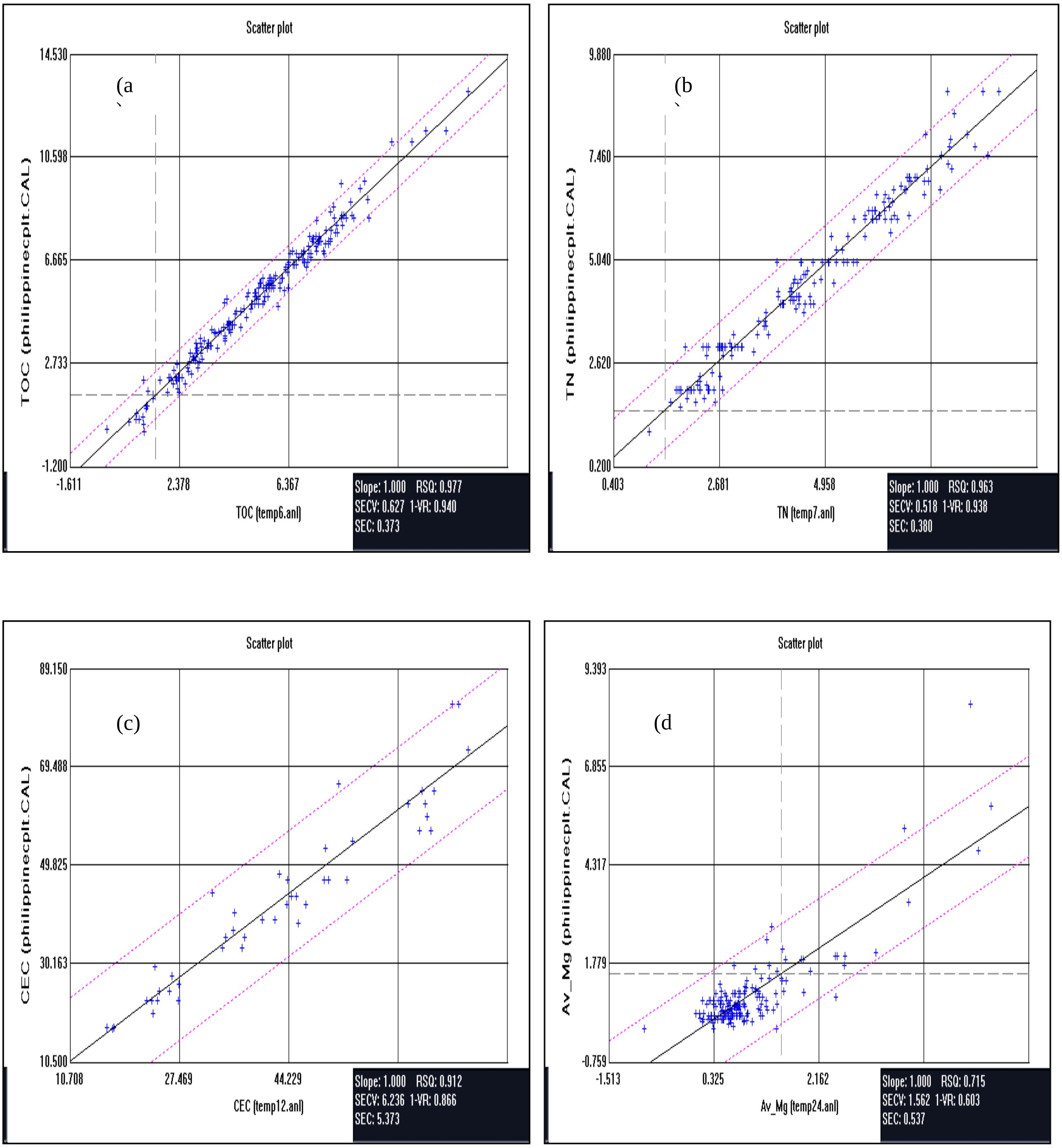
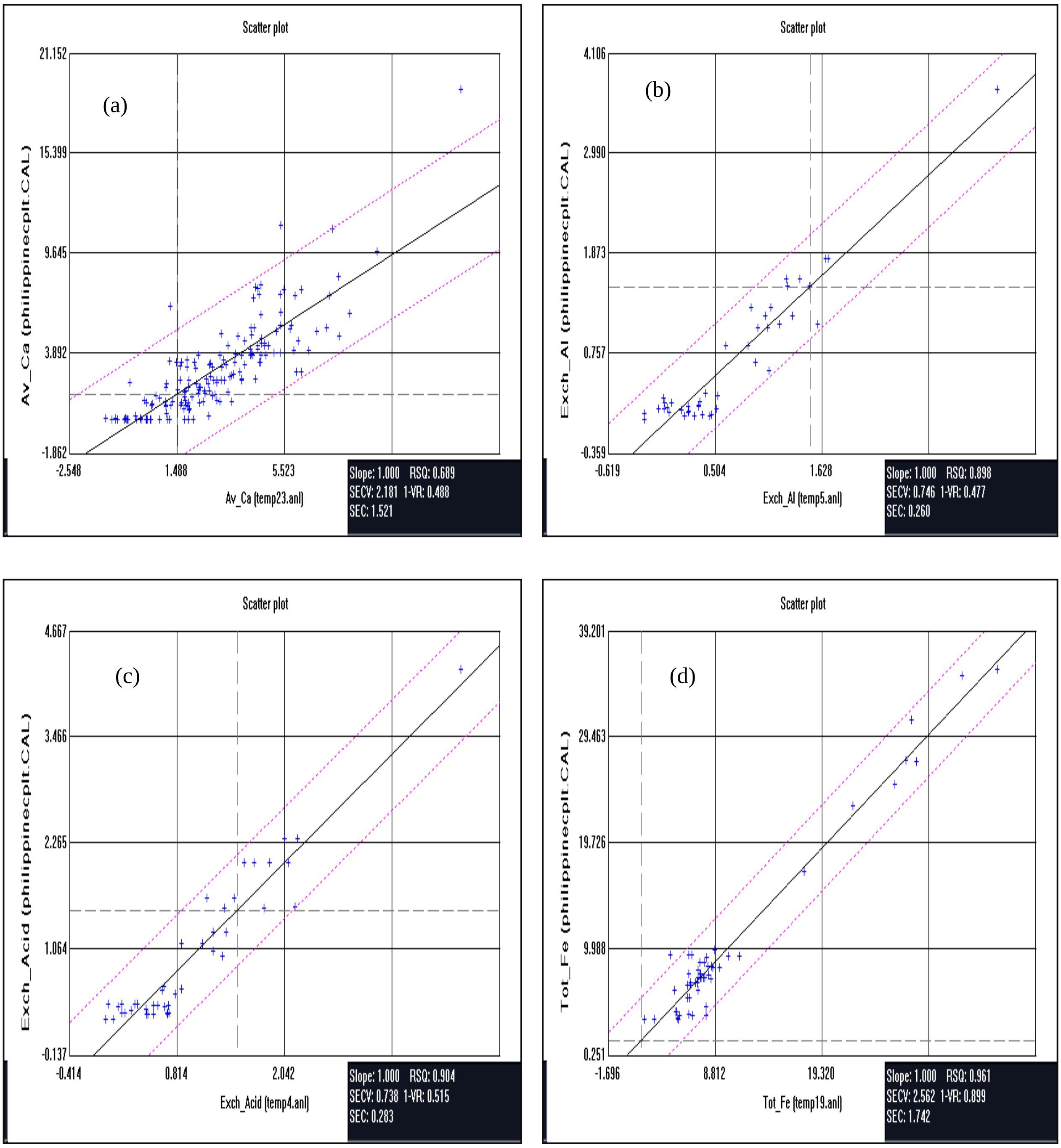


Figure VI-1. Correlations between the actual and predicted values of soil nutrients on samples tested by NIRS: (a) TOC, (b) TN, (c) CEC, and (d) available Mg. Figures were provided by Dr. Valerie Genot of Provincial Agriculture Laboratory, Liege, Belgium.



Figures V-2. Correlations between the actual and predicted values of soil nutrients on samples tested by NIRS: (a) available Ca, (b) exchangeable Al, (c) exchangeable acidity, and (d) total Fe. Figures were provided by Dr. Valerie Genot of the Provincial Agriculture Laboratory, Liege, Belgium.

6. Chapter Conclusion

The research work has established a SRS that contributes in developing a Land Information System (LandIS) for land use planning in the highlands of Mindanao, Philippines. This facilitates the connection of data into a line of facts which traces the course of soil formation with the natural and anthropogenic factors as drivers of soil development. By looking into the integrated soil data, the relationships between physical and chemical properties can be appreciated. Developed protocol shall serve as template for instruction and research on soil studies. Research findings provide scientific reference for land use planning which are essential in extension work on soil management at plot level scale.

Establishing the regional SRS for Miarayon and Bendum is a pioneering documented work in agricultural highland areas in Bukidnon. This is a work-in-progress which may need additional data that are fitted to local development needs. Replicating the model for its enhancement should be done in highland areas of primary importance. In Bukidnon, mountainous areas, like Miarayon and Bendum are still undifferentiated, and these two study sites are not the only unmapped areas in Mindanao which are already intruded by agricultural activities. The current trends of development in Mindanao highlands provide accessibility to environmentally significant areas. Thus, local development planners have to be cautious in choosing the use of the land by being informed on the nature and properties and the potentialities and constraints of the natural resource.

The NIRS technology for soil analysis had shown the applicability to the soils in the Philippines. Because of the potential benefits it can offer, the application of this technology is worth pursuing especially for more soil chemical analyses data to be available. However, the basis of comparison should be the results of classical methods that are used in the analyses of soils in the Philippines.

Chapter VII

Conclusions and recommendations

1. Chapter overview

The study was conducted in the highlands of Bukidnon, Mindanao, Philippines, particularly in the upper catchments of Cagayan de Oro River and Pulangui River. Specific areas of investigation were Miarayon, Talakag for Cagayan de Oro River catchment and Bendum, Malaybalay City for Pulangui River catchment. Miarayon is located on the long volcanic footslope of the northwestern side of Mt. Kalatungan and Bendum is situated at the foot of the western side of Pantadon Range.

Bukidnon was chosen as the study location because of its geographical and agro-economic importance not only in Mindanao but the entire Philippines. Specific study sites are the locations of the headwaters of two primary watersheds in Northern Mindanao and adjacent provinces. Bukidnon is the leading contributor to the agricultural economy of Northern Mindanao. However, poverty remains to be a concern. Major agricultural products for export from the Philippines like bananas, pineapple and sugar are also produced in the province. The province supplies highland vegetable crops to Mindanao and the Visayas islands. Highland areas in Bukidnon which are now cultivated for crop production have little or no detailed information at all on soils. With the current development trends in Mindanao, it is envisaged that agricultural activities will expand in the highlands and the demand of soil information for land use planning and sustainable management is foreseen. Therefore, this research engagement is appropriate for the location.

This research had sought to answer the questions on the soil status of the highland areas of Bukidnon regarding:

(i) the soil characteristics and fertility statuses of highland soils in Mindanao,

(ii) the contributions of the physical environment and the anthropogenic activities to soil properties and characteristics,

(iii) the influence of agricultural practices in the fertility of highland soils,

(iv) the capacity of soil in responding to the nutrient needs of plants and,

(v) the suggestions to be made to settle the agro-environmental issues in the highlands.

As an umbrella study, the research has four (4) components:

(i) Geomorphopedology, potentiality and constraint identification,

(ii) Soil fertility assessment by topsoil nutrient analyses and crop yield measurements,

(iii) Soil fertility assessment by plant response through pot experiment, and

(iv) Integration of all information into a SRS for agricultural land use.

Information gathered were connected to establish an array of information that constitutes the Soil Reference System for Bukidnon highlands.

2. Conclusion discussions

Conclusion discussions are developed and are based from the aforementioned four (4) research components.

2.1. Geomorphopedology, potentialities and constraints identification

Investigating the geomorphopedology and identifying the potentialities and constraints of Bukidnon highland soils had paved the way to answer the queries on soil characteristics and fertility statuses. Furthermore, the natural and anthropogenic effects on soil development were also drawn. Miarayon elevation ranges from 1,300 to 1,900 m asl. Bendum has 700 to 1,400 m asl and the study focus location is at 750 to 800 m asl. Miarayon and Bendum soils are both derived from parent materials of volcanic origin. However, their development differs by duration and its rock origin. Miarayon rocks were formed at relatively later time than Bendum. Miarayon rocks are pyroclastic deposits which are trachyandesites and have relatively higher SiO_2. Bendum rocks are varied which are also pyroclastic deposits and ultramafic. Plagioclase dominates in Bendum pyroclastics which has lower SiO_2 content than Miarayon rocks. Bendum ultramafic rocks have high Mg content. The presence of gibbsite in all pedons of Bendum production area shows that the soils have undergone intensive desilication process under strong weathering conditions. These are the outcomes of natural influences in soil formation for the two study sites.

Miarayon soils are ‘Andic’ Cambisols in open and in convex locations, ‘Andic’ Umbrisols in concave positions and in toeslopes, an ‘Andic’ Para acric Cambisol which is an evidence of an existing soil that was overlain by a different material. It is believed to be a mudflow and as a result of geomorphopedological process, the soil is naturally influenced. Bendum soils are Pisoplinthic Acrisol, Ferralic Nitisol, Acric Nitisol and Haplic Cambisols. The Acrisols and the Nitisols are located in areas where ultramafic rocks are found and the Cambisol is located where the pyroclastic deposit rock materials are.

Both sites have different potentialities and constraints. Miarayon soils are medium-textured soils but Bendum soils are relatively heavy. Natural and anthropogenic factors have affected hydraulic conductivity. The andic properties naturally increase the hydraulic conductivity of Miarayon soils. Human-induced factors such as tillage operations have also caused the rapid hydraulic conductivity in both areas. Miarayon’s low soil bulk densities are owed to the soil’s volcanic origin. Nutrients in soils generally reflect the elements in rock formations and the anthropogenic contributions. The high concentration of Mg in Bendum soils is naturally derived because of high Mg content in rocks. The high concentration of Ca in Miarayon soils is human induced because the high levels are found in the topsoils and is corroborated by the soil management practices of Miarayon farmers.

Miarayon soils have high soil organic matter which can be traced from the application of chicken dung by farmers and the soil capacity to slow down the mineralization of organic carbon that builds up in the topsoils. It should be noted that soils of volcanic origin like Miarayon has have the capacity to sequester C and thus may play an important role in reducing carbon dioxide (CO_2) emission from soils to the atmosphere.

2.2. Soil fertility assessment by topsoil nutrient analyses and crop yield measurements

Anthropogenic influence is highlighted in Miarayon soils. The length of cultivation affects the topsoil fertility in Miarayon as it is exhibited by the differences between Salsalan and Mambuaw soil fertility levels. Mambuaw cultivation started since more than 50 years ago while Salsalan gardening is relatively recent. Miarayon topsoils which come from relatively later rock formations are more fertile than Bendum with more developed soils. The disparities in fertility levels are exacerbated by the crop management practices. Miarayon crops which are dominantly for cash are applied with external inputs such as fertilizers (organic and inorganic) and pesticides. Weed and pest control were also regular. Because of economic limitations and the experiences of unproductivity in spite of farming inputs, Bendum farmers generally less or do not at all apply agricultural inputs to soils.

At limited number of observations in yields of Miarayon predominant crops, the data had exhibited good relationships between yields and soil nutrients. Potato yield is a good indicator of the statuses of soil pH, TOC, TN, C:N ratio, available Ca and K in soils. For corn, the relationships between yields and soil available Ca and Mg were promising. Controlling the management practices in carrot may give different perspective on the relationships between the crop yields and soil nutrient levels. However, Miarayon soils are physically and chemically favorable for carrot. Bendum farmers generally do not apply fertilizers and allow the weeds to compete with their crops. Low input in the farming system of Bendum is also shown in the topsoil quality and the yields of the location's predominant crops.

2.3. Soil fertility assessment by plant response through pot experiment

The pot experiment is a scientific way of tracing the transfer of elements from parent rock materials to their absorption in plants. It is a better way in conducting assessments on soil fertility conservation and management because this provides an understanding on the soil's release of elements and likewise the plant's capacity to assimilate nutrients. It also provides the first ideas on the intricacies and dynamics between elements in a particular soil when these are absorbed by plants.

In this study, K and P are inversely related with Ca, Mg and Na. In this, preferable attention needs to be accorded because K and P are macro-nutrients that are needed by plants. Application of lime with Ca or Mg and other Ca rich materials such as chicken dung to soils are popular practices in the Philippines. Supply of Ca and Mg from inputs can possibly deter the absorption of K and P by crops. This has to be looked into because farmers usually invest money for K and P fertilizers in crop production. It was further found out that the absorption of nutrients by plants differs in soils and the reasons of disparities believed to be both natural and anthropogenic.

2.4. Integration of all information into a Soil Reference System for agricultural land use planning

The established Soil Reference System is a contribution to developing a generic protocol for a LandIS to provide scientific references on cultivated soils for land use planning in the agricultural highlands of Mindanao, Philippines. The study is based on the principles that the soil, its formation, quality and type is influenced by rock (parent materials), relief, land use and farmer's management practices at a given climatic condition.

The developed methodology shall serve as template for instruction and research for highland soils in Mindanao, Philippines and the established Soil Reference System can be used as inputs on extension work on highland soil management. The study had demonstrated the path and concentration of soil nutrient elements from parent rock materials weathering and mineralization, to the concentration of elements in soils down to the plant response which were explicitly shown by crop yields and quantitatively indicated in the test plant biomass of the pot experiment. The study had found out that anthropogenic activities which are the farming systems have significant impacts on soil quality.

3. Recommendations

From the findings and conclusions that were drawn, the following are to be recommended for future engagements:

3.1. Disseminate the developed Soil Reference System framework and methodology and replicate the work in other highland areas in Mindanao, Philippines

The Soil Reference System framework and methodology have gone to the details of community ground working, respecting cultural practices and involving farmers in data gathering. To gain a thorough knowledge of the soil, the methodology started from the study of the rocks which are the primary sources of soil nutrients and ended in the assimilation of nutrients by plants. The nature and properties of the soil have to be well understood for an effective land use and management. The Soil Reference System is the integration of information which is useful for highland soil rehabilitation and conservation activities. Due to lack of information on highland soils, there is a need to expand the work in similar areas in Mindanao.

The reasons why farmers do not care about soil analysis for their lands are the inaccessibility of soil laboratory services and the related cost. Soil data density determines the quality of decisions made for land resource management. Even in relatively small number of samples that were tested on the NIRS analysis methods on Miarayon and Bendum soils, the results were promising. It is recommended to explore the possibility of using the technology for Mindanao soils to generate dense information on soils and rapid analyses with low associated cost and more environment friendly method.

3.2. Disseminate the established Soil Reference System in the region

The Soil Reference System presents the state of highland soils in Bukidnon. Established pieces of information are essential inputs in designing sustainable management strategies and choosing agro-environmentally options for the conservation and protection of highland agricultural soils. The reference system is tailor-made for the locality and therefore it fits into the extension work of government authorities, academe and the civil society that provide technical assistance to farmers at the local level. The Soil Reference System presents the influences of natural factors and anthropogenic activities to the soil fertility. For its effective use, results of the Soil Reference System shall be translated into the local dialect for the community stakeholders to thoroughly understand its content.

3.3. Study the sustainability of highland agricultural production

Reflections in Chapter IV explain that farmers need to examine the viability of their ventures. Interviews with farmers revealed that there are no quantitative bases on agricultural input applications as there is no soil analysis information in the area. Furthermore, farmers do not measure the sizes of the plots and therefore, the rates of input application per unit area are not certain. Over or under application of inputs can happen that will lead to wastage of chemical fertilizers and pesticides. The financiers control the dates of harvesting, transporting, and marketing and have direct access to farmers' loan payments. The farmer is more restrained in the operation which indicates their dependency on financiers. It is recommended that economic studies shall be made to determine the profitability of the operation and to find some means in order for farmers to have more control in the operation.

Unmaintained areas are due to the scarcity of farming resources. It is posited that the sizes of the land which are opened for cultivation are larger than what the farmer can afford to maintain. More lands that are opened up for cultivation can further degrade the environment. This is because once the areas are opened, these will be vulnerable to soil erosion and it will take a long time to rehabilitate these areas. It is recommended that a study shall be conducted to determine the optimum size of land that a farming family can maintain which can also be enough for its subsistence. It is also recommended to study the economic valuation of soil erosion and other forms of soil degradation for farmers to understand the environmental cost of using unsound farming practices.

3.4. Make follow-up studies on nutrient dynamics

Study results had shown that the soils have high P retention and the available P which is needed by the plant is very low. However, the conducted pot experiment had shown that P is absorbed by the test plants. It is recommended to determine the better ways of assessing P availability for Mindanao highland soils in order to prove that low P availability does not necessarily mean P limitation in soils. It is further recommended to study the timing of P release in soils to be synchronized with the stage of plant growth when the nutrient is critically needed.

Chicken dung is popularly used in vegetable farming and is an external source of Ca. Moreover, liming application, with Ca and/or Mg, to raise the soil pH is practiced by farmers not only in Bukidnon but in the Philippines. The effects of adding Ca-rich materials to the soil are apparent. In the pot experiment conducted on the soils of Miarayon and Bendum, it was observed that Ca and Mg have negative relationships with K and P absorption in plants. Since K and P are important nutrient for plants, it is recommended that the long term effects of Ca and/or Mg-rich material use on K and P availability in soils shall be studied.

The TOC is very high in volcanic soils like Miarayon has because of slow mineralization of organic matter. The effects of organic matter in releasing P to the soil solution has to be comprehended in order to get the idea of the P release timing. The contribution of volcanic soils in reducing the release of greenhouse gas CO_2 into the atmosphere should be recognized and hence this kind of soil should be protected. It is recommended to have in-depth studies on the dynamics of organic carbon in volcanic soils to further harness their contribution in combating climate change and soil degradation.

3.5. Study the hydropedology of highland areas

Most of the soils in the highland areas of Mindanao are volcanic in origin. Study results revealed that Miarayon soils have andic properties. It was observed that these soils have low bulk densities and are fluffy. When the soil gets too dry, in relation to climate and land cover change, this can be land slide prone at the onset of heavy rains. The nature of andic soils when it comes to its capacity in holding water needs to be clearly understood. This study had found out that the soil has very high water content at field capacity and at permanent wilting point. A soil with very high water content at field capacity and at permanent wilting point has low water availability. Therefore at the initial stage of the irrigation process, the soil needs to consume high amounts of water. Soil with very low water holding capacities require frequent irrigation. This information is essential if irrigation is factored-in in agricultural development planning in highland area particularly in the feasibility of putting up an irrigation system. Hydropedological information is essential in designing strategies for climate change impacts in highland agriculture particularly for irrigation as drought mitigation measures.

Furthermore, the study shall determine the soil erodibility, and with the data gathered from this research on land use and topography, the soil's vulnerability to erosion has to be cross-checked by determining the rain erosivity in the highland areas. Investigations shall also include the rainfall measurement component.

3.6. Establish soil conservation programs for agriculture in highland areas

It is apparent in both study sites, and in other highland areas, that farmers do not employ soil conservation and management strategies. Topsoil in open and convex areas is thin and in concave surfaces and footslopes are thick. These can be evidences of soil erosion and deposition. It was also found out that soil fertility levels decline with long duration of cultivation without proper replenishment of slowly mined nutrients. There is need for the farmers to understand the repercussions of long and continuous cultivation in the fertility status and yield of crops. Soil conservation awareness using the findings of this study can be the trail-blazing work to invite participant farmers in joining the program.

3.7. Conduct environmental toxicology studies in highland vegetable areas

It was mentioned on the cropping management practices (Chapter IV) in commercial vegetable production that farmers apply pesticides every three or five days in the crops' entire growing season and thus constantly exposing them to chemical hazards. Vegetables are sprayed days before harvest to preserve their quality when shipped to the market. It was also observed that farming parents bring their under-school-age children to the production areas and these areas serve as the children's play ground. In Salsalan, Miarayon for instance, farming families live in production areas where they also get their water supplies for domestic consumption. Because the soil has high water conductivity, the transport of agrochemicals from soil to water bodies is not remote. Therefore, it is recommended that studies on pesticide residues shall be conducted in water bodies, soil, humans and vegetable products that are shipped to the market for human health safety.

VIII. Bibliography

Asian Development Bank, 2009, *Poverty in the Philippines, causes, constraints and opportunities,* Asian Development Bank, 6 ADB Avenue, Mandaluyong City, 1550 Metro Manila, Philippines, 136p.

Asio, V.B., Jahn, R., Perez, F.O., Navarrete, I.A., and Abit, S.M. Jr., 2009, A review on soil degradation in the Philippines, *Annals of Tropical Research* 31[2] :69-94(2009), VSU, Leyte, Philippines.

Aurelio, M.A., Pena, R.E. and Taguibao, K.J.L., 2012, Sculpting the Philippine archipelago since the Cretaceous through rifting, oceanic spreading, subduction, obduction, collision and strike slip-faulting: Contribution to IGMA5000, *Journal of Asian Earth Sciences*, 72(2013) 102-107, Elsevier Ltd.

Auxtero, E., Van Ranst, E. and Sakagami, K, 1996, Properties and related management implications of major soils in Bukidnon, Philippines, *Soil Science,* Volume.161, No. 1, William and Wilkins, pp. 46-57.

Bacatio, C.D., Kubotera, H., Nanzyo, M. and Yamada, I., 2005, Partial rejuvenation of the soil of Intavas Demo Farm, Bukidnon, Mindanao, Philippines by volcanic ash materials, *Special Review, JIFS,* 2:19-27 (2005).

Baldock, J.A. and Nelson, P.N., 2000, Soil organic matter, In Sumner, M (ed.), 2000, *Handbook of Soil Science,* CRC Press LLC, B25-B84.

Barbieux, S., 2012, *Enrichment of the geomorphopedological identification and intensification of agropedological evaluation of two sites in Mindanao (Philippines),* MSc Thesis, University of Liege-Gembloux Agro Bio Tech, Gembloux, Belgium, 74p.

BAS, 2013, *Country statistics of the Philippines,* Bureau of Agricultural Statistics, Quezon City, Philippines, www.bas.gov.ph, Accessed: 18 July 2013.

Bear, F.E. and Toth, S.J., 1948, Influence of Calcium on availability of other cations, in *Soil Science,* Volume 65, Rutgers University, New Brunswick, New Jersey USA, 65:69-74.

Bertrand, S. and Fagel, N., 2008, Nature, origin, transport and deposition of Andosol parent material in south-central Chile (36-42°S), *Catena* 73(2008) 10-22, Science Direct, Elsevier, B.V.

Bock, L., 1994, *Analyses de sols et gestion de l'espace – plaidoyer pour leur cadrage geomorphopedologique dans les projets, expertises et services de conseils,* Etude et Gestion des Sols, n° 1:23-33.

Bock, L., Ducat, N., Roisin, V., Hanotiaux, G. and Mathieu, L., 1994, *Characteristics and effects of organic matter on Belgian loamy soils: a reference system,* In Neeteson, J.J. and Hassink (eds,), 1994, Nitrogen mineralization in agricultural soils; process symposium, Institute for Soil Fertility Research, Haren, NL., 19-20 April 1993, AB-DLO Thema's, Haren, 185-190.

Bock, L., Colinet, G., and Lacroix, D., 2010, A case study in Southeast China of operational pedology as a contribution to a project linking research and training, A paper presented to the *2010 19th World*

Congress of Soil Science: Soil Solutions for a Changing World, 1-6 August 2010, Brisbane, Australia, Published in DVD.

Bouis, H.E. and Haddad, L.J., 1990, Effects of agriculture commercialization on land tenure, household resource allocation and nutrition in the Philippines, *Research Report 79,* International Food Policy Research with Research Institute for Mindanao Culture, Xavier University, Cagayan de Oro City, Philippines, 76p.

Bowichean, B., Thanachit, S., Anusontpornperm, S. and Kheoruenrome, I., 2013, Green manuring effect on yield of cassava-sweet corn sequential cropping on degraded sandy soil, Northeast Thailand, *Kasetsart J. (Nat. Sci.)* 47:342-357 (2013).

Brady, N.C. and Weil, R.R., 1999, *The nature and properties of soils,* Twelfth edition, Prentice Hall, 881p.

Bukidnon Provincial Development Staff, 1985, *The Geological Map of Bukidnon,* Scale: 1:200,000, Ministry of Agriculture and Food Region 10, Bukidnon, Philippines.

Bukidnon Provincial Development Staff, 1989a, *The Geomorphopedological Map of Talakag, Bukidnon,* Scale: 1:50,000, Ministry of Agriculture and Food Region 10, Bukidnon, Philippines.

Bukidnon Provincial Development Staff, 1989b, *The Geomorphopedological Map of Malaybalay, Bukidnon,* Scale: 1:50,000, Ministry of Agriculture and Food Region 10, Bukidnon, Philippines.

Buol, S.W., 2008, *Soils, land and life,* Prentice Hall, Pearson Education, Inc., Upper Saddle, New Jersey, 301p.

Camberato, J.J. and Pan, W.L., 2000, Bioavailability of Calcium, Magnesium and Sulfur, in Sumner, 2000, *Handbook of Soil Science,* CRC Press.

CAO, 2010, *Annual accomplishment report calendar year 2010,* Malaybalay City Agricultural Office, Malaybalay City, The Philippines.

Carating, R.B., Galanta, R.G. and Bacatio, C.D., 2013, *The soils of the Philippines,* World Soils Book Series, Springer 2014 Edition, 346p.

CENRO-Talakag, 1999, *Cagayan de Oro watershed profile,* Community Environment and Natural Resources, Talakag, Bukidnon, Philippines, 29p.

CMU, 2012, *Agro–meteorological data* (1988-2011), Central Mindanao University, Bukidnon, The Philippines.

Concepcion, R.N., 2000, The state of land, water and plant nutrition resources: Philippine National Report, Land Resources Information Systems in Asia. Proceedings of a regional workshop in Quezon City, Philippines, *World Soil Resources Report,* Food and Agriculture. Rome, 41-49.

Cramb, R. A., 2005, Farmers' strategies for managing acid upland soils in Southeast Asia: an evolutionary perspective, *Agriculture, Ecosystems and Environment* 106 (2005) 69-87, Elsevier.

Dalrymple, J.B., Blong, R.J., and Conacher, A.J., 1968, *A hypothetical nine unit landsurface model,* Zeitschrift fur Geomorphologie, 12, 60-76.

Deenik, J., 2006, Nitrogen mineralization in important agricultural soils of Hawai'i, *Soil and crop management*, Cooperative Extension Service, College of Tropical Agriculture and Human Resource, University of Hawai'I at Manoa, Honolulu, Hawai'i, 1-5.

Delecour, F. and Kindermans, M., 1977, *Profile description*, Soil Science Service, University of Liege-Gembloux Agro Bio Tech, Gembloux, Belgium.

DENR-10, 2014, *Cagayan de Oro River Basin map,* Department of Environment and Natural Resources Region 10, Cagayan de Oro City, Philippines.

DENR, 2003, *Implementing rules and regulations (IRR) of the Philippine Environmental Impact Statement (EIS) System,* DENR Administrative Order No. 2003-30, Department of Environment and Natural Resources, Diliman, Quezon City, Philippines, 22p.

De Souza, M.F., Magalhaes, W.L.E. and Persegil, M.C., 2002, Silica derived from burned rice hulls, *Materials Research,* Vol. 5, No. 4, 467-474, 2002.

Donald Ahrens, C, 2007, *Meteorology today: An introduction to weather, climate and the environment,* Eighth edition, Thomson Brooks/Cole, 537p.

Driessen, P., Deckers, J., Spaargaren, O. and Nachtergaele, F., 2001, *Lecture notes on major soils of the world*, Food and Agriculture Organizations of the United Nations, Rome, 334p.

ESSC, 2010, *Map of Upper Pulangui Watershed and Bendum Sub catchment*, Environmental Science for Social Change, Malaybalay City, Bukidnon, Philippines.

FAO-UN, 2015, International Year of Soils 2015, Food and Agriculture Organization of the United Nations, http://www.fao.org/soils-2015/about/key-messages/en/, downloaded 17 August 2015.

FAO, 2006, *Guidelines for soil profile description*, Food and Agriculture, Rome, 97p.

FAO, 1989, *Guidelines for land use planning, Interdepartmental Working Group on Land Use Planning,* Food and Agriculture Organization of the United Nations, Rome, Italy, 121p.

FAO, 1979, *Provisional methodology for soil degradation assessment,* Food and Agriculture Organization of the United Nations, Rome, 84p.

Fieldes, M. and Perrot, K. W., 1966, *The nature of allophanes soils*: 3. Rapid field and laboratory test for allophanes, N.Z.J. Sci., 9:623-629.

Fischer, G., Nachtergaele, F., Prieler, S., van Velthuizen, H.T., Verelst, L., and Wiberg, D., 2008, *Global agro-ecological zones assessment for agriculture (GAEZ 2008),* IIASA, Laxenburg, Austria and Food and Agriculture, Rome, Italy, http://www.fao.org/nr/land/soils/harmonized-world-soil-database/soil-quality-for-crop-production/en/, Accessed: 05 September 2014.

Foss, J.E., Moorman, F.R. and Reiger, K., 1983, Chapter 10: Inceptisols, in Wilding, L.P., Smeck, N.E., and Hall, G.F. (Editors), *Pedogenesis and Soil Taxonomy. II. The Soil Orders*, Elsevier Science Publisher, B.V., Amsterdam, 35-381, 1983.

Fritz, V.A., Tong, C.B.S., Rosen, C.J. and Nennich, T., 2013, *Carrots -vegetable crop management,* University of Minnesota Extension, www.extension.umn.edu., 612-264-122, http://www.extension.umn.edu/garden/fruit-vegetable/carrots-vegetable, Accessed: 24 June 2014.

Genot, V., Colinet, G., Bock, L., Vanvyve, D., Reuser, R and Dardenne, P., 2011, Near Infrared Reflectance Spectroscopy for estimating characteristics valuable in the diagnosis of soil fertility, Near Infrared Spectrosc., 19, 117-138 (2011).

Gerrard, J., 1992, *Soil geomorphology: An integration of pedology and geomorphology,* Chapman and Hall, 269p.

Granados, G., 2000, Post-harvest management, in FAO (2000), *Tropical maize: Improvement of production,* FAO Plant Production and Protection Series # 28, FAO, Rome, Italy, 301-307.

Grotzinger, J., Jordan, T.H., Press, F. and Siever, R. 2007, *Understanding Earth*, Fifth Edition, W.H. Freeman and Company, NY, 381-384, 598p.

Hauser, G.F., 1973, *Soil fertility investigations on farmers' fields*, Food and Agriculture Organizations for the United Nations, Rome, Italy. 75p.

Holmer, R.J., 1997, *Sustainable vegetable production for small farmers on problem soils in the highlands of Bukidnon, Philippines for fresh marketing and processing,* PhD Dissertation, Technical University of Munich, Germany, 239p.

Horne, P.M. and Stur, W.W., 1999, Developing forage technologies with smallholder farmers – how to select the best varieties to offer to farmers in Southeast Asia, *ACIAR Monograph No. 62*, 80pp.

IUSS Working Group WRB, 2006, *World Reference Base for Soil Resources 2006: A Framework for International Classification, Correlation and Communication*, World Soils Report 103, Food and Agriculture Organization of the United Nations, Rome, 128p.

Jahn, R., Blume, H.P., Asio, V.B., Spaargaren, O., Schad, P., Langohr, R., Brinkman, Nachtergaele, F.O. and Pavel Krasilnikov, R., 2006, *Guidelines for soil profile description*, Fourth Edition, Food and Agriculture of the United Nations, Rome, Italy, 97p.

Kang, W., Fan, M., Ma, Z., Shi, X. and Zheng, H., 2014, Luxury absorption of potassium by potato plants, *American Journal of Potato Research* (2014), 9:573-578.

Kastner, T. and Nonhebel, S., 2010, Changes in the land requirements for food in The Philippines: A historical analysis, *Land Use Policy* 27 (2010) 853-863, Elsevier.

Kimsey, M.J. Jr., Garrison-Johnston, M.T. and Johnson, L., 2011, Characterization of volcanic ash-influenced forest soil across geoclimatic sequence, *Soil Science Society of America Journal,* 75:267-279.

Lal, R., 1988, Erodibility and erosivity, in Lal, R. (ed), (1988), *Soil erosion research methods,* Soil and Water Conservation Society and International Soil Science Society, 141-160.

Landon, J.R., 1991, *Booker Tropical Soil Manual* – A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics, Longman Scientific and Technical, New York, 474p.

Lantican, M.A., Guerra, L.C., and Bhuiyan, S.I., 2003, Impacts of soil erosion in the upper Manupali watershed on irrigated lowlands in the Philippines, *Paddy Water Environ (2003) 1:19-26,* Springer-Verlag 2003.

Lapoot, C.R., Salvani, J.B., Duna, L.V., Bicamon, R. and Tulin, A.B., 2010, Enhancing farmers' knowledge on soil crop nutrient management for vegetable production in Bukidnon, Mindanao, The Philippines, Paper presented to the *2010 19th World Congress of Soil Science*, Soil Solutions for a Changing World, 1-6 August 2010, Brisbane, Australia, 158-161.

Lao, M.M., 1992, *Bukidnon in historical perspective 1946-1985*, Volume II, Central Mindanao University, Musuan, Bukidnon, 166-192.

Lebrun, F., 2011, *Geomorphopedological identification and agropedological evaluation in Miarayon (Mindanao, The Philippines)*, MSc Thesis, University of Liege-Gembloux Agro Bio Tech, Gembloux, Belgium, 107p.

Levard, C., Doelsch, E., Basile, I., Abidin, Z., Miche, H., Masion, A., Rose, J., Borschneck, D. and Bottero, J.Y., 2012, Structure and distribution of allophanes, imogolite and proto-imogolite in volcanic soils, *Geoderma 183-184 (2012)* 100-108, Elsevier, B.V.

Licker, M.D., 2003, *Mc Graw-Hill Dictionary of Geology and Mineralogy*, Second Edition, Mc Graw-Hill Companies, 420p.

Mac Kenzie, W.S. and Adams, A.E., 2011, *A colour atlas of rocks and minerals in thin section*, Manson Publishing, 192p.

Manna, P., Basili, A., Bonfante, A., De Mascellis, R., and Terribilie, F., 2009, Comparative land evaluation approaches: An itinerary from FAO Framework to simulation modeling, *Geoderma* 150(2009) 367-378, Elsevier, B.V.

Mariano, J.A., Yniguez, T.M., and Aguas, E.H., 1955, *Soil survey of Bukidnon Province,* The Philippines with a discussion on the chemical characteristics and fertilizer requirements of the soils *in* Bukidnon, Province, Soils Report 21, Department of Agriculture and Natural Resources, Manila, The Philippines, 90p.

Mariano, J.A., Salazar, F.G., Bello, C.A. and Camba, F.E., 1950, *Soil Map of Bukidnon Province*, Bureau of Soils, Department of Agriculture and Natural Resources, Manila, Philippines

Maurissen, S., 2014*, Geological characterization of Bendum and Miarayon (Philippines) and relation with the pedology*, MSc Thesis, Universite Libre de Brussels, Brussels, Belgium, 119p.

McKenzie, N. and Cresswell, H.P., 2002, Selecting method for hydraulic conductivity, In McKenzie, N., Coughlan, K. and Cresswell, H., 2002, *Soil physical measurement and interpretation and evaluation*, CSIRO Publishing, 90-107.

MDA, 2012, *Demography-land area classification,* Mindanao Development Authority, Republic of the Philippines, minda.gov.ph/site/Mindanao /statistics/Demography---Land-Area-Classification-, Accessed: 9 July 2014.

Mejias, J.M., Alfaro, M. and Harsh, J., 2013, Approaching environmental phosphorus limits on a volcanic soil of Southern Chile, *Geoderma* 207-208 (2013) 49-57, Elsevier B.V.

Merino, G., 1952, Introduction, in *Half a century of Philippine agriculture*, Bureau of Agriculture, Manila, Philippines, 463 p.

Mertz, O., Padoch, C., Fox, J., Cramb, R.A., Leisz, S., Lam, N.T. and Vien, T.D., 2009, Swidden change in Southeast Asia: Understanding causes and consequences, *Human Ecolo*gy (2009) 37:259-264 Springer.

Mileti, F.A., Langella, G., Prins, M.A., Vingiani, S. and Terribili, F., 2013, The hidden nature of parent material in soils of Italian mountain ecosystems, *Geoderma* 207-208(2013) 291-309, Elsevier, B.V.

Navarrete, I.A., 2011, Chemical, mineralogical, and morphological characteristics of a late quaternary sedimentary rock-derived soil in Leyte, Philippines, *Technical Article Soil Science*, Volume 176, Number 12, Lippincott Williams and Wilkins, 699-708.

Navarrete, I.A., Tsutsuki, K., Asio, V.B. and Kondo, R., 2009, Characteristics and formation of rain forest soils derived from late Quaternary basaltic rocks in Leyte, Philippines, *Environmental Geology* (2009) 58:1257-1268.

Ndayiragije,S. and Delvaux, B., 2003, Coexistence of allophane, gibbsite, kaolinite and hydroxy-Al-interlayered 2:1 clay minerals in a perudic Andosol, *Geoderma* 117 (2003) 2013-2014.

NSO, 2012, *The population density increases by 53 persons per square km*, Reference Number: 2012-067, National Statistics Office, The Philippines, Release date: August 30, 2012, www.census.gov.ph, Accessed: 16 September 2013.

NSO, 2011, Total population by Province, Municipality and Barangay of Bukidnon as of 01 May 2010, *Census of population and housing*, National Statistics Office, www.nso.gov.ph, downloaded: 20 June 2013.

Ooms, L., 1992, *Analytical methods for soil*, Soil fertility conservation project, Department of Soils and Fertilizers, Mae Jo Institute in Agricultural Technology, Chiang Mai, Thailand. 89p.

Opfergelt, S., Burton, K.W., Georg, R.B., West, A.J., Guicharnaud, R.A., Sigfusson, B., Siebert, C., Gislason, S.R. and Halliday, A.N., 2013, Magnesium retention on the soil exchange complex controlling Mg isotope variations in soils, soil solutions and vegetation in volcanic soils, Iceland, *Geochimica et Cosmochimica Act*a 125 (2014) 110-130, Elsevier Ltd.

PAGASA-DOST, 2014, Rainfall normal values (1981-2010), Philippine Atmospheric, Geophysical and Astronomical Services Administration, Department of Science and Technology, Diliman, Quezon City, Philippines, Http://www.pagasa.dost.gov.ph/climate-info-statistics/climatological-normals, Accessed: 7 April 2014.

PCARRD, 2006, *The Philippine Recommends for Soil Fertility Management*, Philippine Recommends Series No- 36 – D, Philippine Council for Agriculture, Forestry, and Natural Resources Research and Development, Department of Science and Technology, Los Banos, Laguna, Philippines, 201p.

PENRO-Malaybalay, 1999, *Pulangui watershed profile*, Department of Environment and Natural Resources, Capitol Drive, Malaybalay City, 51p.

Plice, M.J., 1942, Factors affecting soil color (Progress Report), *Proceedings of the Oklahoma Academic of Science for 1942*, pp49-51, digital.library.okstate.edu/OAS/oas_pdf/V23/p49-51.pdf, downloaded, 01 January 2014.

Poudel, D.D., Midmore, D.J. and West, L.T., 2000, Farmer participatory research to minimize soil erosion on steepland vegetable systems in the Philippines, *Agriculture, Ecosystems and Environment* 79(2000) 113-127, Elsevier Science B.V.

Poudel, D.D. and West, L.T., 1999. Soil development and fertility characteristics of a volcanic slope in Mindanao, the Philippines. *Soil Science Society of America*, Volume 63: 1258-1273.

PSA, 2004, *A Review of the Agriculture Sector in Northern Mindanao*, Philippine Statistics Authority-National Statistics Office, Reference Number: 2004-125, Released: November 10, 2004, http://www.census.gov.ph/content/review-agriculture-sector-northern-mindanao.

Putzel, J., 1992, *A captive land: The politics and agrarian reform in the Philippines*, Ateneo de Manila University Press, Bellarmine Hall, Katipunan Avenue, Loyola Heights, Quezon City, Philippines, 427p.

Quantin, P., 1986, Properties and Genesis of Andisols *(Propriétés et formation des Andisols)*, Colloques et Congrés, Cah. ORSTOM, sér Pédol., vol. XXII, n° 1, 1986:105-111.

Queensland Department of Agriculture, Fisheries and Forestry, no date, *Chicken litter*, Queensland Government, Australia, https:/www.daff.qld.gov.au/animal-industries/dairy/feed-and-nutrition, downloaded 29 November 2014.

Rabbi, S.M.F, Wilson, B.R., Lockwood, P.V., Daniel, H. and Young, I.M., 2014, Soil organic carbon mineralization rates in aggregate under contrasting land uses, *Geoderma* 216 (2014) 10-18.

Raymundo, M.E., Dayot, R.A., Alcalde, C.B., 1985, The soils of The Philippines: Their association with geology and landforms, *Proceeding of the 7th International Forum on Soil Taxonomy: Tool for Agrotechnology Transfer*, 12 to 23 March 1984, PCARRD, Los Banos, Laguna, Philippine, 78-87.

Raymundo, M.E. and Vicente, P.R. 1985. Crop production capabilities of a volcanic ash soil and Tropical Latosols in the Philippines. *Proceeding of the 7th International Forum on Soil Taxonomy: Tool for Agrotechnology Transfer*, 12 to 23 March 1984. Philippine Council for Agriculture Resources Research and Development (PCARRD), Los Banos, Laguna, Philippines.

Richelle, L., 2010, *Identification geomorpho-pedologique et evaluation des sensibilites environnementales d' un sous-bassin versant a Mindanao avec le souci d'y associer les collectivites locales*, MSc Thesis, Universite de Liege-Gembloux Agro Bio Tech, Gembloux, Belgium, 76p.

Rossiter, D.G., 2008, Book Review, Land evaluation: Towards a revised framework, Land and Water Discussion Paper 6, FAO, Rome (2007), *Geoderma* 148(2008) 428-429.

Rubatzky, R.B., Quiros, C.F. and Simon, P.W., 1999. *Carrots and related vegetable umbelliferae*, CABI Publishing, 294p.

Rushemuka, N.P., Bizoza, R.A., Mowo, J.G., and Bock, L., 2014, Farmers' soil knowledge for effective participatory watershed management in Rwanda: Toward soil-specific fertility management and farmers' judgmental fertilizer use, *Agriculture, Ecosystems and Environmental Journal* 183 (2014) 145-159, Elsevier.

Sajona, F.G., Maury, R.C., Pubellier, M., Leterrier, J., Bellon, H. and Cotton, J., 2000, Magmatic source enrichment by slab derived melts of young-post collision setting, central Mindanao (The Philippines), *Lithos* 54(2000) 173-206, Elsevier Science B.V.

Sajona, F.G., Bellon, H., Maury, R.C., Pubellier, M., Quebral, R.D., Cotton, J., Bayon, F.E., Pagado, E. and Pamatian, P., 1997, Tertiary and Quaternary magmatism in Mindanao and Leyte (The Philippines): geochronology, geochemistry and tectonic setting, *Journal of Asian Earth Sciences,* Vol.15, Nos 2-3, 121-153, Elsevier.

Sanchez, P., Couto, W. and Buol, S.W., 1982, The fertility capability soil classification system: interpretation, applicability and modification, *Geoderma,* 27 (1982) 283-309, Elsevier Scientific Publishing Company, Amsterdam.

Sandoval, M.A., Stolpe, N.B., Zagal, E.M. and Mardones, M., 2007, The effect of crop-pasture rotations on the C, N, and S contents of soil aggregates and structural stability in a volcanic soil of south-central Chile, *Acta Agriculturae Scandinavica*, Section B-Soil and Plant Science, 2007, 57:255-262, Taylor and Francis.

San Valentin, G.O., 1985, Properties and management of soil for corn production, *Proceeding of the 7th International Forum on Soil Taxonomy and Agrotechnology Transfer*, 12 to 23 March 1984, PCARRD, Los Banos, Laguna, Philippines, 135-148.

Schmidt-Vogt, D., Leisz, S.J., Mertz, O., Heinimann, A., Thiha, T., Messerli, P., Epprecht, M., Cu, P.V., Chi, V.K., Hardiono, M. and Dao, T.M., 2009, An assessment of trends in the extent of swidden in Southeast Asia, *Human Ecology* (2009) 37:269-280, Springer.

Sonneveld, M.P.W., Hack-ten Broeke, M.J.D, Van Diepen, C.A., and Boogard, H.L., 2010, Thirty years of systematic land evaluation in the Netherlands, *Geoderma* 156 (2010) 84-92, Elsevier.

Stenberg, B., Viscarra Rossel, R.A., Mouazen, A. M. and J Witterlind, 2010, Visible and near infrared spectroscopy in Soil Science, In Donald L. Sparks, editor: *Advances in Agronomy*, Vol. 107, Burlington: Academic Press, 2010, pp.163-215, http"//dx.doi.org/10.1016/S0065-2113 (10)07005-7

Stephen, R.C. and Waid, J.S,. 1963, Pot experiments on urea as a fertilizer: III. The influence of rate, form, time and placement, *Plant and Soil* XIX, no. 2, 184-192.

Su, S.W., Tsui, C.C., Lai, H.Y. and Chen, Z.S., 2014, Food safety and bioavailability evaluations for four vegetable grown in the highly Arsenic-contaminated soils in the Guando Plain of Northern Taiwan, *International Journal of Environmental Research and Publc Health*, 4092-4107, www.mdpi.com/journal/ijerph.

Sumner, M. E. and Wilding, L.P., 2000, Introduction: in *Soil Science Handbook*, CRC Press.

SWEMRC, 2013, *Climate profile of Bukidnon*, Sustainable Watershed Ecosystem Management Resource Center, swem.bukidnon.gov.ph/section/climate-profile-Bukidnon, Accessed 7 April 2014.

Tatoy, B.F., Abragan, F.N., Lapoot, C.R., Apiag, C.T., Salvani, J.B., Madriaga, C.S., Bacho, A.P., Tumapon, A.S., Duna, L.V., Dumayaca, C.A., Flores, M.A., Ramos, L.A. and Maape, E.S., 2001, Bacterial Wilt Management in Potato through Agro-Technical Approach, *Research Compendium 2001, Northern Mindanao Integrated Agriculture Research Center (NOMIARC),* Department of Agriculture Regional Field Unit 10, Dalwangan, Malaybalay City, Philippines, 34-55.

Tsui, C.C., Tsai, C.C. and Chen, Z.S., 2013, Soil organic carbon stocks in relation to elevation gradients in volcanic ash soils of Taiwan, *Geoderma*, 2019-201 (2013) 119-127.

Tuna, A.L., Kaya, C., Ashraf, M., Altunlu, H., Yokas, I. and Yagmur, B., 2007, The effects of calcium sulphate on growth, membrane stability and nutrient uptake of tomato plants grown under salt stress, *Environmental and Experimental Botany* 59 (2007) 173-178, Elsevier B.V.

Van Daele, S., 2012, *Soil hydrodynamic behavior characterization in Mindanao-Philippines*, MSc Thesis, University of Liege, Gembloux Agro Bio Tech, Gembloux, Belgium, 89p.

Vos, H.M.J., Ros, M.B.H., Koopmans, G.F. and van Groenigen, J.W., 2014, Do earthworms affect phosphorous availability to grass? A pot experiment, *Soil Biology and Biochemistry* 79(2014) 34-42 Elsevier LTD.

Walpole, P.W., 2002, *An analysis of the drivers and impacts of lanc use change in the Tropical Upland of Mindanao, Philippines,* PhD Thesis, Department of Geography, King's College London, p.703.

Wilberts, S., Suter, M., Walser, N., Edwards, P.J., Venterink, H.O., and Ramseier, D., 2013, Testing experimentally the effect of soil resource mobility on plant competition, *Journal of Plant Ecology*, pp. 1-11, Downloaded at http://jpe.oxfordjournals.org/atBibliotheque/FacdeMedecine on October 13, 2014.

World Bank Group, 2014, World Bank development indicators, data.worldbank.org/country/Phils., Accessed: 5 July 2014.

Wysocki, D.A., Schoeneberger, P.J. and La Garry, H.E., 2000, Geomorphology of soil landscapes, in Sumner, M.E. (ed), 2000, *Handbook of Soil Science,* CRC Press, E5-E39.

Yu, S.B., Hsu, Y.J., Bacolcol, T., Yang, C.C., Tsai, Y.C. and Solidum, R., 2013, Present-day crustal deformation along the Philippine Fault in Luzon, The Philippines, *Journal of Asian Earth Sciences,* 65(2013) 64-74.