SOIL GREENHOUSE GAS BALANCE, YIELD, AND PROFIT IN INTENSIVELY FERTILIZED VEGETABLE FARMS ON AN ANDOSOL SOIL IN LEYTE, PHILIPPINES

Dissertation to attain the degree Doctor of Philosophy (Ph.D.)
of the Faculty of Agricultural Sciences
Georg–August–Universität–Göttingen

Submitted by
Cecille Marie O. Quiñones
Born in Baybay City, Leyte, Philippines

Göttingen, November 2022

1st Referee: Dr. Marife D. Corre

2nd Referee: Prof. Dr. Carola Paul

Date of oral examination: 24 January 2023

Dedicated to my tatay Cesar, nanay Lilia, and my siblings, namely Cherryl, Kristine Joyce, Sherlie, Lesle Mae, and to kuya Alain and family

TABLE OF CONTENTS

LIST OF FIGURES

Chapter 1

Chapter 2

Chapter 3

LIST OF TABLES

Chapter 2

Chapter 3

SUMMARY

The vegetable industry is a vital sector in the Philippines' agriculture, providing a significant contribution to the country's total agricultural production and its overall economy. Vegetable farms in the Philippines are typically fragmented, small-scaled, and established in newly cleared forests with highly fertile soils. Increases in production and area are parallel with the increasing occurrences of forest conversion to vegetable farms. On top of deforestation, farmers practice high fertilization rates, successive cropping periods, deep soil tillage, and unregulated pest control applications. Despite various intensive cultivation practices implementation, average yield remains below optimum while high crop production costs penalize vegetable growers. Moreover, patterns of soil greenhouse gas (GHG; N_2O, CH_4, and CO_2) fluxes that cover various crop production systems in the Philippines are less studied. To date, neither an investigation on field-based measurements of soil GHG fluxes nor an evaluation of vegetable yield response and farm-gate profit in intensively fertilized vegetable farms, has been undertaken.

This research project aimed to (1) quantify and assess the soil GHG patterns in the secondary forest and in smallholder vegetable farms, (2) estimate the GHG budget of the latter land use, and (3) evaluate the optimum limits of plant-available nutrients, fertilization rates, vegetable yield response, and also the farm-gate profit following long-term intensive fertilization in vegetable farms. In addressing the abovementioned objectives, we performed our study on an Andosol soil in Cabintan, Leyte, Philippines. Nine spatially independent forest plots (each 64 m^2) were established and 10 vegetable farms (≤ 0.30 ha) that covered the typical cultivation practices in the area were studied. These replicates have the same geology and climatic conditions. The secondary forest has tree vegetation that belongs to the families of old dipterocarp forest, while the studied vegetable farms cultivated cabbages and solanaceous vegetables during cropping periods. These farms practiced high fertilizer and pesticide application rates, introduced deep plowing during land preparations to create cultivation zones plant row and inter-row, and abstained from soil fallow in place for two to three cropping periods in a year. The vegetables produced in the study area catered to the demands not only in the Leyte province but also in adjacent islands, including the northern and southern provinces.

To address our first objective, we assessed the soil GHG fluxes and controlling variables (mineral N: NH_4^+ and NO_3^-, water-filled pore space (WFPS), and soil temperature) in the studied vegetable farms (current land use) and compared these with that in the secondary forest (reference land use). Monthly measurements of soil GHG fluxes in the top 0.05 m were carried out using vented static chambers from May 2018 to May 2019. We also determined the stocks of mineral N and dissolved organic N in the 1-m soil depth of the current land use and the change of soil organic carbon (SOC) stock arising from land-use conversion as supporting information for the patterns of soil GHG fluxes. Both land uses consistently emitted soil N_2O, consumed soil CH_4, and released soil CO_2; these soil GHG fluxes were overall significantly higher in the vegetable farms than in the secondary forest. The increase in soil N_2O emissions from the farms reflected the application of fertilizers, particularly in plant rows, whereby the availability of mineral N as substrates stimulated soil N_2O emissions. Furthermore, the substantial accumulation of mineral N down to 1-m soil depth supported the large soil N_2O emissions. In terms of CH_4 fluxes, the increasing NO_3^- levels in the plant row possibly dampened CH_4 production, thereby promoting the CH_4 uptake in vegetable farms but at a reduced rate relative to the forest. This reduction was also ascribed to increased bulk density in the inter-row, which inhibited the diffusion of atmospheric CH_4 into the soil pronouncedly during the wet season and simultaneously reduced methanotrophic activity. Soil CO_2 in both land uses was mainly controlled by the WFPS, while microbial decomposition largely influenced the emissions from the vegetable farms.

For our second objective, we estimated the GHG budget of our studied vegetable farms by incorporating the net primary production (NPP), net ecosystem C exchange (NEE), and the net ecosystem productivity (NEP) in the calculation of its global warming potential (GWP). NPP was approximated using the harvest indices and root:shoot ratios of the vegetables, while NEE covered both the C output as represented by heterotrophic respiration from the farms' inter-row due to the absence of plant roots in this cultivation zone and the C input from NPP and chicken manure, and NEP accounted the C export from the vegetable harvested yield. Heterotrophic respiration has an overriding effect over the combined C inputs from NPP and chicken manure, which in turn, contributed primarily to the NEE in farms. The latter and the overall GWP have indicated the vegetable farms as net soil CO_2 source. The theme which covered the first and second objectives, with a corresponding title 'Soil greenhouse gas fluxes from tropical vegetable farms, using forest as a reference', is now accepted for publication in the Nutrient Cycling in Agroecosystems Journal (https://doi.org/10.1007/s10705-022-10222-4).

For our final objective, we evaluated the optimum limits for plant-available N, fertilization rates P and K, vegetable harvested yield, N response efficiency (NRE) and partial factor productivity from applied fertilizer P (PFP_P) and K (PFP_K). We additionally ascertained the farm-gate profit of the studied vegetable farms which has been under long-term intensive fertilization. The optimum plant-available N corresponded to the optimum harvested yield and NRE from cultivating Chinese cabbage, while optimum rates of P and K produced the optimum harvested yield, PFP_P, and PFP_K from cultivating eggplant and chili pepper. Beyond the optimum limits of plant-available N and fertilization rates of P and K, harvested yield did not increase proportionally and additional fertilizer input only disposed monetary losses. Although the highest NRE was attained from the Chinese cabbage, cropping periods for solanaceous vegetables (tomato, sweet pepper, eggplant, and chili pepper) delivered a higher farm-gate profit, which suggested that profit was possibly driven by the vegetables' market value. A higher farm-gate profit was also in agreement with the highest PFP_P and PFP_K from solanaceous vegetables compared with the cabbages, which implied that the increase in profit was dictated by higher harvested yield combined with reduced P and K fertilization inputs. The manuscript of this theme will be submitted for publication to the Journal of the Science of Food and Agriculture.

The findings of this research project showed that vegetable production system on an Andosol soil in Leyte, Philippines, also possibly on other soil types throughout the entire country, is heavily fertilized. This agricultural activity, alongside more intensive management practices will continue to drive deforestation on remaining intact forests, release significant emissions of soil N_2O and CO_2, contribute to water quality contamination, incur monetary losses from fertilizer costs, and lead to serious soil degradation. To offset these drawbacks, there is a need for knowledge support for vegetable farmers on sustainable cultivation practices, which may include promotion of organic matter storage, introduction of fallow periods, and adherence to optimum limits of fertilization rates. The employment of these practices should be incentivized and considered as an integral strategy in the policy-making decisions, and for mitigation approaches in reducing soil GHG fluxes, minimizing expenditures on fertilizer costs, while optimizing farm-gate profit.

ZUSAMMENFASSUNG

Die Gemüseindustrie ist ein entscheidender Sektor in der philippinischen Landwirtschaft, der einen wesentlichen Beitrag zur gesamten landwirtschaftlichen Produktion des Landes sowie zur Gesamtwirtschaft leistet. Die Gemüsebetriebe auf den Philippinen sind in der Regel fragmentierte Kleinbetriebe, angesiedelt in neu gerodeten Wäldern mit sehr fruchtbaren Böden. Die Zunahme von Produktion und Anbaufläche geht einher mit der zunehmenden Umwandlung von Wäldern in Gemüsebetriebe. Zusätzlich zur Entwaldung praktizieren die Landwirte hohe Düngeraten, aufeinanderfolgende Anbauperioden, tiefe Bodenbearbeitung und unregulierte Schädlingsbekämpfung. Trotz verschiedenster intensiver Anbaumethoden bleibt der durchschnittliche Ertrag unter dem Optimum, während hohe Produktionskosten die Gemüsebauern benachteiligen. Darüber hinaus sind die Dynamiken von Treibhausgasflüssen im Boden (THG;N_2O, CH_4 und CO_2), die verschiedene Anbausysteme auf den Philippinen abdecken, noch weitestgehend unbekannt. Bislang wurden weder Feldmessungen der Bodentreibhausgasflüsse im Gemüseanbau noch eine Bewertung der Verhältnisse von Gemüseerträgen und Betriebsgewinn in intensiv gedüngten Gemüsebetrieben durchgeführt.

Dieses Forschungsprojekt zielte darauf ab, (1) die Boden-Treibhausgasdynamik des Sekundärwaldes und in kleinbäuerlichen Gemüsebetriebe zu quantifizieren und zu bewerten, (2) das Treibhausgasbudget der vorherigen Landnutzung abzuschätzen und (3) die optimalen Grenzwerte für pflanzenverfügbare Nährstoffe, die Düngungsraten, die Auswirkungen der Gemüseerträge, sowie den Betriebsgewinn bei langfristiger Intensivdüngung in Gemüsebetrieben zu bewerten.

Um die oben genannten Ziele zu erreichen, führten wir unsere Studie auf einem Andosol in Cabintan, Leyte, Philippinen, durch. Hierfür wurden neun räumlich unabhängige

Waldparzellen (je 64 m²) angelegt, und 10 Gemüsebetriebe (≤ 0,30 ha), welche die typischen Anbaupraktiken in der Region abdecken, untersucht. Die Replikate weisen die gleichen geologischen und klimatischen Bedingungen auf. Die Vegetation des Sekundärwaldes gehört zu der Familie des alten Dipterocarp-Waldes, während die untersuchten Gemüsebetriebe innerhalb der Ackerbauzeiten Kohl und Nachtschatten-Gemüse anbauten. Diese Betriebe brachten hohe Düngemittel- und Pestizidraten aus, führten tiefes Pflügen für die Bodenvorbereitung ein, um Anbauzonen mit Pflanzreihen und Zwischenreihen zu schaffen, und verzichteten für zwei bis drei Vegetationsperioden pro Jahr auf brachliegenden Boden. Das im Untersuchungsgebiet produzierte Gemüse deckte nicht nur den Bedarf in der Provinz Leyte, sondern auch auf den angrenzenden Inseln, einschließlich der nördlichen und südlichen Provinzen.

Um unser erstes Ziel zu erreichen, haben wir die Treibhausgasflüsse und Kontrollvariablen (Mineralischer N (NH_4^+ und NO_3^-), wassergefüllter Porenraum (WFPS), Bodentemperatur) in den untersuchten Gemüsefarmen (aktuelle Landnutzung) gemessen und mit denen im Sekundärwald (Referenzlandnutzung) verglichen. Von Mai 2018 bis Mai 2019 wurden monatliche Messungen der THG-Flüsse im Boden in den oberen 0,05 m mit belüfteten statischen Kammern durchgeführt. Außerdem wurden die Bestände an mineralischem N(NH_4^+, NO_3^-) und gelöstem organischem N in 1-m-Bodentiefe der aktuellen Landnutzung sowie die Veränderung der organischen Kohlenstoff -Vorräte im Boden (SOC), welche sich aus der Umstellung der Landnutzung ergeben, als unterstützende Informationen für die Dynamiken der THG-Flüsse im Boden bestimmt.

Beide Landnutzungen emittierten durchweg N_2O, verbrauchten CH_4 und setzten CO_2 aus dem Boden frei; diese Boden-THG-Flüsse waren in den Gemüsefarmen insgesamt deutlich höher als im Sekundärwald. Der Anstieg der Boden-N_2O-Emissionen aus den landwirtschaftlichen Betrieben spiegelte den Einsatz von Düngemitteln, insbesondere in den Pflanzenreihen, wider, wobei die Verfügbarkeit von mineralischem N als Substrat die N_2O-Emissionen des Bodens stimulierte. Darüber hinaus unterstützte die erhebliche Anreicherung von mineralischem N bis hinunter zu einer Bodentiefe von 1 m die hohen N_2O-Emissionen des Bodens. In Bezug auf die CH_4-Flüsse dämpften die steigenden NO_3^- Werte in der Pflanzenreihe möglicherweise die CH_4-Produktion, wodurch die CH_4-Aufnahme in Gemüsefarmen gefördert wurde, jedoch mit einer geringeren Rate im Vergleich zum Wald. Diese Reduktion wurde auch auf eine erhöhte Bodendichte in den Zwischenreihen zurückgeführt, die die Diffusion von atmosphärischem CH_4 in den Boden während der Regenzeit deutlich hemmte und gleichzeitig die methanotrophe Aktivität reduzierte. Die Boden-CO_2-Emissionen in beiden Landnutzungen wurden hauptsächlich durch den WFPS kontrolliert, während die mikrobielle Zersetzung die Emissionen der Gemüsebetriebe weitgehend beeinflusste.

Für unser zweites Ziel haben wir das THG-Budget unserer untersuchten Gemüsebetriebe geschätzt, indem wir die Nettoprimärproduktion (NPP), den Netto-Ökosystem-C-Austausch (NEE) und die Netto-Ökosystemproduktivität (NEP) in die Berechnung des globalen Erwärmungspotenzials (GWP) einbezogen haben. Die NPP wurde unter Verwendung der Ernteindizes und des Wurzel-Trieb-Verhältnisses des Gemüses angenähert, während die NEE sowohl den C-Ausstoß, der durch die heterotrophe Atmung aus den Zwischenreihen der Betriebe aufgrund des Fehlens von Pflanzenwurzeln in dieser Anbauzone dargestellt wird, als auch den C-Input aus der NPP und dem Hühnermist abdeckte und die NEP verbuchte den C-Export aus dem Gemüseernteertrag. Die heterotrophe Atmung hat einen übergeordneten Effekt gegenüber den kombinierten C-Inputs aus NPP und Hühnermist, die wiederum in erster Linie zum NEE in den landwirtschaftlichen Betrieben beigetragen haben. Letzteres und das Gesamt-GWP deuten darauf hin, dass die Gemüsebetriebe eine Netto-CO_2-Quelle für den Boden sind. Das Thema, das die erste und zweite Zielsetzung abdeckte, mit dem entsprechenden Titel "Treibhausgasflüsse aus tropischen Gemüsebetrieben unter Verwendung von Wäldern als Referenz", wurde jetzt zur Veröffentlichung in der Zeitschrift für Nährstoffkreislauf in Agrarökosystemen angenommen (https://doi.org/10.1007/s10705-022-10222-4).

Für unser letztes Ziel haben wir die optimalen Grenzwerte für pflanzenverfügbares N, Düngeraten P und K, Gemüseertrag, der N-Ertrageeffizienz (NRE) und der partiellen Faktorproduktivität aus ausgebrachtem P (PFP_P) und K (PFP_K) ermittelt. Zusätzlich ermittelten wir den Betriebsgewinn der untersuchten Gemüsebetriebe, die langfristig intensiv gedüngt wurden. Der optimale pflanzenverfügbare N entsprach dem optimalen Ernteertrag und NRE aus dem Anbau von Chinakohl, während optimale Raten von P und K den optimalen Ernteertrag, PFP_P und PFP_K, für den Anbau von Auberginen und Chilischoten erzeugten. Jenseits der optimalen Grenzen des pflanzenverfügbaren N und der Düngergaben von P und K stiegen die Ernteerträge nicht proportional an und zusätzliche Düngergaben führten nur zu monetären Verlusten. Obwohl der höchste NRE aus dem Chinakohl erzielt wurde, lieferten die Anbauperioden für Nachtschattengewächse (Tomaten, Paprika, Auberginen und Chilischoten) einen höheren Betriebsgewinn, was darauf hindeutete, dass der Gewinn möglicherweise vom Marktwert des Gemüses bestimmt wurde. Ein höherer Betriebsgewinn stimmte auch mit dem höchsten PFP_P und PFP_K von Nachtschattengemüse im Vergleich zu den Kohlköpfen überein, was implizierte, dass die Gewinnsteigerung auf einen höheren Ernteertrag in Kombination mit reduzierten P- und K-Düngemitteln zurückzuführen war. Das Manuskript zu diesem Thema wird zur Veröffentlichung bei der Fachzeitschrift der Wissenschaft für Ernährung und Landwirtschaft eingereicht.

Die Ergebnisse dieses Forschungsprojekts haben gezeigt, dass der Gemüseanbau auf einem Andosol-Boden in Leyte, Philippinen, möglicherweise auch auf anderen Bodentypen im ganzen Land, stark gedüngt wird. Diese landwirtschaftlichen Aktivitäten werden zusammen mit intensiveren Bewirtschaftungspraktiken die Entwaldung auf den verbleibenden intakten Wäldern weiter vorantreiben, erhebliche Emissionen von N_2O und CO_2 des Bodens freisetzen, zur Verunreinigung der Wasserqualität beitragen, monetäre Verluste durch Düngemittelkosten verursachen und zu einer ernsthaften Bodendegradation führen. Um diese Nachteile auszugleichen, besteht ein Bedarf die Gemüsebauern über nachhaltige Anbaupraktiken aufzuklären. Dazu können die Erhöhung der Speicherung organischer Stoffe, die Einführung von Brachzeiten und Einhaltung der optimalen Grenzen der Düngemengen gehören. Die Anwendung dieser Praktiken sollte gefördert und als integrale Strategie bei politischen Entscheidungen berücksichtigt werden, um die Treibhausgasflüsse im Boden zu verringern, die Ausgaben für Düngemittel zu minimieren und gleichzeitig den Gewinn des Betriebs zu optimieren.

CHAPTER 1

GENERAL INTRODUCTION

1.1. Tropical vegetable production systems and their associated properties

As an agricultural activity, vegetable production is vital to support the population’s food supply and demand, nutrition, and employment; it is creating an industry that is key in most agriculture-driven economies. In Asia, vegetable production levels increased at an annual average of 3.4% in the 1980s and early 1990s, initially recording 144 million Mg in 1980 to 218 million Mg in 1993 (Ali 2000). Although global production of vegetables is dominated by Asia, its present vegetable production levels remain inadequate for the escalating demand (Congreves and Van Eerd 2015; Johnson et al. 2008a). This can be attributed to insufficient support for factors such as key inputs (agrochemicals, farm machinery, fertilizers, seeds, labor, sustainable agricultural practices, postharvest technology, logistics), including finance and marketing systems, which all together support improved regional production (Johnson et al. 2008a). Despite the supply-demand gap, a pressing year-round production and access are needed, since vegetables are an important component of a nourishing diet due to their health-promoting benefits (Ali and Tsou 1997; Slavin and Lloyd 2012). In addition, its small-scale production employs a considerable farming-dependent populace (de la Peña and Hughes 2007). Tropical Asia's vegetable production of 124 million Mg of fresh vegetables in 2005 delivered an industry value of US$ 29 billion, and 90% of this was represented by the combined production from India (66%), Thailand (2%), the Philippines (3.5%), Indonesia (11%), and Vietnam (7.5%) (Johnson et al. 2008a). Tomato, cabbage, onion, peppers, and eggplant are considered the most economically important vegetables, whereby most of the productivity occurs in the East where the climate is temperate and sub-temperate, while the least yield happens in Southeast Asia where the climate is hot and humid (Brown et al. 2005). While the variations in production are a reflection of the differences in seasons and regions, the limited soil moisture and high temperature in the tropics are the major causes of low yields (de la Peña and Hughes 2007). Superseding these limitations is the evident consumption of major fertilizers in South and East Asia, i.e., 65.6% of global use for urea (increasing at 3.4% yr^{-1}) and 59.5% of P as di-ammonium phosphate (increasing at 0.3% yr^{-1}), to 49.1% and 40.4% of ammonia and potash, respectively (Johnson et al. 2008a).

Vegetable farms are one of the land uses established following the conversion of intact forests by a migrating population from the lowlands to the highlands and started as subsistence farms (i.e., agricultural products raised mainly to cover only the needs of farming households and surpluses are kept for future consumption) (Ruthenberg 1971). Small-scale subsistence cropping on fragmented and small land size farms on pristine forest soils requires minimal nutrient, moisture, and overall maintenance, and is commonly integrated with multipurpose livestock – typical smallholder farming system in Asian agriculture (Dawe et al. 2019; Devendra and Thomas 2002; Ruthenberg 1971). As the soil experience nutrient depletion, shifts of cultivated areas and priority for high-value crops such as vegetables are widely practiced subsequently instigating more deforestation, abandonment of previously tilled parcels, and ultimately soil degradation (Devendra and Thomas 2002). The shift from subsistence farming to vegetable production is commonly associated with the commercialization of agricultural systems which increases the economic orientation of farm production (Pingali 1997).

Vegetable production systems are generally small-scale ventures and intensively managed. Because commercially important vegetables, mostly in hybrid varieties, have generally high soil nutrient and water requirements, and farms are often on nutrient-exhausted soils, smallholder farmers apply excessive fertilization to reach the vegetables' maximum potential yield (Roy et al. 2016; Vlek et al. 1997). Production expansion in farms, despite the small-sized area, is achieved through intensification of other cultivation practices, such as frequent soil tillage (Pandey et al. 2010), increased irrigation (Aryal et al. 2020; Devendra and Thomas 2002), heavy pest control application (Moeskops et al. 2010; Schreinemachers et al. 2015), and multiple cropping phases within a year and increased cropping intensity (Waha et al. 2020). As these intensive management practices become long-term, vegetable production systems subsequently reduce soil properties' quality, serve as substantial source of soil GHG emissions, and promote nutrient leaching.

1.2. Environmental impacts of intensive vegetable production systems

Deforestation of intact forests in place for intensive agricultural land uses seriously alters soil properties and functions with negative effects that are enduring and extensive (Veldkamp et al. 2020). Forest conversion to croplands resulted in a 26% loss of soil C stock (top 0.3 m) of most Andosol soils in Japan even after > 85 years of deforestation (Koga et al. 2020). However, the increases in soil organic C (SOC) and N stocks, including exchangeable base cations (Ca, K, Mg), and micronutrients (Cu, Mn, Zn), in the top 1-m depth of the same soil type and elapsed time of deforestation are ascribed to intensive agricultural management to horticultural crops and may display strong resilience of the soil from disturbance (Anda and Dahlgren 2020). In contrast, C storage stability is low in the Andosol soils of Ecuador following the conversion of forests to agronomic land use, indicating fast turnover and loss of C in volcanic soils (Paul et al. 2008). This instability is also reflected in the Andosol soils of Leyte, Philippines, whereby SOC and N stocks in the top 0.5 m decreased by 61% and 40%, respectively, in intensively cultivated vegetable farms relative to the secondary forest (Quiñones et al. 2022). The soil microbial community, as well as soil enzyme activities such as dehydrogenase, β-glucosidase, and β-glucosaminidase which are influenced by C from soil organic matter, are also depressed by small-scale conventional vegetable farming (Moeskops et al. 2010; Moeskops et al. 2012). As C has a direct influence on dynamic soil properties, its loss following the conversion of forest to croplands can be exacerbated by intensive crop production practices and ultimately cause serious soil degradation, impair soil functions, and overall soil productivity (Veldkamp et al. 2020).

Agricultural soils under intensive vegetable production systems contribute to deleterious environmental impacts, such as soil greenhouse gas (GHG; N_2O, CH_4, CO_2) emissions and nutrient leaching (Quiñones et al. 2022; Rezaei Rashti et al. 2015). N_2O is a potent greenhouse gas with a thermal absorption capacity 265 times higher than CO_2 (100-year time horizon) and the most important substance causing stratospheric ozone depletion (Ravishankara et al. 2009). Its production from the soil is mainly regulated by the rates of N_2O-producing processes microbial nitrification and denitrification, which in turn largely dictated by soil factors mineral N availability and favorable soil moisture conditions (influenced by climate variables temperature and precipitation) (Davidson et al. 2000). N fertilization rate, which proportionally influences the above-mentioned processes, is the main regulator and predictor of N_2O emissions from agricultural soils, including those under vegetable cultivation (Rezaei Rashti et al. 2015; Shcherbak et al. 2014). The percentage of applied N fertilizer transformed to fertilizer-derived emissions or the emission factor (EF) of vegetable fields is close to the default 1% for soils receiving mineral N fertilizers (IPCC Guidelines for National Greenhouse Gas Inventories 2006). Given the high mineral N fertilization in vegetable fields, the total N_2O emission from global vegetable production is approximately 9.5×10^7 kg N_2O-N yr^{-1}, accounting for 9.0% of the total N_2O emissions from mineral fertilizers (~ 0.94% EF) and 24.4% of the global N_2O emissions from agricultural land (Rezaei Rashti et al. 2015). As N fertilization application rates exceed beyond crop requirements, as in the case of vegetable production systems, the N_2O emissions are foreseen to advance from exponential increases (Shcherbak et al. 2014). Since the application of manure in vegetable fields has been an integral practice, N_2O emissions can further be exacerbated if taking thoroughly into account 2–2.5% emissions contributed from manure N (Davidson 2009; IPCC Guidelines for National Greenhouse Gas Inventories 2006).

The balance between C input through plant production and C output by decomposition results in the organic C storage in soils. In agricultural soils, the rate of C loss often exceeds C accumulation ascribing 50% of the organic C stock reduction to cultivation (Schlesinger 1986). The increase in temperature, which is a characteristic of climate change, even worsened the loss of C stocks as CO_2 emissions due to hastened organic matter decomposition (Davidson 2022). Recent estimate of the global rate of CO_2 emissions from agricultural activities is 3.5 Pg C yr^{-1} (Crippa et al. 2021). Several farming practices are promoted to increase the net C sequestration in agricultural soils to reduce CO_2 emissions and mitigate climate change. However, even with the best cultivation practices (e.g., cover cropping, biochar application, manure + synthetic fertilizer combination), these can only serve marginal net C sequestration (Schlesinger 2022). Therefore, agricultural soils such as under intensive vegetable production systems remain as C loss hotspots.

Vegetable farms established in tropical soils which experienced frequent deep tillage are sources and sinks of atmospheric CH_4 (Mosier et al. 2004). CH_4 is a potent gas with a global warming potential (GWP) 28 higher than CO_2 (100-year time horizon) (Smith 2017). The microbial processes involved in the production of soil CH_4 and uptake of atmospheric CH_4 are methanogenesis and methanotrophy, respectively. The dominance of these processes is dictated by oxygen availability or soil aeration and is directly influenced by soil properties porosity, moisture content, including C and N availability, and by cultivation management and land-use change (Nazaries et al. 2013). Methanotrophic activity holds in well-aerated soils wherein methanotrophs have access to atmospheric CH_4 as the source of C and energy, whereas methanogenesis prevails in strictly anaerobic soils whereby methanogens of the domain Archaea predominate in the advance fermentation of organic matter (Le Mer and Roger 2001; Nazaries et al. 2013). The practices of deep soil plowing, frequent cultivation and irrigation, and other farm activities during intensive vegetable cropping periods that all together introduce soil compaction or reduced soil porosity, have limited the diffusion of atmospheric CH_4 into an Andosol soil (Quiñones et al. 2022). Considering the overuse of N fertilizer, it can on one hand offset the above limitation as increased NO_3^- levels dampen methanogenic activity (Quiñones et al. 2022; Veldkamp et al. 2020), while on the other hand, excessive N input to the soil is tied to the N_2O-producing processes and nutrient losses such as NO_3^- leaching (Endo et al. 2013; Jahangir et al. 2012).

The serious occurrence of NO_3^- leaching in highly fertilized Andosol soils is invigorated under high rainfall conditions and poses a serious concern for NO_3^- pollution to groundwater. Large applications of animal waste compost pellets are found to significantly increase the NO_3^- content in deeper layers of a humic Andosol in Japan and thus, the underground contamination during rainy days (Yan et al. 2002). Conditions of high rainfall intensity also weakened the NO_3^- retention in Andosol soils in Mexico, stimulated NO_3^- mobility below the effective rooting depth, and led to high NO_3^- concentration down to ~ 1-m soil depth (Prado et al. 2011). Moreover, umbric Andosol subjected to vegetable cultivation holds extremely high NO_3^- levels in the soil pore water resulting from heavy rainfall (Endo et al. 2013). In sum, intensively managed vegetable cropping systems are substantial sources of soil GHGs and conducive environments for considerable NO_3^- leaching losses.

1.3. Intensive vegetable production systems in the Philippines

The Philippines' agriculture sector is a vital component of the country's economy, contributing ~ 10% (2015–2020) to its gross domestic product and employing ~ 32% of the economically active population (Dikitanan et al. 2017; Philippine Statistics Authority 2020a). The vegetable industry is one of the dynamic sub-sectors which contribute ~ 30% to its total agricultural output and advances at a rate of 2.8% per year (Briones 2009; Johnson et al. 2008b). Approximately 6% of the total agricultural area (i.e., 800000 ha) was cultivated for vegetable crops generating the production of 6638 ± 85 million Mg yr^{-1} between 2015 and 2019 (FAOSTAT 2021). Eggplant, tomato, and cabbage are among the economically important vegetables corresponding to the highest volume and value of production (Philippine Statistics Authority 2020b). The overall increase in vegetable production and area has been closely linked to increases in deforested areas and overall fertilizer utilization; on average 220 ha yr^{-1} of forests are converted to smallholder vegetable farms (Johnson et al. 2008b). About 20% of the country's mineral fertilizer use is allocated for vegetable production systems, wherein N fertilizers such as urea and ammonium sulfate are utilized the highest, followed by P fertilizers such as diammonium phosphate and ammonium phosphate, and the least by potash fertilizer (Briones 2014, 2016). Compared with other Southeast Asian countries, vegetable production in the Philippines is not lagging but it has promising potential in increasing yields through sufficient technical and financial supports, management know-how for improved and sustainable farm practices, and the addition of new technologies (Johnson et al. 2008b). An increase in production is expected in the coming years, in parallel with the growing national population, to meet consumer demand, secure food sufficiency and nutrition, and employment.

Smallholder agriculture, which covers various crop production systems including vegetable farming, is practiced by most of the five million farmers in the Philippines (Dikitanan et al. 2017). This fraction of the population, distributed across the country and immersed in this agriculture-based employment, experiences high poverty rates, low labor productivity, and depressed daily pay (Briones 2017). Vegetable farming, providing small-scale employment, initially started from agricultural activities for subsistence and is common where fertile soils, like Andosol soils, or nutrient-exhausted soils are. Despite small-scale areas, vegetable production systems are characterized by intensive management practices that include excessive fertilizer and pesticide inputs, frequent cultivation and irrigation, deep soil tillage, and absence for fallow periods and crop rotation practices (Librero and Rola 2000). Aside from greatly increasing production costs, such unsustainable practices did not guarantee the highest yields but instead offset optimum farmer's profit and contribute to detrimental environmental impacts.

According to official reports, the Philippines' agriculture is contributing ~ 30% of the country's total GHG emissions (UNFCCC 1999, 2014). However, the Philippine GHG inventories can overall display large uncertainties and likely underestimated its GHG emissions and sinks, since the accounting relies on estimations using Tier 1 default values specified by the IPCC, alongside insufficient field-based quantification of GHG, and data gaps or inconsistencies (Kawanishi et al. 2019; Kawanishi et al. 2020; Ogle et al. 2013). Lack of personnel and technical capability are also important factors (Kawanishi et al. 2019; Kawanishi et al. 2020). Moreover, agriculture sector GHG inventories mainly account for emissions from rice cultivation and failed to cover other intensively managed agroecosystems that occupy the entire country which are likely sources of soil GHG. For instance, vegetable production systems receive high fertilizer inputs but patterns of soil GHG from this land use have not been quantified and possibly not integrated into the inventory. Nutrient leaching, (i.e., N and P) from this agroecosystem under humid tropical conditions (i.e., high annual precipitation) is also believed to be high but field-based quantifications are not yet been undertaken. Leached NO_3^- is an indirect source of soil N_2O emissions and causes serious contamination of groundwater (Endo et al. 2013; Tubiello et al. 2013). The latter consequence holds following excessive P fertilizer inputs (Abdala et al. 2012). Besides these, nutrient losses also incur strain on the working capital for vegetable production.

The capital for production, a key constraint to smallholder farmers and mostly obtained from loans, is mainly allotted for fertilizers (Cramb et al. 1999; Eder 2006; Laborte et al. 2009). Fertilizer quantities beyond the crop's requirement only instill unnecessary expenses and do not essentially deliver the production more than the vegetables' maximum potential yield. In addition, over-expenditure on other farming inputs such as agricultural chemicals for pests, diseases, and weeds control also caused needless stress to the capital (Schreinemachers et al. 2015). Over the course of many years of intensive cultivation practices, the fertilizer and pesticide procurement are not cost-effective, subsequently undermining the farmer's optimum yield and so profit. Therefore, the identification of optimum fertilization rates that correspond to the optimum crop yield in excessively fertilized vegetable farms, can offer realistic and feasible solutions that can minimize damaging environmental impacts and augment farmers' yield and profit. The optimum fertilization limits will also serve as initial efforts in promoting sustainable vegetable production systems (Tei et al. 2020).

1.4. Objectives and hypotheses

In the Philippines, pieces of field-based information are deficient about the impacts of intensive crop production systems on the soil GHG budget, optimum fertilization rates that produce optimum yield, and farmer's farm-gate profit. These areas were addressed in this research project, particularly in overly fertilized vegetable farms on an Andosol soil in Leyte, Philippines.

Intensively managed vegetable production systems, are significant source of soil GHGs (Rezaei Rashti et al. 2015; Tei et al. 2020). The first objective of this research was to assess the soil N_2O, CO_2, and CH_4 fluxes, and soil-controlling variables (soil mineral N, water-filled pore space (WFPS), soil temperature) covering a year of cropping periods in smallholder vegetable farms and compared these with that in the secondary forest. The second objective was to estimate the soil greenhouse gas budget of an excessively fertilized vegetable production system. We hypothesized that relative to the forest, vegetable farms will have increased soil N_2O emissions ascribed to immoderate N availability, larger soil CO_2 efflux attributed to C availability, and frequent soil tillage, while reduced soil CH_4 uptake due to soil compaction. The large inputs for synthetic N fertilizers and chicken manure during multiple cropping periods and farm activities contributing to reduce soil porosity will, all together, contribute to a substantial GWP of smallholder vegetable farms.

Excessively fertilized vegetable production systems also contribute to nutrient leaching losses and can only be shifted as environmentally sustainable if an overall balance of fertilization inputs and crop nutrient requirements are achieved (Rezaei Rashti et al. 2015; Tei et al. 2020). In this regard, the third objective was to identify the optimum limits for plant-available nutrients and fertilization rates, the corresponding yield response of the limits, and the cost-benefit relationship in typical smallholder vegetable productions. In doing so, nutrient and monetary losses from cropping periods may be minimized and farmer’s profit will be significantly improved. It is hypothesized that the identified optimum levels for plant-available nutrients and fertilization rates will produce the optimum vegetable harvested yield. Moreover, the farmer’s costs of production will be dictated by the choice of vegetable type, the vegetable’s farm-gate price (Laborte et al. 2009), and by fertilizer cost (Cramb et al. 1999), whereas farmer’s profit can improve significantly by adhering to optimum fertilization rates.

1.5. Description of the study site

1.5.1. Location, climate, and soil properties

This research project was performed in Cabintan (600–900 m above sea level and 11° 03–06' N, 124° 42–45' E), an administrative area of Ormoc City, Leyte, Philippines, and consisted of land uses secondary forest and small-scale vegetable farms (Fig. 1.1a,b). Cabintan covers a total area of 4100 ha: 88% is classified as forests while 12% of the area is categorized disposable for other utilities such as agriculture and residential zone (Fig. 1.2a,b; Department of Environment and Natural Resources 1981). The entire study site is characterized as inland valley on a volcanic landscape, where the remaining forests are located in steep slopes of surrounding hills and a large part of lands between hills including moderately deep gullies are mostly occupied by vegetable farms (Fig. 1.1b). Tree vegetation in the forest is composed of tree families under the Dipterocarpceae and considered endemic in the Philippines (Margraf and Milan 1996; Schneider et al. 2014). Although a serious disturbance by Super typhoon Haiyan occurred in 2013, the forest has regenerated during our study in 2018 until 2019 and thus, referred as secondary forest (Fig. 1.2a). Vegetable farms were either owned by different farmers or leased by other farmers. These land uses had the same climate and soil type (Fig. 1.2b).

Leyte Island illustrates a tropical rainforest climate and humid tropical monsoon type (Köppen climate classification). Under a local classification, the climate is characterized by less distinct dry season and pronounced maximum rainfall, particularly from December to February (modified Coronas climate classification). In prior years, the mean annual precipitation was 3000 ± 390 mm and mean annual temperature was 28 ± 0.2 °C (2014 – 2017; data gathered from the provincial weather bureau of the Department of Science and

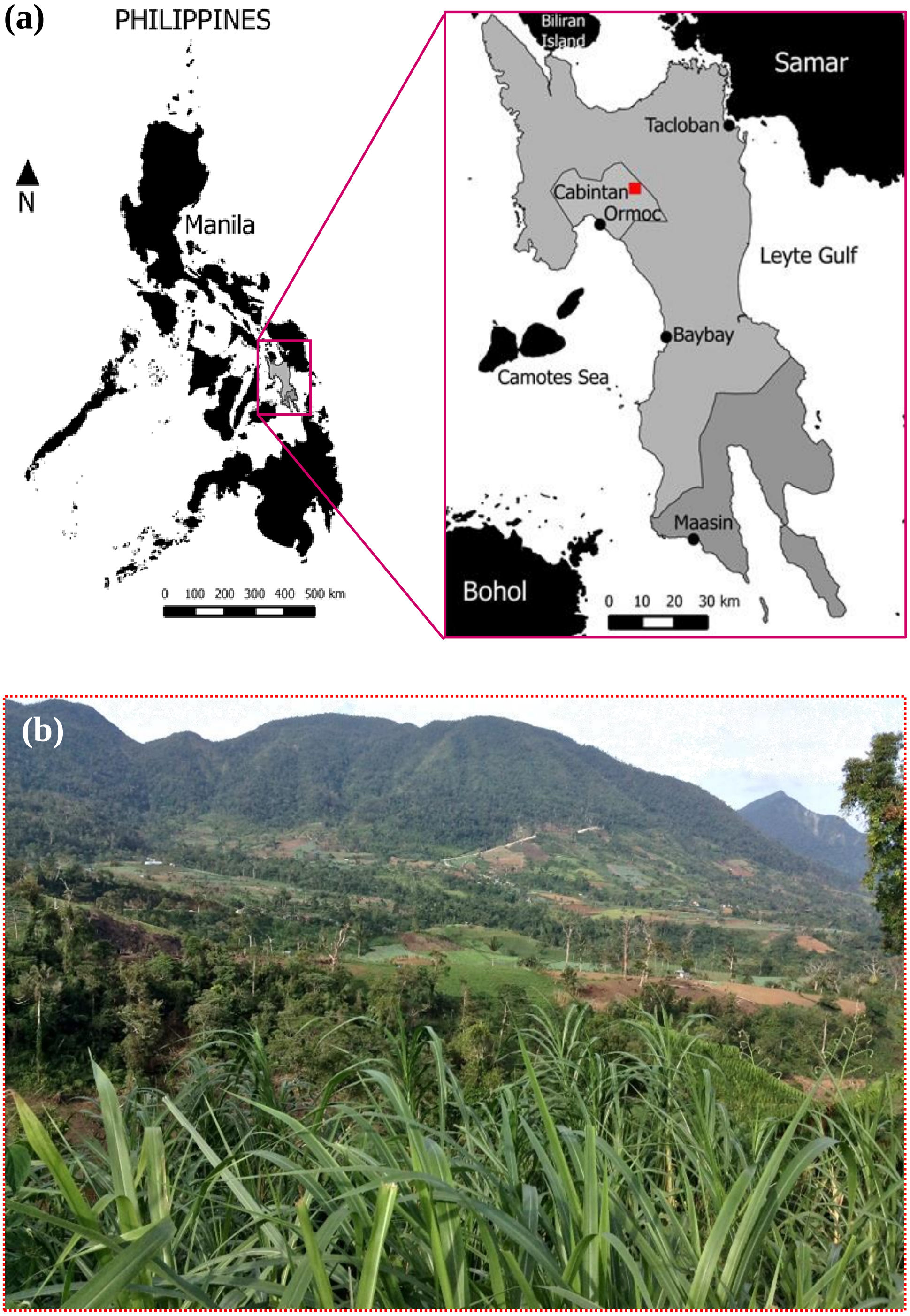

Fig. 1.1 Research area location (a) and its dominant land uses composed of forest and small-scale vegetable farms (b)

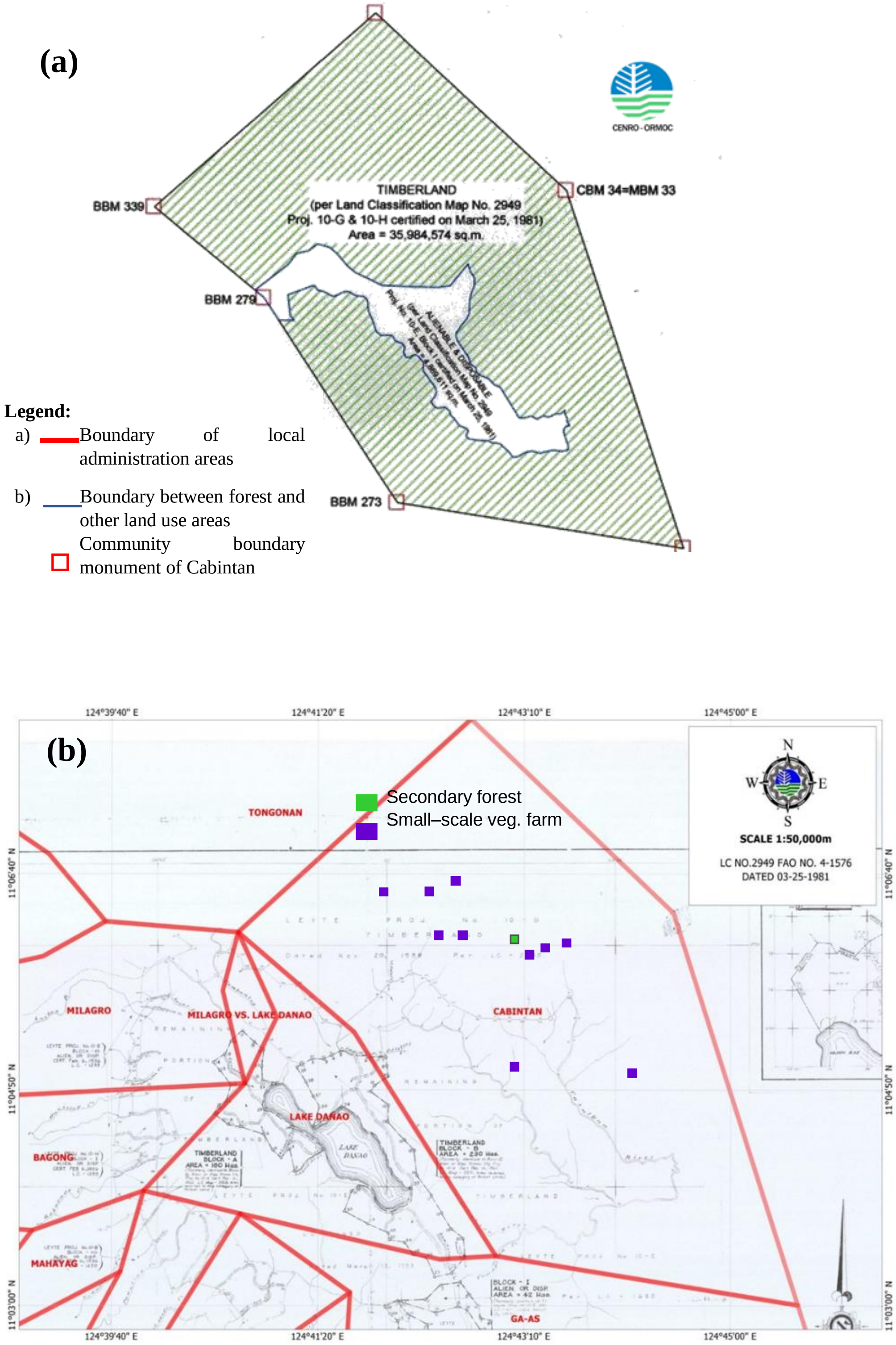

Fig. 1.2 Land classification of Cabintan, Ormoc, Leyte, Philippines (a) and the studied land uses (b: red lines indicate local administration area (Department of Environment and Natural Resources 1981); nine forest plots in elevated location and 10 replicates of vegetable farms)

Technology–Philippine Atmospheric, Geophysical and Astronomical Services Administration (DOST–PAG ASA); 130 km away from the study area). During our sampling in 2018 and 2019, the study area experienced lesser rain than indicated above. In particular, the average annual rainfall was 2730 mm (230 ± 40 mm month^{-1}), wherein the highest amounts between 360 mm and 485 mm were in December to February (Fig. 1.3). The low rainfall measurements, between 110 mm and 130 mm in March to May, indeed fell during the warm months of the year. However, rainfall prior to the wet season, particularly in August towards October, was on par with that of the dry season. The annual air temperature ranged between 25 and 32° C (2018–2019; weather records obtained from DOST PAG-ASA – Tacloban City and from the automatic weather station of City Agriculture Office, Ormoc City; established in 2014 and 20 km away from the study area).

The volcanic soil developed from extrusive igneous rocks andesite-basalt during the late quaternary period (20,000–30,000 years before present), and has udic and isohyperthermic as soil moisture and temperature regimes, respectively (Asio et al. 1998; Jahn and Asio 1998). Composite soil samples from the secondary forest and vegetable farms were collected down to 1-m in five depth intervals (0–0.1, 0.1–0.3, 0.3–0.5, and 0.5–1.0 m) for comparison of physico-biochemical properties and nutrient stocks (see Chapter 2); these all together decreased in vegetable farms, relative with the secondary forest (Quiñones et al. 2022). The soil’s good aggregation and capacity to hold moisture and the mild upland climate, overall, supported successful vegetable production in the study area.

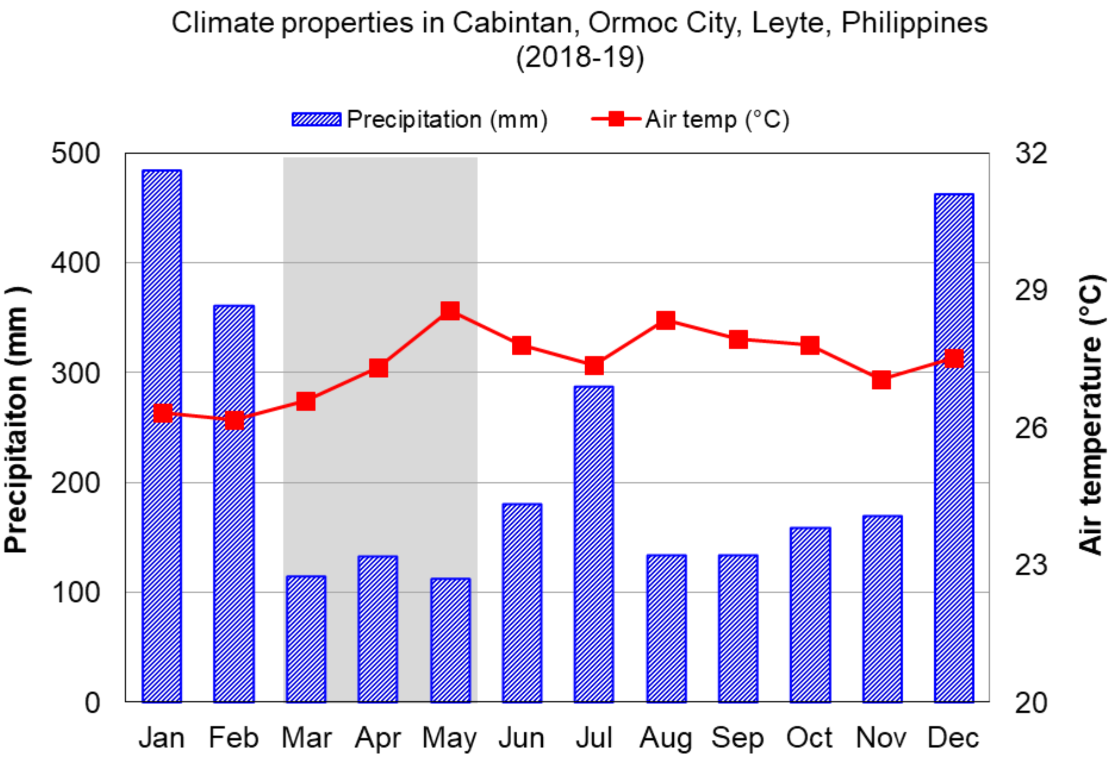

Fig. 1.3 Mean monthly precipitation and air temperature of the study area during the sampling period

1.5.2. Brief land-use history and experimental design

Clearing of forests and farming activities in the 1960s were instigated by a migrating populace from the lowlands in search for agricultural lands (Pulhin et al. 2006). A relatively small community mainly cultivated corn and root crops for subsistence and started planting coconut trees to augment long-term income. More forests were cleared for agricultural expansion in the 1980s, accompanied by a growing farming community which planted more subsistence crops, while abandoning previously cultivated areas. Cultivation of seasonal vegetable crops begun in the 2000s and farmers learned to grow more high-value crops which were more marketable than subsistence crops (Szinicz et al. 2005). Thereafter, smallholder production for vegetables became the dominant agricultural activity, while farming for subsistence crops persisted but regarded secondary. More than

90% of the community relied mainly to small-scale vegetable production as a form of economic employment and thus, intensive cultivation practices in parallel with clearing of accessible forest areas are evident in the study area (Quiñones et al. 2022). The land-use history details of the area are described in Supplementary Table 2.1.

For our study, nine plots in the secondary forest were established as reference land use and 10 smallholder farms were randomly selected as the present land use; these land uses were all on the same soil type and climate (Fig. 1.2b). We identified the tree vegetation of the forest plots (64 m^2 $plot^{-1}$) and found that the most abundant tree species belong to families Myristicaceae, Apocynaceae, Fagaceae, and Myrtaceae (Chapter 2, Table 2.1). These are common in dipterocarp old growth forest of Leyte (Margraf and Milan 1996). Presently, this natural vegetation covers only 2% of the island and endures in more confined steeper slopes of the Leyte Cordillera (Schneider et al. 2014). The trees in our forest plots, however, were regenerations following the disturbance brought by the super typhoon Haiyan five years before this study; the diameter at breast height of most trees was <10 cm. During the study period, there were no agricultural activities close to the forest plots. Before final selection of the replicate vegetable farms, we conducted an ocular survey and farmer interviews, to capture information such as the farm attributes, fertilization and crop protection practices, and knowledge of previous land use. The replicate farms were representative, in terms of the area’s vegetable production management practices and in space (1.5–2 km distance between farms) of the entire research area (~ 10 km road distance between boundaries). Our measurement of the variables covered the farms’ cultivation zones, namely the plant-row where vegetables are planted, left to grow and mature, and the plant-row which provided access for farm activities such as weeding, fertilizer and pest control applications, harvesting, and installation for crop support like trellis.

1.5.3. Vegetable cultivation practices and capital for production

Vegetable farms were the dominant land use following several shifts of agricultural activity in the last 50 years (Supplementary Table 2.1). Farmers perform two to three cropping periods in a year and apply variable fertilization rates using mineral fertilizers in combination with partly decomposed chicken manure. Prior to each cropping period, farms were cleared from weeds using several applications of Glyphosate-containing herbicide and thereafter, cultivated using animal-drawn plow with 0.6 m depth to establish the cultivation zones. Vegetables frequently raised were either cabbages (*Brassica* sp) or solanaceous vegetables (tomato, eggplant, pepper), while spring onion and squash were also considered during unbraced cropping periods. Application of mineral fertilizers was from weekly to bi-weekly subsequent to the type of vegetables, while chicken manure was applied twice during the cropping period. Pest control involved a mixture of agricultural chemicals containing highly (Methomyl), moderately (Cypermethrin, Cartap hydrochloride, Difeconazole) to least (Chlorothalonil) hazardous active ingredients. Its application was customarily dictated on the initial occurrence or degree of pest damage and a day before each harvest. Products for crop protection were first introduced by Bayer and Monsanto, and later followed by related local companies. Fertilizer and pest control application rates were largely based on farmer’s experience and thus, in most cases dispensed beyond crop requirement. Overall, the smallholder vegetable farms were intensively managed (Table 2.1). The vegetable production in Cabintan was distributed to the entire province and adjacent islands, including areas in the north and southern provinces of the country.

In most smallholder farming systems in the Philippines including the study area, working capital is a key constraint (Cramb et al. 1999; Eder 2006; Laborte et al. 2009).

The capital is spent for procuring key farm inputs particularly fertilizers and hiring labor for cultivation activities. Farmers mostly obtain their capital through credits or loans from private lending individuals or institutions and pay these plus the interest rates at the end of the cropping season (Laborte et al. 2009), while others seek off-farm employment to secure the necessary capital to increase farm production (Eder 2006). Despite the relatively large interest from loans, farmers continue to utilize this scheme with crop harvest as security (Cramb et al. 1999). Since farm profit was dependent on the quantity of marketed harvested yield, farmers aim for high vegetable yield and protect the yield from pest damage by excessive fertilizer and pest control applications. However, expenditures for these beyond necessary and high loan payments as an integral pattern during cropping periods continue to beset farmer’s optimum profit.

1.6. References

Abdala DB, Ghosh AK, Da Silva IR et al (2012) Phosphorus saturation of a tropical soil and related P leaching caused by poultry litter addition. Agric Ecosyst Environ 162:15–23. doi: 10.1016/j.agee.2012.08.004

Ali M (2000) Dynamics of vegetables in Asia: A synthesis. In: Ali M (ed) Dynamics of vegetable production, distribution and consumption in Asia. AVRDC, Shanhua, Taiwan, pp 1-29

Ali M, Tsou SC (1997) Combating micronutrient deficiencies through vegetables—a neglected food frontier in Asia. Food Policy 22(1):17–38. doi: 10.1016/S0306-9192(96)00029-2

Anda M, Dahlgren RA (2020) Long-term response of tropical Andisol properties to conversion from rainforest to agriculture. Catena 194:104679. doi: 10.1016/j.catena.2020.104679

Aryal JP, Sapkota TB, Khurana R et al (2020) Climate change and agriculture in South Asia: Adaptation options in smallholder production systems. Environ Dev Sustain 22(6):5045–5075. doi: 10.1007/s10668-019-00414-4

Asio VB, Jahn R, Stahr K, Margraf J (1998) Soils of the tropical forests of Leyte, Philippines II: Impact of differrent land uses on status of organic matter and nutrient availability. In: Schulte A, Ruhiyat D (eds) Soils of tropical forest ecosystems. Springer Verlag, Berlin, pp 37-44

Briones RM (2009) Agricultural diversification and the fruits and vegetables subsector: Policy issues and development constraints in the Philippines. Philippine Institute for Development Studies, Discussion Paper Series No. 2009-02:1–31

Briones RM (2014) The role of mineral fertilizers in transforming Philippine agriculture. Philippine Institute for Development Studies, Discussion Paper Series No. 2014-14:1–24

Briones RM (2016) The fertilizer industry and Philippine agriculture: Policies, problems, and priorities. Philippine Journal of Development 43:29–49

Briones RM (2017) Characterization of agricultural workers in the Philippines. Philippine Institute for Development Studies, Policy Notes No. 2017-26:1–8

Brown P, Lumpkin T, Barber S et al (2005) Global horticulture assessment. Interantional Society of Horticultural Science, pp 1-135

Congreves KA, Van Eerd LL (2015) Nitrogen cycling and management in intensive horticultural systems. Nutr Cycl Agroecosyst 102(3):299–318. doi: 10.1007/s10705-015-9704-7

Cramb RA, Garcia JNM, Gerrits RV, Saguiguit GC (1999) Smallholder adoption of soil conservation technologies: evidence from upland projects in the Philippines. Land

Degrad Dev 10(5):405–423. doi: 10.1002/(SICI)1099-145X(199909/10)10:5<405:AID-LDR334>3.0.CO;2-J

Crippa M, Solazzo E, Guizzardi D et al (2021) Food systems are responsible for a third of global anthropogenic GHG emissions. Nat Food 2(3):198–209. doi: 10.1038/s43016-021-00225-9

Davidson EA (2009) The contribution of manure and fertilizer nitrogen to atmospheric nitrous oxide since 1860. Nature Geosci 2(9):659–662. doi: 10.1038/ngeo608

Davidson EA (2022) Is the transactional carbon credit tail wagging the virtuous soil organic matter dog? Biogeochemistry 161(1):1–8. doi: 10.1007/s10533-022-00969-x

Davidson EA, Keller M, Erickson, Heather E et al (2000) Testing a conceptual model of Soil emissions of nitrous and nitric oxides. BioScience 50(8):667. doi: 10.1641/0006-3568(2000)050[0667:TACMOS]2.0.CO;2

Dawe D, Lamkowsky M, Ahuja V, Turner C (2019) Farming systems in Southeast Asia. In: Encyclopedia of Food Security and Sustainability 3:107–113. doi: 10.1016/B978-0-08-100596-5.22166-5

de la Peña R, Hughes J (2007) Improving vegetable productivity in a variable and changing climate. International Crops Research Institute for the Semi-Arid Tropics 4, pp 1–22

Department of Environment and Natural Resources (1981) Land Classification No. 2949 Forestry Administrative Order No. 4-1576. Tacloban City, Leyte, Philippines

Devendra C, Thomas D (2002) Smallholder farming systems in Asia. Agric Syst 71(1-2):17–25. doi: 10.1016/S0308-521X(01)00033-6

Dikitanan R, Grosjean G, Nowak A, Leyte J (2017) Climate-resilient agriculture in the Philippines. CSA Country Profiles for Asia Series. International Center for Tropical Agriculture (CIAT); Department of Agriculture -Adaptation and Mitigation Initiatives in Agriculture, Government of the Philippines. Manila, Philippines, pp 1-24

Eder JF (2006) Land use and economic change in the post-frontier upland Philippines. Land Degrad Dev 17(2):149–158. doi: 10.1002/ldr.721

Endo A, Mishima S-I, Kohyama K (2013) Nitrate percolation and discharge in cropped Andosols and Gray lowland soils of Japan. Nutr Cycl Agroecosyst 95(1):1–21. doi: 10.1007/s10705-012-9544-7

FAOSTAT (2021) FAOSTAT Online. Food and Agriculture Organization of the United Nations. Rome, Italy

IPCC Guidelines for National Greenhouse Gas Inventories (2006) Chapter 11: N_2O emissions from managed soils, and CO_2 emissions from lime and urea application. doi: 10.1093/owc/9780198814269.003.0012

Jahangir M, Khalil MI, Johnston P et al (2012) Denitrification potential in subsoils: A mechanism to reduce nitrate leaching to groundwater. Agric Ecosyst Environ 147:13–23. doi: 10.1016/j.agee.2011.04.015

Jahn R, Asio VB (1998) Soils of the tropical forests of Leyte, Philippines I: Weathering, soil charcateristics, classification and site qualities. In: Schulte A, Ruhiyat D (eds) Soils of tropical forest ecosystems. Springer Verlag, Berlin, pp 29-36

Johnson GI, Weinberger K, Wu MH (2008a) The vegetable industry in tropical Asia: An overview of production and trade, with a focus on Thailand, Indonesia, the Philippines, Vietnam, and India. AVRDC Exploration Series No. 1, pp 1-56

Johnson GI, Weinberger K, Wu MH (2008b) The vegetable industry in tropical Asia: The Philippines. AVRDC Exploration Series No. 1, pp 1-84

Kawanishi M, Kato M, Matsuda E, Fujikura R (2019) Comparative Study of Reporting for Transparency under International Agreements on Climate Change and Ozone Protection: The Case of the Philippines. IJESD 10(1):1–8. doi: 10.18178/ijesd.2019.10.1.1137

Kawanishi M, Kato M, Matsuda E et al (2020) Comparative study on institutional designs and performance of national greenhouse gas inventories: The cases of Vietnam and the Philippines. Environ Dev Sustain 22(6):5947–5964. doi: 10.1007/s10668-019-00460-y

Koga N, Shimoda S, Shirato Y et al (2020) Assessing changes in soil carbon stocks after land use conversion from forest land to agricultural land in Japan. Geoderma 377:114487. doi: 10.1016/j.geoderma.2020.114487

Laborte AG, Schipper RA, Van Ittersum MK et al (2009) Farmers' welfare, food production and the environment: a model-based assessment of the effects of new technologies in the northern Philippines. NJAS: Wageningen Journal of Life Sciences 56(4):345–373. doi: 10.1016/S1573-5214(09)80004-3

Le Mer J, Roger P (2001) Production, oxidation, emission and consumption of methane by soils: A review. Eur J Soil Biol 37(1):25–50. doi: 10.1016/S1164-5563(01)01067-6

Librero AR, Rola AC (2000) Philippines. In: Ali M (ed) Dynamics of vegetable production, distribution and consumption in Asia. AVRDC Publication No. 00-498. Shanhua, Tainan, pp 303–347

Margraf J, Milan PP (1996) Ecology of dipterocarp forests and its relevance for island rehabilitation in Leyte, Philippines. In: Schulte A, Schöne D (eds) Dipterocarp forest ecosystems: towards sustainable management. World Scientific Singapore, pp 124-154

Moeskops B, Buchan D, Sukristiyonubowo et al (2012) Soil quality indicators for intensive vegetable production systems in Java, Indonesia. Ecol Indic 18:218–226. doi: 10.1016/j.ecolind.2011.11.011

Moeskops B, Sukristiyonubowo, Buchan D et al (2010) Soil microbial communities and activities under intensive organic and conventional vegetable farming in West Java, Indonesia. Appl Soil Ecol 45(2):112–120. doi: 10.1016/j.apsoil.2010.03.005

Mosier A, Wassmann R, Verchot L et al (2004) Methane and nitrogen oxide fluxes in tropical agricultural soils: Sources, sinks and mechanisms. Environ Dev Sustain 6:11–49. doi: 10.1007/978-94-017-3604-6_2

Nazaries L, Murrell JC, Millard P, Baggs L, Singh BK (2013) Methane, microbes and models: Fundamental understanding of the soil methane cycle for future predictions. Environ Microbiol 15(9):2395–2417. doi: 10.1111/1462-2920.12149

Ogle SM, Buendia L, Butterbach-Bahl K et al (2013) Advancing national greenhouse gas inventories for agriculture in developing countries: improving activity data, emission factors and software technology. Environ Res Lett 8(1):15030. doi: 10.1088/1748-9326/8/1/015030

Pandey CB, Chaudhari SK, Dagar JC et al (2010) Soil N mineralization and microbial biomass carbon affected by different tillage levels in a hot humid tropic. Soil Tillage Res 110(1):33–41. doi: 10.1016/j.still.2010.06.007

Paul S, Veldkamp E, Flessa H (2008) Soil organic carbon in density fractions of tropical soils under forest – pasture – secondary forest land use changes. Eur J Soil Science 59(2):359–371. doi: 10.1111/j.1365-2389.2007.01010.x

Philippine Statistics Authority (2020a) Agricultural Indicators System (Economic Growth: Agriculture). Republic of the Philippines, ISSN-2012-0435

Philippine Statistics Authority (2020b) Selected Statistics on Agriculture. Republic of the Philippines, ISSN-2012-0362

Pingali PL (1997) From subsistence to commercial production systems: the transformation of asian agriculture. Am Journal Agric Econ 79(2):628–634. doi: 10.2307/1244162

Prado B, Duwig C, Etchevers J et al (2011) Nitrate fate in a Mexican Andosol: Is it affected by preferential flow? Agric Water Manag 98(9):1441–1450. doi: 10.1016/j.agwat.2011.04.013

Pulhin JM, Chokkalingam U, Peras RJJ et al (2006) Historical Overview. In: Chokkalingam U, Carandang AP, Pulhin JM et al (eds) One century of forest rehabilitation in the Philippines: Approaches, outcomes, and lessons

Quiñones CMO, Veldkamp E, Lina SB et al (2022) Soil greenhouse gas fluxes from tropical vegetable farms, using forest as a reference. Nutr Cycl Agroecosyst 124(1):59–79. doi: 10.1007/s10705-022-10222-4

Ravishankara AR, Daniel JS, Portmann RW (2009) Nitrous oxide (N_2O): The dominant ozone-depleting substance emitted in the 21st century. Science 326(5949):123–125. doi: 10.1126/science.1176985

Rezaei Rashti M, Wang W, Moody P et al (2015) Fertiliser-induced nitrous oxide emissions from vegetable production in the world and the regulating factors: A review. Atmos Environ 112:225–233. doi: 10.1016/j.atmosenv.2015.04.036

Roy ED, Richards PD, Martinelli LA et al (2016) The phosphorus cost of agricultural intensification in the tropics. Nature plants 2(5):16043. doi: 10.1038/nplants.2016.43

Ruthenberg H (1971) Farming systems in the tropics. Clarendon Press, Oxford

Schlesinger WH (1986) Changes in soil carbon storage and associated properties with disturbance and recovery. In: Trabalka JR, Reichle DE (eds) The changing carbon cycle: A global analysis. Springer, New York, pp 194-220

Schlesinger WH (2022) Biogeochemical constraints on climate change mitigation through regenerative farming. Biogeochemistry 161(1):9–17. doi: 10.1007/s10533-022-00942-8

Schneider T, Ashton MS, Montagnini F, Milan PP (2014) Growth performance of sixty tree species in smallholder reforestation trials on Leyte, Philippines. New Forests 45(1):83–96. doi: 10.1007/s11056-013-9393-5

Schreinemachers P, Balasubramaniam S, Boopathi NM et al. (2015) Farmers' perceptions and management of plant viruses in vegetables and legumes in tropical and subtropical Asia. Crop Prot 75:115–123. doi: 10.1016/j.cropro.2015.05.012

Shcherbak I, Millar N, Robertson GP (2014) Global metaanalysis of the nonlinear response of soil nitrous oxide (N_2O) emissions to fertilizer nitrogen. Proceedings of the National Academy of Sciences of the United States of America 111(25):9199–9204. doi: 10.1073/pnas.1322434111

Slavin JL, Lloyd B (2012) Health benefits of fruits and vegetables. Adv Nutr 3(4):506–516. doi: 10.3945/an.112.002154

Smith KA (2017) Changing views of nitrous oxide emissions from agricultural soil: Key controlling processes and assessment at different spatial scales. Eur J Soil Sci 68(2):137–155. doi: 10.1111/ejss.12409

Szinicz G, Martin K, Sauerborn J (2005) Abundance of selected insect species in natural and agricultural habitats of a tropical upland (Leyte, Philippines). Agric Ecosys Environ 111(1-4):104–110. doi: 10.1016/j.agee.2005.05.008

Tei F, De Neve S, de Haan J, Kristensen HL (2020) Nitrogen management of vegetable crops. Agric Water Manag 240:106316. doi: 10.1016/j.agwat.2020.106316

Tubiello FN, Salvatore M, Rossi S et al (2013) The FAOSTAT database of greenhouse gas emissions from agriculture. Environ Res Lett 8(1):15009. doi: 10.1088/1748-9326/8/1/015009

UNFCCC (1999) The Philippines' initial national communication on climate change. https://unfccc.int/documents/139218. Accessed 10 November 2021

UNFCCC (2014) Second national communication to the United Nations Framework Convention on Climate Change: Philippines. https://unfccc.int/documents/139241. Accessed 10 November 2021

Veldkamp E, Schmidt M, Powers JS, Corre MD (2020) Deforestation and reforestation impacts on soils in the tropics. Nat Rev Earth Environ 1(11):590–605. doi: 10.1038/s43017-020-0091-5

Vlek PLG, Kühne. R. F., Denich M (1997) Nutrient resources for crop production in the tropics. Phil Trans R Soc Land B 352:975–985. doi: 10.1098/rstb.1997.0076

Waha K, Dietrich JP, Portmann FT et al (2020) Multiple cropping systems of the world and the potential for increasing cropping intensity. Glob Environ Change 64:102131. doi: 10.1016/j.gloenvcha.2020.102131

Yan W, Yamamoto K, Yakushido K (2002) Changes in nitrate N content in different soil layers after the application of livestock waste compost pellets in a sweet corn field. Soil Sci Plant Nutr 48(2):165–170. doi: 10.1080/00380768.2002.10409187

CHAPTER 2

SOIL GREENHOUSE GAS FLUXES FROM TROPICAL VEGETABLE FARMS, USING FOREST AS A REFERENCE

A revised version of this chapter is published in the Journal *Nutrient Cycling in Agroecosystems* (DOI https://doi.org/10.1007/s10705-022-10222-4)

Cecille Marie O. Quiñones[1]*, Edzo Veldkamp[1], Suzette B. Lina[2], Marlito Jose M. Bande[3], Arwin O. Arribado[4], Marife D. Corre[1]

[1] Soil Science of Tropical and Subtropical Ecosystems, Faculty of Forest Sciences and Forest

Ecology, University of Goettingen, Buesgenweg 2, 37077 Goettingen, Germany

[2] Department of Soil Science, College of Agriculture and Food Science, Visayas State University Main Campus, Baybay City, 6521 Leyte, Philippines

[3] College of Forestry and Environmental Science, Visayas State University Main Campus, Baybay City, 6521 Leyte, Philippines

[4] College of Agricultural and Environmental Sciences, Visayas State University Alangalang Campus, Alangalang, 6517 Leyte, Philippines

2.1. Abstract

Field-based quantification of soil greenhouse gas emissions from the Philippines' agriculture sector is missing for vegetable production systems, despite its substantial contribution to agricultural production. We quantified soil N_2O emission, CH_4 uptake, and CO_2 efflux in vegetable farms and compared these to the secondary forest. Measurements were conducted for 13 months in 10 smallholder farms and nine forest plots on Andosol soil in Leyte, Philippines using static chambers. Soil N_2O and CO_2 emissions were higher, whereas CH_4 uptake was lower in the vegetable farms than in the forest. Vegetable farms had annual fluxes of 12.7 ± 2.6 kg N_2O-N ha^{-1} yr^{-1}, –1.1 ± 0.2 kg CH_4-C ha^{-1} yr^{-1}, and 11.7 ± 0.7 Mg CO_2-C ha^{-1} yr^{-1}, whereas the forest had 0.10 ± 0.02 kg N_2O-N ha ha^{-1} yr^{-1}, –2.0 ± 0.2 kg CH_4-C ha^{-1} yr^{-1}, and 8.2 ± 0.7 Mg CO_2-C ha^{-1} yr^{-1}. Long-term high N fertilization rates in vegetable farms resulted in large soil mineral N levels, dominated by NO_3^- in the topsoil and down to 1-m depth, leading to high soil N_2O emissions. Increased soil bulk density in the vegetable farms probably increased anaerobic microsites during the wet season and reduced CH_4 diffusion from the atmosphere into the soil, resulting in decreased soil CH_4 uptake. High soil CO_2 emissions from the vegetable farms suggest decomposition of labile organic matter, possibly facilitated by plowing and large N fertilization rates. The global warming potential of these vegetable farms was 31 ± 2.7 Mg CO_2-eq ha^{-1} yr^{-1} (100-year time frame).

Keywords: *Andosol soil, greenhouse gas budget, Philippine agriculture, soil N_2O, CH_4, and CO_2 fluxes, soil nutrient stocks, soil organic carbon*

2.2. Introduction

Globally, agriculture contributes 78% of anthropogenic nitrous oxide (N_2O) emissions, 39% of methane (CH_4) emissions (Jia et al. 2019), and land-use change accounts 14% of anthropogenic carbon dioxide (CO_2) emissions (Friedlingstein et al. 2019). Aside from being potent greenhouse gases (GHG), N_2O and CH_4 are also the most important ozone-depleting substances in the stratosphere (Ravishankara et al. 2009; Wuebbles and Hayhoe 2002). Although productive agricultural soils can be a sink of atmospheric CO_2, continued harvest export combined with reduced biomass input and decomposition of available organic matter often turn croplands into a net CO_2 source with low soil organic carbon (SOC) stocks (Sauerbeck 2001).

Since the 1950's, forest conversion has been substantial in the Philippines, driven by upland migration, agricultural expansion, and pressure from a growing population (Carandang et al. 2013; Kummer 1992). One of the economically important commodity crops of these converted lands is vegetable production, comprising 6% of the total agricultural area (supplied $6.6 \pm 0.1 \times 10^6$ Mg yr^{-1} vegetables in 2015–2019) and > 30% of the total agricultural production in the Philippines (Briones 2009; FAOSTAT 2021). Vegetable production is commonly associated with intensive management practices, including multiple cropping periods in a year, large mineral fertilizer inputs, pesticide applications, frequent cultivation and irrigation, and has been estimated to contribute 9% of the global N_2O emissions from nitrogen (N) fertilizers (Librero and Rola 2000; Rezaei Rashti et al. 2015). Long-term high N fertilization mainly drives large N_2O emissions from tropical agricultural systems, as N fertilization increases soil ammonium (NH_4^+) and nitrate (NO_3^-) which are substrates of nitrification and denitrification – the main microbial-mediated processes producing N_2O in the soil (Mosier et al. 2004; Veldkamp et al. 1998). As depicted by the hole-in-the-pipe (HIP) model, the two main soil regulating factors of soil N_2O emissions are N availability and water content (Davidson et al. 2000), which are both favorable in intensively managed vegetable production systems. Moreover, land-use conversion can affect soil CH_4 fluxes due to changes in soil bulk density, water content, and management practices including N fertilization and liming (Bodelier and Laanbroek 2004; Veldkamp et al. 2008; Veldkamp et al. 2013). Losses of SOC from forest conversion to agriculture can reach as much as 58–66% (Beheshti et al. 2012; Powers et al. 2011; Veldkamp et al. 2020) and are attributed to direct C losses from land use conversion (biomass and organic matter burning; Achard et al. 2014), decrease in C input combined with harvest export (e.g., Meijide et al. 2020), and continued decomposition even decades after conversion due to regular cultivation, microclimate modification, and other changes in soil properties that influence SOC stabilization (e.g., van Straaten et al. 2015; Veldkamp et al. 2020).

The Philippines' agriculture sector is claimed to be a significant source of GHG, contributing ~ 30% of the country's total emissions (UNFCCC 1999, 2014). However, this GHG accounting was largely based on indirect data. Field-based quantification of soil GHG fluxes remains sparse at present and is particularly missing for vegetable production systems, despite its ~ 20% consumption of the country's mineral fertilizer use (Briones 2014, 2016). Thus, there is a knowledge gap in the Philippine GHG inventories with large uncertainties, attributed to the lack of reliable GHG estimates and deficient field-based measurements (Kawanishi et al. 2019; Kawanishi et al. 2020; Ogle et al. 2013). Information on soil N_2O, CH_4, and CO_2 fluxes from agriculture, including the economically important vegetable production systems in the country, will provide a basis for mitigation measures and policy implementation in addressing climate change.

Our present study aimed to 1) assess the differences in soil GHG fluxes between secondary forest and vegetable farms on an Andosol soil in Leyte, Philippines, and 2) generate a GHG budget for a typical smallholder vegetable production system. Field-based measurements of soil N_2O, CH_4, and CO_2 fluxes were carried out for a year in these two adjacent land uses. We hypothesized that compared to the secondary forest, smallholder vegetable farms will have increased soil CO_2 efflux as a consequence of regular soil tillage under multiple cropping periods (Sauerbeck 2001), substantial N_2O emissions due to large N fertilizer inputs (Rezaei Rashti et al. 2015), and reduced CH_4 uptake in the soil as a result of soil compaction (Mosier et al. 2004). Our field-based quantification of soil GHG budget contributed in filling the knowledge gap for improving the GHG accounting of the Philippines' agriculture sector.

2.3. Materials and methods

2.3.1. Site description

This study was conducted in Cabintan, Ormoc, Leyte, Philippines (Fig. A2.1). This area is characterized by a volcanic landscape (600–900 m above sea level and 11° 03–06' N, 124° 42–45' E), and comprises about 4100 ha wherein 3600 ha are categorized as forest and 500 ha are utilized for agriculture and other uses (Department of Environment and Natural Resources 1981). The vegetable production in Cabintan had started in the early 2000s and is the most recent agricultural activity which was preceded by cycles of shifting cultivation (i.e., between periods of cultivation, the area is fallowed allowing re-growing of secondary forest). The general land-use history of Cabintan for the last 60 years is given in the Table A2.1. The mild upland climate and favorable physical properties of the volcanic soil, coupled with the use of fertilizers and pesticides, permit continuous vegetable production in this area possible.

The area had a mean annual precipitation of 3000 ± 390 mm (± SE of the mean) and temperature of 28 ± 0.2 °C (2014–2017 data from Tacloban City weather station of the Department of Science and Technology Philippine Atmospheric, Geophysical and Astronomical Services Administration (DOST PAG-ASA), Leyte, Philippines). During our study year (2018–2019), annual rainfall was 2730 mm with monthly rainfall ranging from 360 to 485 mm from December to February, between 110 and 130 mm during March to May, and an average of 180 mm in the remaining months, which allowed vegetable cropping two to three times a year. Average monthly air temperature ranged between 23 °C and 32 °C (2018–2019 data from weather stations at the City Agriculture Office, Ormoc City and DOST PAG-ASA, Tacloban City).

Soils in the study area have developed from intermediate volcanoclastics (55% SiO_2) of trachytic basalt-andesite rocks from late quaternary period (Asio et al. 1998; Jahn and Asio 1998). The soils are characterized by inherently low soil bulk density, low pH, high P adsorption capacity, and dominance of amorphous allophane and imogolite minerals (Asio et al. 1998; Jahn and Asio 1998; Navarrete et al. 2008), and classified as Typic Hapludand (USDA soil classification) or Umbric Andosol (FAO soil classification).

2.3.2. Experimental design and farm management practices

We selected nine plots in the secondary forest, representing the original land use before conversion, and 10 farms presently engaged in vegetable production each owned by a smallholder farmer, all located on the same soil type and climate. Forest plots were at least 600 m away from the vegetable farms. These plots were 64 m^2 each, with a distance between plots of at least 25 m, and were spatially independent in terms of soil GHG flux measurements, based on statistical test using the von Neumann's ratio test (Bartels 1982). The forest plots, therefore, can be considered as replicates in the succeeding statistical analysis of the repeatedly measured variables during the study period. Within each forest plot, we counted the number of individuals of all tree species present and reported the top eight species with the highest number of individuals in each plot (Table 2.1). These tree species are endemic in the Philippines and classified under the families of an old dipterocarp forest in Leyte Island (Margraf and Milan 1996; Schneider et al. 2014). There were no slash and burn activities near our forest plots during our study. The forest is described as secondary growth since it recovered from serious disturbance caused by the super typhoon Haiyan in 2013 (wind speed exceeding 220 km per hour; Cinco et al. 2016), which was considered the strongest cyclone in the Western North Pacific (Mori et al. 2014; Takagi et al. 2017).

We randomly selected 10 smallholder vegetable farms based on field survey (e.g., distance to the forest site, comparability of land-use independent soil property (see below)) and farmers' interviews. Farm-scale information included farm size, vegetables grown, yield, fertilization rates and sources, crop protection practices, and previous land use. Our studied farms had an area allocated for vegetables of ≤ 0.30 ha with 1.5–2 km distance between farms. Farmers practiced two to three cropping periods in a year with typically varied fertilization rates (Table 2.1), depending on the vegetables grown, and applied in combinations of synthetic fertilizers and chicken manure (containing 288 ± 10 g C kg^{-1}, 51 ± 3 g N kg^{-1}, 30 ± 2 g P kg^{-1}, 15 ± 1 g Mg kg^{-1}, 54 ± 5 g Ca kg^{-1}, 56 ± 2 g K kg^{-1}). Occasionally, some farmers also applied lime ($CaCO_3$) but they could not give the exact rate. The synthetic fertilizers commonly utilized were urea (46% N), muriate of potash (50% K), ammonium phosphate (16% N–9% P), ammonium sulfate (21% N), diammonium phosphate (18% N–20% P), and complete formula (14% N–6% P–12% K).

Table 2.1

Site characteristics of the secondary forest (reference, n = 9 plots) and small-scale vegetable farms (n = 10 farms), all located on an Andosol soil in Leyte, Philippines

Land use	Tree families present	Dominant tree species (local names and in parentheses are scientific names) [a]
Secondary forest	Myristicaceae, Apocynaceae Fagaceae, Myrtaceae Euphorbiaceae, Dilleniaceae Guttiferae, Melastomaceae	Duguan (*M. philippensis* Lamk.), Lanete (*W. pubescens* R. Br.), Ulayan (*L. ovalis* (Blanco) Rehd.), Maka-asim (*S. nitidum* Benth.), Balante (*M. caudatifolia* Elm.), Katmon *(D. philippinensis* Rolfe), Bitanghol (*C. blancoi* Pl. and Tr.), *Melastoma* sp.

Small-scale vegetable farm [b]	Crops (common names and in parentheses are scientific names)	Cropping period	Harvested yield (kg dry biomass ha^{-1})	N fertilization rate (kg N ha^{-1} cropping period^{-1})	
				Synthetic fertilizer	Chicken manure
Farm 1	Chinese cabbage (*B. rapa* subsp. *pekinensis*)	first	1010	210	125
	Cabbage (*B. oleracea* var. *capitata*)	second	544	475	125
	Chinese cabbage (*B. rapa* subsp. *pekinensis*)	third	40	230	125
Farm 2	Chinese cabbage (*B. rapa* subsp. *pekinensis*)	first	1078	155	175
	Chinese cabbage (*B. rapa* subsp. *pekinensis*)	second	414	50	170
	Chinese cabbage (*B. rapa* subsp. *pekinensis*)	third	1311	110	150

Table 2.1 continuation…

Small-scale vegetable farm [b]	Crops (common names and in parentheses are scientific names)	Cropping period	Harvested yield (kg dry biomass ha^{-1})	N fertilization rate (kg N ha^{-1} cropping period^{-1})	
				Synthetic fertilizer	Chicken manure
Farm 3	Tomato (*S. lycopersicum* L.)	first	479	370	200
	Cabbage (*B. oleracea* var. *capitata*)	second	857	100	300
Farm 4	Tomato (*S. lycopersicum* L.)	first	82	140	140
	Cabbage (*B. oleracea* var. *capitata*)	second	44	200	155
	Cabbage (*B. oleracea* var. *capitata*)	third	452	85	130
Farm 5	Tomato (*S. lycopersicum* L.)	first	420	85	240
	Squash (*Cucurbita* sp.)	second	312	125	110
	Sweet pepper (*C. annuum* L.)	third	792	150	180
Farm 6	Sweet pepper (*C. annuum* L.)	first	486	125	85
	Tomato (*S. lycopersicum* L.)	second	153	170	140
Farm 7	Spring onion (*A. fistulosum* L.)	first	593	280	0
	Spring onion (*A. fistulosum* L.)	second	382	360	245
	Chinese cabbage (*B. rapa* subsp. *pekinensis*)	third	816	170	350

Table 2.1 continuation…

Small-scale vegetable farm [b]	Crops (common names and in parentheses are scientific names)	Cropping period	Harvested yield (kg dry biomass ha^{-1})	N fertilization rate (kg N ha^{-1} cropping period^{-1})	
				Synthetic fertilizer	Chicken manure
Farm 8	Tomato (*S. lycopersicum* L.)	first	138	150	245
	Eggplant (*S. melongena* L.)	second	846	285	540
Farm 9	Chinese cabbage (*B. rapa* subsp. *pekinensis*)	first	168	75	70
	Eggplant (*S. melongena* L.)	second	1254	145	115
Farm 10	Chinese cabbage (*B. rapa* subsp. *pekinensis*)	first	786	140	225
	Chinese cabbage (*B. rapa* subsp. *pekinensis*)	second	45	260	170
	Chili pepper (*Capsicum* sp.)	third	1292	70	80

[a] These tree species are the most dominant in terms of the number of individuals present in the forest plots

[b] These farms have commonly varied fertilization regimes in accordance to the cultivated vegetables and reflected the common management practices of farmers in the study area

Cultivation practices employed in all farms during the cropping periods depict distinct zones, namely plant rows (~ 70% areal coverage), where crops were planted and received fertilizers, and inter-rows (~ 30% areal coverage), where access for rendering manual management activities occurred. These cultivation zones were established using an animal-drawn (*Bubalus bubalis carabenesis*) plow to a depth of ~ 0.6 m. Vegetables can vary from leafy, mainly of the Brassicaceae family, to fruit-bearing types, which included tomato, eggplant, pepper, and squash (Table 2.1). Fertilization frequency of synthetic fertilizers ranged from weekly to biweekly, depending on the grown vegetable, whereas air-dried chicken manure was applied in once to twice instances during the early stage of the cropping period. Fertilizers were applied directly to the soil close to the crop base (~ 0.1 m away) during the wet season or first dissolved in water for application during low rainfall months. Crop protection practices included insecticide, molluscicide, and fungicide that range from highly hazardous (Methomyl in Scorpio 40 SP^{TM}, Lannate 40 SP^{TM}, Check Mate 40 SP®), moderately hazardous (Cypermethrin in Magnum®, Metaldehyde in Stop®, Cartap hydrochloride in Contract 50 SP®, Difenoconazole in Montana®) to least hazardous (Chlorothalonil in Rover®) (based on LD_{50} test; World Health Organization 2010). A mixture of at least two to three of these pesticides was frequently practiced, and their use was largely based on the extent of pest incidence during cropping and a day before each harvest. As to weed control, the farmers applied broad-spectrum herbicides (Glyphosate IPA in Tekweed 480 SL®, Sharp Shooter 480 SL®, Mower 48 SL®) as a cheaper alternative to manual weeding. The vegetable farms were intensively managed (Table 2.1), and the produced vegetables were marketed not only in Leyte Island but also to adjacent islands, including the country’s capital in the north and cities in the southern provinces.

2.3.3. Soil physical and biochemical properties

In an area adjacent to each farm or forest plot, we dug a pit (1 m × 1 m × 1 m) to measure soil bulk density (core method; Blake and Hartge 1986) at depth intervals of 0–0.1, 0.1–0.3, 0.3–0.5, and 0.5–1.0 m. Within each forest plot or farm, we collected soil samples once in 2018 at the same depth intervals. The collection was done on five sampling points within each plot for each depth using an auger; the five soil samples were composited, totaling to 76 samples (4 depths × (9 forest plots + 10 farms)). Soils were air-dried and sieved using 2-mm mesh. These soil samples were determined for texture at the Visayas State University, Leyte, Philippines, using hydrometer method (ISRIC 2002) after pre-treatments for removal of organic matter and with 1 mol L^{-1} NaOH to increase particle dispersion. Soil samples were transported by air to the laboratory of Soil Science of Tropical and Subtropical Ecosystems (SSTSE), University of Goettingen, Germany for biochemical analysis. Soil pH (1:2.5 ratio of soil to distilled H_2O) was measured potentiometrically. Effective cation exchange capacity (ECEC) was determined by percolating with unbuffered 1 mol L^{-1} NH_4Cl solution and the percolates were analyzed for exchangeable cations (Mg, Ca, K, Na, Al, Fe, Mn) using an inductively coupled plasma-atomic emission spectrometer (ICP-AES; iCAP 6300 Duo VIEW ICP Spectrometer, Thermo Fischer Scientific GmbH, Dreieich, Germany). Base and Al saturations were calculated as the mole charge ratio of exchangeable bases (Mg, Ca, K, Na) and Al on ECEC, respectively. SOC and total N were analyzed from finely ground soil samples using a CN analyzer (Elementar Vario EL; Elementar Analysis Systems GmbH, Hanau, Germany).

To check for comparability of the initial soil conditions between the reference forest and the vegetable farms, we used a land-use independent soil variable – the soil texture in the 0.5–1.0 m depth – as used by other studies (e.g., Allen et al. 2016; de Blécourt et al. 2013; Tchiofo Lontsi et al. 2019; van Straaten et al. 2015; Veldkamp 1994). The forest plots and vegetable farms had similar ($P = 0.76$) soil texture (forest, mean ± SE: 10 ± 1% clay, 72 ± 3% sand, 18 ± 2% silt; farms: 10 ± 3% clay, 64 ± 3% sand, 26 ± 3% silt). To evaluate the changes in element stocks attributable to land-use change, we used equal soil mass between the land uses by taking the soil bulk density of the secondary forest (as the original land use) and used this in the conversion of element concentrations from soil mass basis to area basis for each depth interval down to one meter (de Blécourt et al. 2013; van Straaten et al. 2015; Veldkamp 1994). We present the element stocks in the top 0.5 m as the sum of the three depth intervals (0–0.1, 0.1–0.3, and 0.3–0.5 m) and for the other soil properties as depth-weighted averages.

2.3.4. Soil greenhouse gas flux measurement and soil controlling variables

Soil N_2O, CH_4, and CO_2 fluxes were measured from May 2018 to May 2019 at monthly interval (13 measurement periods) on each replicate plot, employing the vented static chamber method (e.g., Tchiofo Lontsi et al. 2020). A chamber base (made of a polyvinyl chloride pipe with 0.04 m^2 area, 0.05 m height, and inserted into the soil to ~ 0.02 m) was installed permanently in each of the nine forest plots. For the 10 vegetable farms, each had a total of eight chamber bases with four chambers installed on the plant rows and another four on the inter-rows. On each measurement day, a polyethylene chamber hood (equipped with a Luer lock sampling port) was placed on the chamber base, totaling the chamber head space volume to 8.4 L. Gas samples were taken using a syringe at 2, 12, 22, and 32 minutes following chamber closure. A 22-mL gas sample was collected at each time interval and stored in pre-evacuated 12-mL glass vials (Exetainer; Labco Limited, Lampeter, United Kingdom); these exetainers have been tested to be leak-proof, as shown by their maintained overpressure and no change in concentrations of stored standard gases (e.g., Hassler et al. 2015; Iddris et al. 2020). The gas samples were transported by air to the laboratory of SSTSE, Goettingen University, Germany and were analyzed for N_2O, CH_4 and CO_2 concentrations using a gas chromatograph (GC; SRI 8610C, SRI Instruments Europe GmbH, Bad Honnef, Germany) equipped with an electron capture detector (^{63}Ni, ECD; for N_2O with a make-up gas of 5% CO_2–95% N_2), a flame ionization detector (for CH_4 and CO_2 with a methanizer), and an autosampler. These three gases were analyzed from the same gas sample. We regarded the linear increase of CO_2 concentration with chamber closure time as our reference for quality check of the other GHG concentrations. All chamber measurements showed significant linear increases in CO_2 concentrations during the 32-minute chamber closure ($R^2 = 0.99$), justifying that all N_2O and CH_4 fluxes must all be included in our data analysis. Soil gas fluxes from each chamber were calculated based on the linear increase (CO_2, N_2O) or decrease (CH_4) with chamber closure, corrected with the in-situ measured air pressure and temperature (as elaborated in our earlier studies; e.g., Hassler et al. 2015; Iddris et al. 2020; Koehler et al. 2009a; Koehler et al. 2009b; Tchiofo Lontsi et al. 2020). Annual N_2O, CH_4, and CO_2 fluxes from each chamber were calculated using the trapezoidal rule by interpolating the measured fluxes between monthly intervals during the study period from May 2018 to May 2019. The annual soil GHG fluxes from the vegetable farms were further weighted by the areal coverages of the two distinctive cultivation zones (70% for plant rows and 30% for inter-rows).

To assess if we missed possible high N_2O fluxes immediately after fertilization, we established a supplementary study covering two seasons whereby we conducted intensive measurements following N fertilizer applications. For this follow-on investigation, we selected four from the 10 farms, and in each farm we delineated 20-m^2 plot; each plot received a specific N fertilization rate (equivalent to 75, 180, 230, and 480 kg N ha^{-1} yr^{-1}, based on our farmers' practices; Table 2.1), which was split into eight weekly applications, similar to farmers' practice. In each plot, we installed three chambers on the plant rows and three chambers on the inter-rows. We measured soil GHG fluxes a day after each weekly fertilizer application for two months. In summary, we found that the soil GHG fluxes from weekly measurements (data not reported) did not differ from the monthly measurements ($P = 0.15$; based on statistical analysis described below) indicating that we have captured the pulse of N_2O fluxes after fertilization.

Concurrent with each measurement of soil GHG fluxes, we also determined soil variables (i.e., mineral N, water-filled pore space (WFPS), and soil temperature) in the top 0.05 m. In each forest plot on each measurement day, we took five soil samples at ~ 1 m away from the chamber and mixed into one composite sample. In each vegetable farm on each measurement day, we collected four soil samples at ~ 0.5 m from each of the four chambers deployed on the plant rows or inter-rows, and subsequently mixed into one composite sample for each cultivation zone. A portion of the composite soil was oven-dried (105°C) for one day for gravimetric moisture determination; this was expressed as WFPS using the measured soil bulk density and a particle density of 2.65 g cm^{-3}. In-situ extraction of soil NH_4^+ and NO_3^- was conducted by bringing to the field prepared polyethylene bottles filled with 150 mL 0.5 mol L^{-1} K_2SO_4 into which subsample of the composite soil from each forest plot or cultivation zone of each vegetable farm was added. Extraction continued upon arrival at the field station by shaking the extraction bottles for an hour and filtering the extracts, which were then immediately frozen. Soil extracts were kept frozen and transported by air to the laboratory of SSTE, Goettingen University, Germany, where analysis was conducted. Mineral N concentrations were determined using continuous flow injection colorimetry (SEAL Analytical AA3, SEAL Analytical GmbH, Norderstedt, Germany).

We also quantified the soil extractable NH_4^+, $NO_3^–$, and organic N within 1-m depth at four depth intervals (0–0.1, 0.1–0.3, 0.3–0.5, and 0.5–1.0 m) once in the dry season and another in the wet season of 2019 for additional evidence to explain the large N_2O emissions from these farms. In each vegetable farm, we took five soil samples for each depth interval and composited for each depth. These soil samples underwent the same in-situ extraction procedure as described above. We report the stocks of extractable N separately for the top 0.5 m and 0.5–1.0 m soil depths.

We calculated the overall soil GHG footprint of smallholder vegetable production at our study area in the following:

$$\text{GWP} = (\text{NEP}) + (\text{soil } N_2O \times 298) + (\text{soil } CH_4 \times 25) \qquad (\textit{Eq. 1})$$

For each replicate farm, GWP is the global warming potential (Mg CO_2-eq $ha^{–1}$ $yr^{–1}$). NEP is net ecosystem productivity (Mg C $ha^{–1}$ $yr^{–1}$) = net ecosystem C exchange (NEE) + C exported by harvested yield. NEE (Mg C $ha^{–1}$ $yr^{–1}$) = heterotrophic respiration – [net primary production (NPP; above- and belowground NPP) + chicken manure] (Malhi et al. 1999). Aboveground NPP was derived from our actual measurements of harvested yields (Table 2.1) and the vegetables' harvest indices (HI = harvestable yield ÷ (herbage + harvestable yield)); Table A2.2). We expressed the yields in dry mass using the moisture contents of the harvested vegetables (Table 2.1), determined by drying samples at 70 ºC for at least three days or until stable weights were attained. Belowground NPP was calculated based on the root:shoot ratios of these vegetables (Table A2.2). The NPP and the C exported by the harvested yield were converted to biomass-C based on C content analysis of each vegetable (measured as described above). Heterotrophic respiration was represented by the inter-rows as this cultivation zone did not have plant roots. For the final GWP calculation, NEP was multiplied by 3.67 to convert C to CO_2. Soil N_2O (Mg N_2O ha^{-1} yr^{-1}) and CH_4 fluxes (Mg CH_4 ha^{-1} yr^{-1}) were converted to 100-yr CO_2 equivalent by multiplying with 298 for N_2O and 25 for CH_4 (IPCC Guidelines for National Greenhouse Gas Inventories 2006). Our GWP calculation was limited only during the crop production of our study period and to the farm level, while excluding other GHG sources (e.g., fertilizer manufacturing and transport to the field).

2.3.5. Statistical analysis

We first tested the soil GHG fluxes and soil variables measured in the top 0.05 m for normality of distribution (Shapiro Wilk's test) and equality of variance (Levene's test); variables with non-normal distributions were log-transformed (i.e., soil N_2O, CH_4, CO_2 fluxes, mineral NH_4^+ and NO_3^-, WFPS, soil temperature). To answer our main objective (i.e., quantify the changes in soil GHG fluxes between forest and smallholder vegetable farms), the nine forest plots were considered replicates of the reference land use whereas the 10 vegetable farms were regarded as replicate plots to represent the inherent varied management practices (Table 2.1) common to smallholders at our study area. Thus, the eight chambers (four on plant rows and four on inter-rows) at each farm on each measurement day were taken as subsamples and were nested within each farm (replicate) in the succeeding statistical analysis. We used the linear mixed-effects (LME) models (Crawley 2013) for repeatedly measured parameters (i.e., soil GHG fluxes and soil variables) in assessing differences between forest and vegetable production, or between plant rows and inter-rows if the purpose was to test between these cultivation zones within farms. In LME, land use or cultivation zone (for vegetable production only) was considered as fixed effect whereas measurement day and replicate plot were random effects. In the LME models, we included 1) a first-order temporal autoregressive process that assumes a decreasing correlation between measurements with increasing time distance (Zuur et al. 2009), and 2) a variance function that allows different variances of the fixed effect (Crawley 2013). The best LME model was chosen based on the Akaike information criterion. We also determined the temporal correlations of soil GHG fluxes with the soil variables. We used the average of the nine forest plots or 10 vegetable farms on each measurement period and conducted Pearson's correlation test over the 13 monthly measurements ($n = 13$ for the forest and $n = 26$ for the vegetable farms, with 2 cultivation zones × 13), as the correlation patterns remained statistically the same when using the individual replicate plots of each land use.

For the additional measurements of extractable mineral N down to 1-m depth, the difference between seasons was assessed using either paired T test (normal distribution) or the non-parametric Wilcoxon signed-rank test. Similarly, for soil physical and biochemical properties measured once, comparison between the two land uses for each depth was conducted using either independent T test or non-parametric Wilcoxon rank-sum test. We considered the significant level at $P \leq 0.05$ for all the tests. Statistical analyses were carried out using R version 4.0.2 (R Core Team 2020). R packages central to our analyses involved car (Fox and Weisberg 2019), lme4 (Bates et al. 2015), MASS (Venables and Ripley 2002), multcomp (Hothorn et al. 2008), pgirmess (Giraudoux 2022), and ggplot2 (Wickham 2016) packages.

2.4. Results

2.4.1. Soil properties and nutrient stocks

In the top 0.5 m, soil bulk density was larger in the vegetable farms than the forest ($P < 0.01$; Table 2.2). Soil pH and stocks of Ca, K, and Mn did not differ between land uses ($P = 0.10$–0.65). Al saturation was larger in the forest than the vegetable farms ($P < 0.01$; Table 2.2). In contrast, base saturation was ~ 50% higher in the farms than the forest ($P < 0.01$). ECEC, SOC, and total N stocks decreased by 36%, 61%, and 40%, respectively, in the vegetable farms compared to the forest (all $P \leq 0.01$; Table 2.2).

In the 0.5–1.0 m, soil bulk density in the vegetable farms remained higher than in the forest ($P < 0.05$; Table 2.2). Soil pH, ECEC, and stocks of Al and Fe were similar between land uses ($P = 0.14$–0.80). Vegetable farms showed larger Mg, Ca and K stocks, and base saturation than the forest ($P \leq 0.01$–0.03; Table 2.2). Conversely, Al saturation, total N, and SOC stocks were lower in the vegetable farms compared to the forest (all $P < 0.01$; Table 2.2).

2.4.2. Differences in soil greenhouse gas fluxes between land uses

The forest soil consistently emitted N_2O, consumed CH_4, and emitted CO_2 over the entire 13-month measurements (Table 2.3; Fig. 2.1a–c). Of the soil variables quantified during the measurement period, only NH_4^+ and WFPS were larger in the wet than in the dry season ($P \leq 0.01$–0.02); soil temperature did not show seasonal variation (Table 2.4). Extractable mineral N showed NH_4^+ dominance over NO_3^- throughout the measurement period (Table 2.4).

Table 2.2

Soil physical and biochemical properties in the top 0.5 m and 0.5–1.0 m of the secondary forest (mean ± SE, n = 9 plots) and small-scale vegetable farms (mean ± SE, n = 10 farms) on an Andosol soil in Leyte, Philippines

Soil depth and characteristic	Secondary Forest	Small-scale vegetable farm
0–0.5 m		
Bulk density (g cm^{-3})	0.3 ± 0.0b	0.5 ± 0.0a
pH (1:2.5 soil-H_2O ratio)	5.1 ± 0.0a	5.1 ± 0.1a
ECEC ($cmol_c$ kg^{-1})	4.1 ± 0.3a	2.6 ± 0.3b
Base saturation (%)	31.1 ± 3.1b	64.7 ± 6.6a
Al saturation (%)	67.0 ± 3.1a	32.4 ± 6.3b
SOC concentration (g C kg^{-1})	93.9 ± 3.3a	36.7 ± 3.6b
Total soil N concentration (g N kg^{-1})	6.2 ± 0.2a	3.4 ± 0.3b
C:N Ratio	15.0 ± 0.4a	10.8 ± 0.2b
SOC stock (kg C m^{-2})	15.3 ± 0.5a	6.0 ± 0.6b
Total soil N stock (kg N m^{-2})	1.0 ± 0.0a	0.6 ± 0.1b
Exch. Mg (g Mg m^{-2})	6.1 ± 0.3a	4.2 ± 0.3b
Exch. Ca (g Ca m^{-2})	22.2 ± 2.2a	31.7 ± 3.8a
Exch. K (g K m^{-2})	10.5 ± 0.6a	15.5 ± 3.1a
Exch. Na (g Na m^{-2})	2.7 ± 0.4a	1.0 ± 0.2b
Exch. Al (g Al m^{-2})	40.1 ± 4.0a	15.8 ± 4.5b
Exch. Fe (g Fe m^{-2})	0.9 ± 0.3a	0.1 ± 0.0b
Exch. Mn (g Mn m^{-2})	1.7 ± 0.2a	3.1 ± 0.7a
0.5–1.0 m		
Bulk density (g cm^{-3})	0.4 ± 0.0b	0.5 ± 0.0a
pH (1:2.5 soil-H_2O ratio)	5.1 ± 0.0a	5.0 ± 0.1a
ECEC ($cmol_c$ kg^{-1})	0.8 ± 0.1a	1.2 ± 0.2a
Base saturation (%)	40.6 ± 3.2b	79.8 ± 6.5a
Al saturation (%)	57.3 ± 3.4a	17.3 ± 6.3b

Table 2.2 continuation…

Soil depth and characteristic	Secondary Forest	Small-scale vegetable farm
SOC concentration (g C kg^{-1})	37.1 ± 2.4a	17.0 ± 2.2b
Total soil N concentration (g N kg^{-1})	2.7 ± 0.2a	1.6 ± 0.2b
C:N Ratio	14.0 ± 0.3a	11.0 ± 0.2b
SOC stock (kg C m^{-2})	7.8 ± 0.5a	3.6 ± 0.5b
Total soil N stock (kg N m^{-2})	0.6 ± 0.0a	0.3 ± 0.0b
Exch. Mg (g Mg m^{-2})	1.7 ± 0.2b	3.3 ± 0.6a
Exch. Ca (g Ca m^{-2})	6.6 ± 0.4b	26.4 ± 4.1a
Exch. K (g K m^{-2})	5.2 ± 0.4b	10.8 ± 2.2a
Exch. Na (g Na m^{-2})	1.7 ± 0.2a	1.2 ± 0.3b
Exch. Al (g Al m^{-2})	9.3 ± 1.3a	5.5 ± 2.7a
Exch. Fe (g Fe m^{-2})	0.0 ± 0.0a	0.0 ± 0.0a
Exch. Mn (g Mn m^{-2})	0.9 ± 0.1b	1.7 ± 0.3a

Means followed by different lowercase letters within a row indicate significant difference between land uses (Independent *T* test or Wilcoxon rank-sum test at $P \leq 0.05$). For the top 0.5 m, values for each replicate plot are weighted average of the sampled depth intervals at 0–0.1, 0.1–0.3, and 0.3–0.5 m, except for element stocks which are the sum of the entire depth

Table 2.3

Soil trace gas fluxes and annual fluxes (top 0.05 m) in the secondary forest (mean ± SE, n = 9 plots) and small-scale vegetable farms (mean ± SE, n = 10 farms), with monthly measurements from May 2018 to May 2019, on an Andosol soil in Leyte, Philippines

Land use	Cultivation zone	N_2O flux ($\mu g\ N\ m^{-2}\ hr^{-1}$)	CH_4 flux ($\mu g\ C\ m^{-2}\ hr^{-1}$)	CO_2 flux ($mg\ C\ m^{-2}\ hr^{-1}$)	N_2O flux ($kg\ N\ ha^{-1}\ yr^{-1}$)	CH_4 flux ($kg\ C\ ha^{-1}\ yr^{-1}$)	CO_2 flux ($Mg\ C\ ha^{-1}\ yr^{-1}$)
Secondary forest		1.2 ± 0.2B	–24.1 ± 1.5B	92.1 ± 3.1B	0.10 ± 0.02	–2.0 ± 0.2	8.2 ± 0.7
Small-scale vegetable farm		133.4 ± 19.7A	–12.9 ± 0.9A	130.3 ± 5.0A	12.7 ± 2.6	–1.1 ± 0.2	11.7 ± 0.7
	Plant row	187.1 ± 30.3a	–13.8 ± 0.9a	136.1 ± 5.2a			
	Inter-row	54.3 ± 7.1b	–9.6 ± 1.3a	109.2 ± 4.0a			

Means followed by different capital letters indicate significant difference between land uses, and different lowercase letters denote significant difference between cultivation zones of vegetable farms (linear mixed-effects models with Fisher's LSD test at $P \leq 0.05$). Annual soil trace gas fluxes are calculated using the trapezoidal rule between monthly measurement intervals; for vegetable farms, annual emissions are area-weighted with 70% plant rows and 30% inter-rows

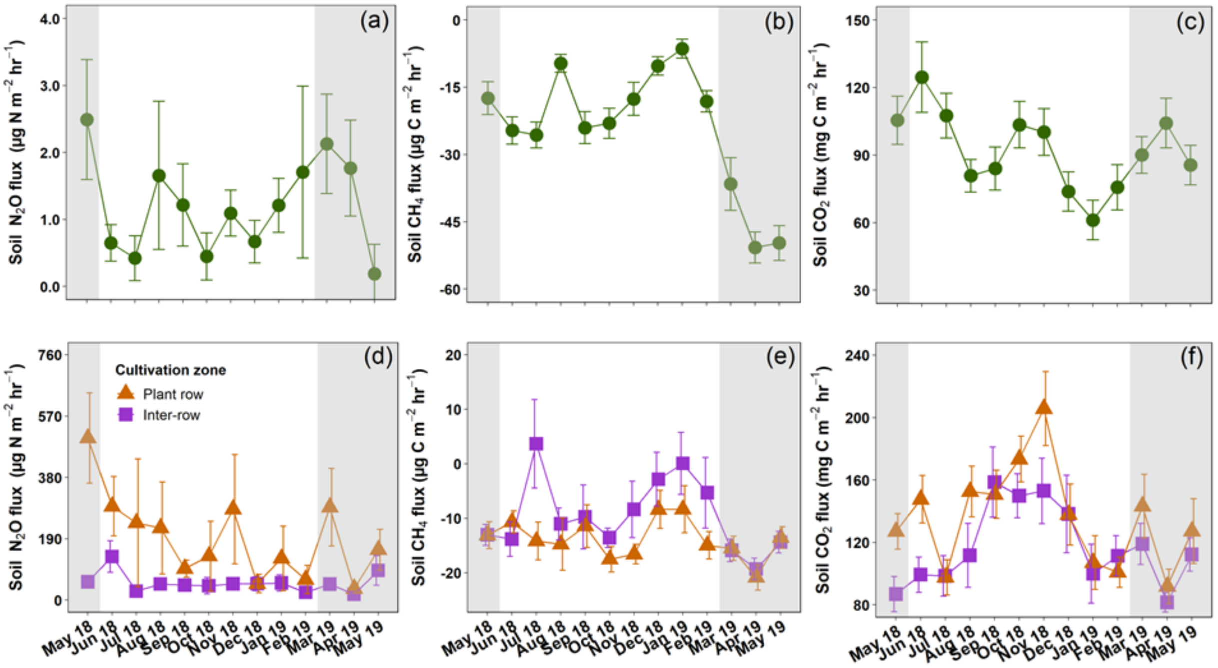

Fig. 2.1 Mean (± SE) soil N_2O, CH_4 and CO_2 fluxes from the secondary forest (n = 9 plots; a–c) and cultivation zones of small-scale vegetable farms (n = 10 farms; d–f), with commonly varied fertilization regimes (Table 2.1), on an Andosol soil in Leyte, Philippines. Gray shadings mark the dry season (< 150 mm rainfall month^{-1})

In the vegetable farms, soil N_2O and CO_2 emissions were consistently higher whereas soil CH_4 uptake was lower compared to the forest (all $P < 0.01$; Table 2.3; Fig. 2.1d–f). Between cultivation zones of the vegetable farms, soil N_2O emissions from the plant row were higher than from the inter-row ($P < 0.01$; Table 2.3; Fig. 2.1d) whereas soil CH_4 and CO_2 fluxes did not differ ($P = 0.06–0.17$; Table 2.3; Fig. 2.11e, f). Moreover, only the soil N_2O emissions from the plant row exhibited seasonal changes with 44% higher emissions during the dry than the wet season ($P < 0.01$; Fig. 2.1d). In the inter-row, only soil CH_4 uptake showed seasonal pattern, which was lower in the wet than the dry season ($P = 0.02$; Fig. 2.1e). The annual soil GHG fluxes were remarkably larger than the forest (Table 2.3), ranging from 7.0–34 kg N_2O-N ha^{-1} yr^{-1}, –2.0– –0.2 kg CH_4-C ha^{-1} yr^{-1}, and 9.0–15 Mg CO_2-C ha^{-1} yr^{-1}.

The GWP in the smallholder farms ranged from 18 to 42 Mg CO_2-eq ha^{-1} yr^{-1} across the studied 10 farms (Fig. 2.4; Table A2.2). The heterotrophic respiration (i.e., 10 ± 0.6 Mg C ha^{-1} yr^{-1}; represented by the CO_2 flux from the inter-row as crop roots were absent from this zone) was larger than the combined C inputs from NPP (1.2 ± 0.2 Mg C ha^{-1} yr^{-1}) and chicken manure (2.6 ± 0.3 Mg C ha^{-1} yr^{-1}), signifying the farms as a net source of CO_2 (Fig. 2.4; Table A2.2). On average, NEP comprised 81% of the GWP, soil N_2O emissions accounted 19%, whereas soil CH_4 uptake counteracted only ~ 0.1%.

2.4.3. Differences in soil variables between land uses and their relationships with greenhouse gas fluxes

Soil NO_3^- and temperature were higher in the vegetable farms than in the forest ($P < 0.01$; Table 2.4) whereas soil NH_4^+ and WFPS did not differ between land uses ($P \geq 0.62$; Table 2.4). In the vegetable farms, NO_3^- was the dominant form of extractable N (Tables 2.4, 2.5). Soil NO_3^- and WFPS did not differ between cultivation zones ($P \geq 0.09$; Table 2.4) but differed between seasons: NO_3^- was higher while WFPS was lower ($P \leq 0.01$) in the dry than the wet season. Soil NH_4^+ in the vegetable farms was higher in the plant row ($P < 0.01$; Table 2.4) than the inter-row but did not vary between seasons ($P = 0.41$). The vegetables farms also showed large stocks of NO_3^- in the entire 1-m depth followed by extractable organic N and NH_4^+, and these were larger in the wet than in the dry season ($P < 0.01$; Table 2.5). Soil temperature in the vegetable farms neither differed between cultivation zones nor between seasons (Table 2.4).

Soil CH_4 fluxes from the forest showed a positive relationship with WFPS, illustrating a decrease in CH_4 uptake with an increase in soil moisture (Fig. 2.2a). Soil CO_2 emissions from the forest displayed positive correlation with soil temperature (Fig. 2.2b). In the vegetable farms, soil N_2O fluxes were positively correlated with total mineral N ($NH_4^+ + NO_3^-$) (Fig. 2.2c). Conversely, soil CH_4 fluxes from the vegetable farms exhibited negative relationship with NO_3^- (Fig. 2.2d). Considering both land uses, soil CO_2 emissions showed a parabolic relationship with WFPS, which was not revealed when only either forest or vegetable farm was considered; soil CO_2 emissions increased within 30–45% WFPS, were optimum at approximately > 55–65% WFPS, and decreased at > 70%

WFPS (Fig. 2.3). There were no other significant relationships observed between soil GHG fluxes and measured soil controlling variables.

Table 2.4

Soil variables (top 0.05 m) in the secondary forest (mean ± SE, n = 9 plots) and small-scale vegetable farms (mean ± SE, n = 10 farms), with monthly measurements from May 2018 to May 2019, on an Andosol soil in Leyte, Philippines. For mineral N, values in parenthesis are expressed in mg N m^{-2} (top 0.05 m), calculated using the soil bulk density of the reference land use

Land use	Cultivation zone	NH_4^+ (mg N kg^{-1})	NO_3^- (mg N kg^{-1})	Water–filled pore space (%)	Soil temp. (°C)
Secondary forest		7.4 ± 0.3A (121.3 ± 5.4)	0.2 ± 0.1B (3.4 ± 1.0)	60.0 ± 1.6A	21.8 ± 0.1B
Small-scale vegetable farm		11.4 ± 1.6A (187.4 ± 25.7)	17.3 ± 1.9A (285.0 ± 32.0)	55.2 ± 1.3A	24.4 ± 0.2A
	Plant row	13.8 ± 2.1a	20.4 ± 2.4a	55.8 ± 1.3a	24.4 ± 0.2a
	Inter-row	5.3 ± 0.3b	10.1 ± 1.2a	54.3 ± 1.4a	24.5 ± 0.2a

Means followed by different capital letters indicate significant difference between land uses, and different lowercase letters display significant difference between cultivation zones of vegetable farms (linear mixed-effects models with Fisher's LSD test at $P \leq 0.05$)

Table 2.5

Mean (± SE) stocks of soil extractable N within 1-m depth in small-scale vegetable farms (n = 10 farms) during the dry and wet seasons of 2019, on an Andosol soil in Leyte, Philippines

Extractable N	Small-scale vegetable farms top 0–0.5 m soil depth		0.5–1.0 m soil depth	
	dry	wet	dry	wet
NH_4^+ (mg N m^{-2})	644 ± 62a	872 ± 115a	252 ± 27b	590 ± 99a
NO_3^- (mg N m^{-2})	6520 ± 2584b	12844 ± 3354a	7423 ± 3915b	15088 ± 8084a
Organic N (mg N m^{-2})	8301 ± 814b	9431 ± 654a	3506 ± 421b	4608 ± 479a

Means followed by different lowercase letters within a row and soil depth indicate significant difference between cropping seasons (Paired *T* test or Wilcoxon signed-rank test at $P \leq 0.05$). Values of extractable N for each replicate plot in the top 50 cm are cumulative N stocks from the sampled soil depth intervals 0–0.1, 0.1–0.3, and 0.3–0.5 m

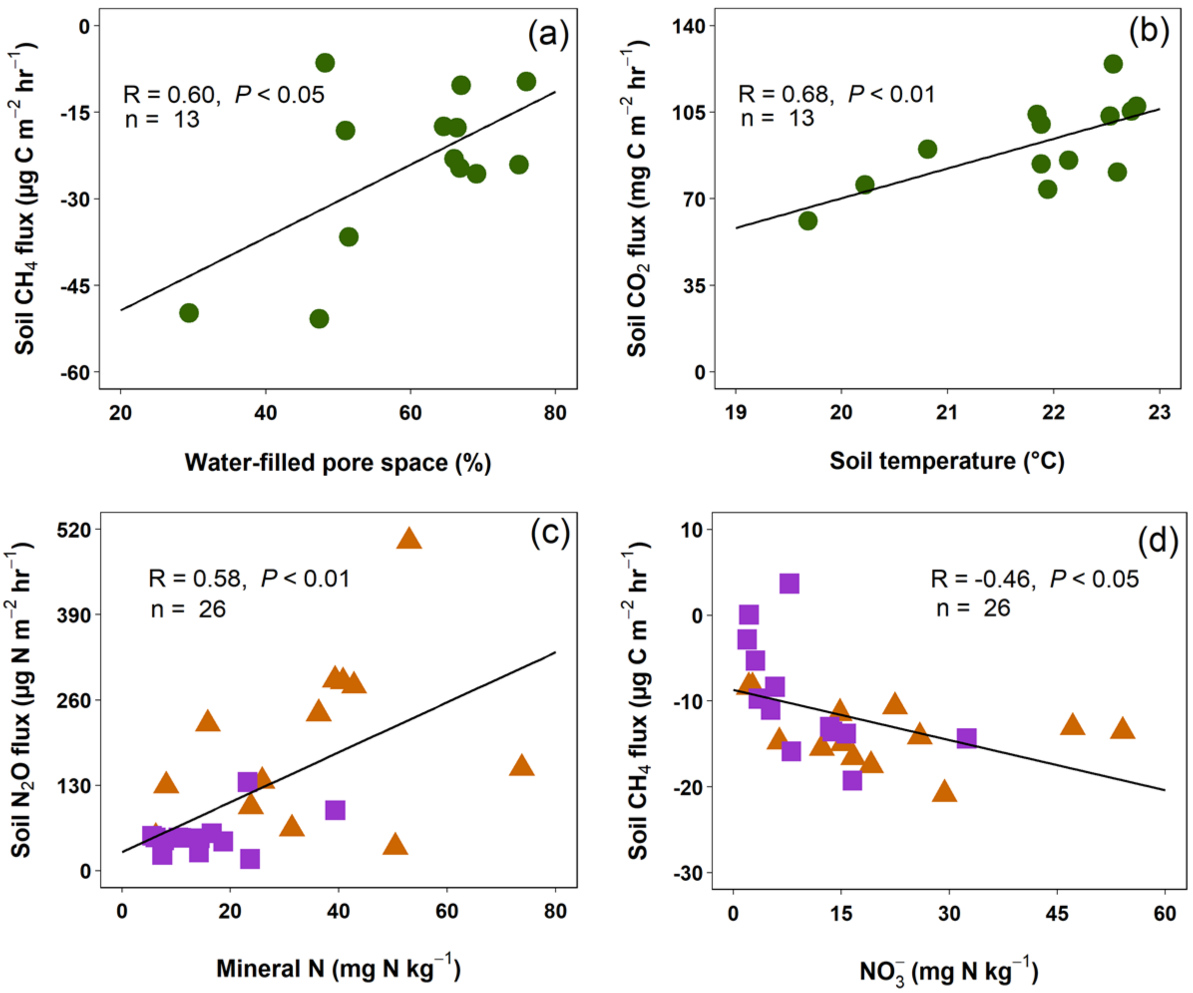

Fig. 2.2 Pearson's correlations between soil greenhouse gas fluxes (top 0.05 m) and soil factors in the secondary forest (a, b) and small-scale vegetable farms (c, d; plant row: ▲ , inter-row: ■) on an Andosol soil in Leyte, Philippines. Each data point is the average of nine plots in the secondary forest and of 10 farms, on each sampling day during monthly measurements from May 2018 to May 2019

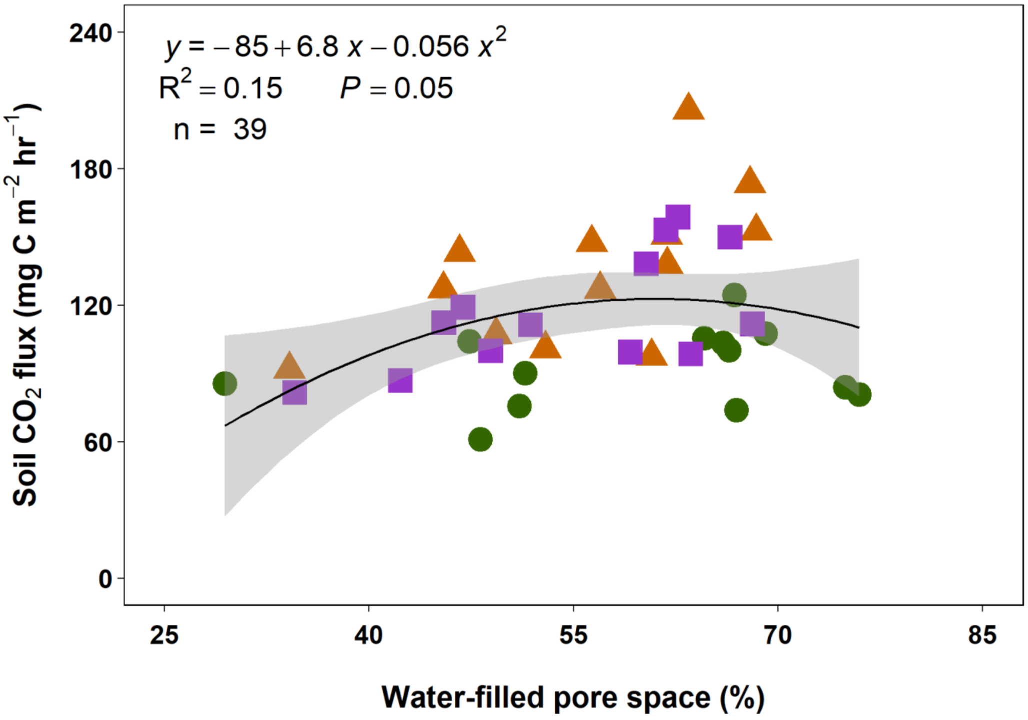

Fig. 2.3 Regression between soil CO_2 fluxes and water-filled pore space (top 0.05 m) in the secondary forest (●) and small-scale vegetable farms (plant row: ▲ , inter-row: ■) on an Andosol soil in Leyte, Philippines. Each data point is the average of nine plots in the secondary forest and of 10 farms, on each sampling day during monthly measurements from May 2018 to May 2019

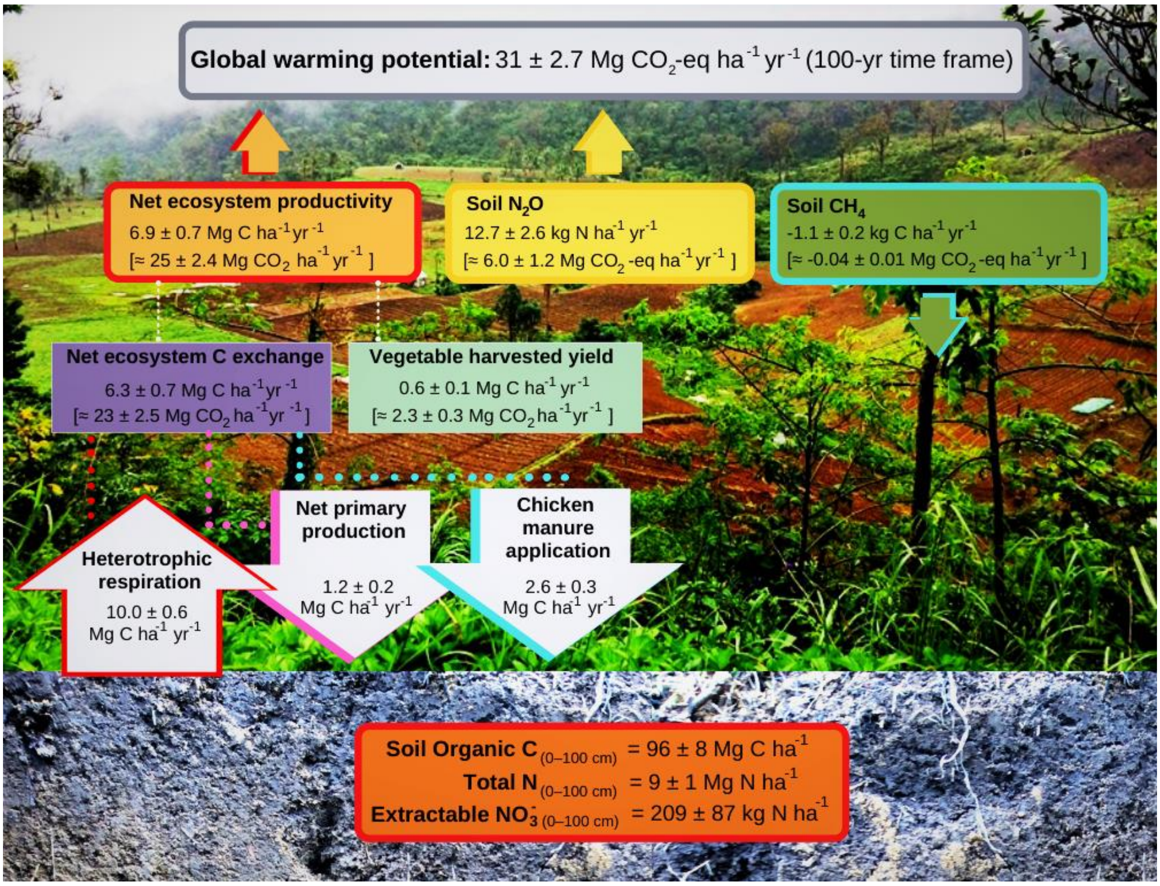

Fig. 2.4 Soil greenhouse gas balance in vegetable production system on an Andosol soil of smallholders in Leyte, Philippines. Net primary production (NPP) is the sum of harvested yield (measured in the field), herbage production (estimated using the harvest index) and root production (estimated using the root:shoot ratio) for each vegetable type (Table A2.2). Heterotrophic respiration was represented by the soil CO_2 emission from the inter-row, as this cultivation zone did not have plant roots. Net ecosystem C exchange (NEE) = heterotrophic respiration – (NPP + chicken manure) (Malhi et al. 1999) and net ecosystem productivity (NEP) = NEE + harvested yield exported from the farm (Meijide et al. 2020). Global warming potential (GWP) is the sum of NEP, N_2O and CH_4 in CO_2-equivalent within a 100-year time frame, for which soil N_2O, and CH_4 were multiplied by 298 and 25, respectively (IPCC Guidelines for National Greenhouse Gas Inventories 2006)

2.5. Discussion

2.5.1. Changes in soil properties between forest and vegetable farms

The SOC stock in our forest soil (Table 2.2) was comparable to other forests on Andosol soils (e.g., 12–14 kg C m^{-2} in the top 0.5 m, Veldkamp 1994; de Koning et al. 2003; 17 kg C m^{-2} in the top 1.0 m, Anda and Dahlgren 2020). Changes in soil properties after forest conversion to croplands can be substantial, persistent (e.g., detectable even after > 25 years), and extensive (e.g., affecting depths > 0.5 m) (Veldkamp et al. 2020). At our study area, the increased soil bulk density and reduced SOC and total N stocks down to 1-m depth in the vegetable farms (Table 2.2) had resulted from soil compaction brought about by foot traffic of farmers' management operations, reduction in input of organic materials (e.g., harvest export) (Koga et al. 2020), and low stability of SOC derived from the present land use as observed for Andosol soils (Paul et al. 2008). The decrease in SOC stock in the vegetable farms (Table 2.2) was at the upper range of those reported for SOC losses from tropical forest-to-cropland conversion (17–58% in the top 0.1 m and 35% in depths > 0.5 m, Veldkamp et al. 2020; 30–66% in the top 0.3–0.4 m, Beheshti et al. 2012; Powers et al. 2011). The decreased soil C:N ratio in the vegetable farms (Table 2.2) was indicative of highly decomposed organic matter (Murty et al. 2002; Piñeiro et al. 2006; Veldkamp et al. 2020), which may have resulted from improved decomposition and respiration losses of labile organic matter due to regular plowing and long-term high N fertilization (e.g., Cusack et al. 2011).

Moreover, the reduced organic matter (i.e., SOC and total N) in the vegetable farms had also resulted in reduced ECEC (Table 2.2), which is largely contributed by organic matter for variable charge soils like Andosols (Dahlgren et al. 2004; Dechert et al.

2004; Iwasaki et al. 2017; Veldkamp et al. 2020). Occasional liming as well as chicken manure application (see “Farm management practices” subsection above) in vegetable farms had increased the base saturation and decreased Al saturation as compared to the forest (Table 2.2). Also, the effect of ash deposition (from biomass burning during forest conversion) on increasing base saturation could last 1–2 decades after forest conversion to croplands (Veldkamp et al. 2020). In the lower depth (0.5–1.0 m), the increased Mg, Ca, and K stocks in the vegetable farms (Table 2.2) may have reflected the legacy of soil amendments (lime, chicken manure, K fertilizer) and base-containing ashes that have been translocated downwards with time (Andriesse and Schelhaas 1987; van Breemen et al. 1983; Veldkamp et al. 2020). In sum, soil properties related to organic matter loss had decreased (SOC, total N, and ECEC), whereas those associated with soil amendment practices have increased (base cation stocks at deeper depths) in these vegetable farms.

2.5.2. Soil greenhouse gas fluxes from the forest

The annual soil N_2O emission from the forest (Table 2.3) was lower than those reported for forests in Southeast Asia (see reviewed studies in Table A2.3). We associated the low soil N_2O emissions from our forest site to the low mineral N levels with the dominance of NH_4^+ over NO_3^- (Table 2.3), which suggests limited nitrification and thus also low substrate availability for denitrification (Ishizuka et al. 2002; Veldkamp et al. 1998). The low mineral N levels at our forest site were comparable to those forests in Puerto Rico, frequently affected by severe tropical storms (Cusack et al. 2016). Months after storm episodes, mineral N may be elevated but eventually returns to low level as the forest recovers from storm disturbances (Silver et al. 1996). In addition, the low soil N_2O emissions from this forest on Andosol soil may have been a consequence of its high soil porosity throughout 1-m depth (i.e., low bulk density; Table 2.2), which may render infrequent or only brief anaerobic conditions (Figs. 2.2a, 2.3) despite high rainfall months (see "Site description" subsection above). Thus, the low mineral N levels and the medium-range WFPS (Table 2.2) indicated the effects of the two main regulating factors (i.e., N availability and aeration status; Davidson et al. 2000) on the low soil N_2O emissions from this forest on Andosol soil.

The soil CH_4 fluxes, displaying the dominance of CH_4 consumption over CH_4 production (Table 2.3; Figs. 2.1b, 2.2a), concurred with other Southeast Asian forests on mineral soils that act as net CH_4 sinks (see reviewed studies in Table A2.3). Our annual soil CH_4 uptake, however, was at the lower end of those reported for montane forests on Cambisol and Regosol soils and for a lowland forest on Acrisol soil in Indonesia (Hassler et al. 2015; Purbopuspito et al. 2006). We observed a decrease in soil CH_4 uptake with increase in WFPS (Fig. 2.2a), suggesting the concurrent reduction in diffusion of atmospheric CH_4 into the soil that can limit methanotrophic activity and possible CH_4 production in anaerobic microsites during the wet season (Hassler et al. 2015; Itoh et al. 2012; Tate et al. 2007; Zhao et al. 2019). The overall low CH_4 uptake in our forested volcanic soil was probably also influenced by its low soil mineral N levels (Table 2.2). Limitation by N availability on soil CH_4 consumption had been reported for forests in Indonesia (Hassler et al. 2015), Panama (Matson et al. 2017; Veldkamp et al. 2013), Ecuador (Wolf et al. 2012), and Cameroon (Iddris et al. 2021) with Andosol, Cambisol and highly weathered Acrisol and Ferralsol soils.

The soil CO_2 efflux, encompassing both microbial and autotrophic respiration (Table 2.3; Figs. 2.1c, 2.2b), was lower than values reported for tropical forests in Southeast Asia on Acrisol and Nitisol soils but slightly higher than a lowland forest on

Ferralsol soil (see reviewed studies in Table A2.3). Our secondary forest had been disturbed by a super typhoon six years prior to our investigation (see “Experimental design” subsection above). The low soil CO_2 efflux from this forest could be due to less autotrophic contribution (which could account for 30% of soil respiration; van Straaten et al. 2011) as well as low heterotrophic activity, if the litter input had not yet recovered to levels prior to this natural disturbance. Although soil CO_2 efflux increased with increase in soil temperature, this effect may also have been confounded by soil moisture, as those low soil CO_2 emissions at the low end of soil temperature (19–20 ºC; Fig. 2.2b) also had low WFPS (29–50%; Fig. 2.4). Confounding effects of soil temperature and WFPS were commonly observed in tropical forests on a wide range of soil types (Koehler et al. 2009a; Matson et al. 2017). The curvilinear relationship between soil CO_2 emissions and soil moisture in both land uses (Fig. 2.3) signified root and microbial respiration towards optimum soil moisture condition (WFPS between 55% and 65%), beyond which high soil moisture can hamper gas diffusion as well as limit soil respiration (Koehler et al. 2009a; Matson et al. 2017; Sotta et al. 2007; Tchiofo Lontsi et al. 2020; van Straaten et al. 2011).

2.5.3. Larger soil greenhouse gas fluxes from the vegetable farms than the secondary forest

Soil N_2O emissions from the vegetable farms (Table 2.3; Fig. 2.1d) were higher than those reported for Andosol soils in Japan planted to Chinese cabbage but lower than those reported for Andosol soils in Costa Rica utilized for banana plantation and pasture (see reviewed studies in Table A2.4). In terms of annual soil N_2O emissions (Table 2.3), our values were similar with those reported for tea plantations (11–19 kg N ha^{-1} yr^{-1}, Hirono and Nonaka 2012; Hou et al. 2015) and 30-year corn field (13–15 kg N ha^{-1} yr^{-1}, Mukumbuta et al. 2017a; 2017b), two of the long-term land uses on Andosol soils in Japan. The large soil N_2O emissions from our vegetable farms had clearly resulted from long-term high N fertilization rates, as evident from the large stocks of mineral N even down to 1-m depth (Tables 2.4, 2.5) and as supported by the positive correlation between soil N_2O emissions and mineral N (Figs. 2.1d, 2.2c). Although the mineral N values used in the correlation test was measured routinely only at the top 0.05 m (due to logistical limitations) during the year-round measurement, the N_2O emitted at the soil surface was likely contributed by the entire soil depth, where substrates (NH_4^+, NO_3^-, extractable organic N; Table 2.5) for nitrification and denitrification remained high, similar to the findings of elevated N_2O concentrations throughout the 2-m soil depth under long-term N fertilization to tropical forests (Corre et al. 2014; Koehler et al. 2012). Furthermore, the large soil N_2O emissions from the plant row, with recurring N fertilization and chicken manure application (providing available organic C), also lent support to the primary control of N and C availability, as exemplified by the HIP model (Davidson et al. 2000). The dominance of NO_3^- over NH_4^+ combined with available organic C and mid-range WFPS (Tables 2.4, 2.5) resulted in large soil N_2O emissions during the dry season (Fig. 2.1e) as reduction of NO_3^- to N_2O in such microaerophilic condition (sufficient oxygen condition in relative sense) is energetically more favorable than further reduction to N_2 (Maier 2009; Stolk et al. 2011). Furthermore, the high NO_3^- stocks with depths (Table 2.5) attested to the anion adsorption capacity of this variable charge Andosol soil. This adsorbed NO_3^- onto the soil's exchange sites is only temporary and is exchangeable when other anions become dominant (e.g., Cl^- and SO_4^{2-} from K-based fertilizers and atmospheric deposition; Formaglio et al. 2020; Kurniawan et al. 2018). This suggests that not only large N_2O emissions but also susceptibility to large NO_3^- leaching (e.g., Formaglio et al. 2020) are the deleterious environmental impacts from this high fertilizer-input vegetable production system on a highly porous Andosol soil under a humid climate.

Soil CH_4 consumption in the vegetable farms (Table 2.3; Fig. 2.1e) were within the range of those reported for corn fields in Japan and pastures in Costa Rica all on Andosol soils (see reviewed studies in Table A2.4). The net CH_4 flux from the soil surface is a net effect of CH_4 production and consumption within the soil. Thus, the lower soil CH_4 uptake in the vegetable farms than in the forest (Table 2.3) suggests the effect of methanogenic activity that may partly offset methanotrophic activity in the vegetable farms. This was demonstrated by the occasional near-zero soil CH_4 fluxes from the inter-row during the wet season (Fig. 2.1e) that concurred to the increased soil bulk density in the vegetable farms (Table 2.2), which may have favored methanogenic activity in anaerobic microsites. Additionally, during the wet season gas diffusion from the atmosphere to the soil could decrease as soil moisture content increased (Fig. 2.1e), which may limit CH_4 availability to microsites where concurrent methanotrophic activity occur (Iddris et al. 2021; Matson et al. 2017; Tchiofo Lontsi et al. 2020; Veldkamp et al. 2013). Additionally, the increasing CH_4 uptake with increasing NO_3^- levels (Fig. 2.2d) in these vegetable farms, reflected the inhibition effect of large NO_3^- levels (Tables 2.4, 2.5) on CH_4 production, as NO_3^- is the preferred electron acceptor over bicarbonate (Schlesinger and Bernhardt 2013). The low NO_3^- levels in the inter-rows (Fig. 2.2d; Table 2.4) may only have low effect on inhibiting CH_4 production during the wet season, resulting in low net CH_4 uptake, whereas the high NO_3^- levels in the plant-rows may have large impact on dampening CH_4 production, resulting in high net CH_4 uptake. Therefore, on one hand the increased soil bulk density in these vegetable farms may increase occurrence of anaerobic microsites in the inter-rows, but on the other hand, the large NO_3^- levels may dampen CH_4 production in the plant rows, resulting in moderate decrease (although statistically significant) in soil CH_4 uptake in the vegetable farms compared to that in the forest.

The soil CO_2 efflux from the vegetable farms (Table 2.3) was within the range of those reported for corn fields on Andosol soils in Japan (see reviewed studies in Table A2.4). While the autotrophic contribution, i.e., on the plant row where roots occurred (Fig. 2.1f), to soil respiration was possibly low owing to low root biomass (Raich and Tufekcioglu 2000) of shallow-rooted vegetables (Table 2.1), heterotrophic respiration may have been enhanced by the increased soil temperature (Table 2.4), frequent deep plowing during two to three cropping periods per year as well as regular chicken manure application (Table A2.2). Heterotrophic respiration of labile organic matter in the vegetable farms may also been enhanced by the large N fertilization rates (e.g., Cusack et al. 2011).

Consequently, heterotrophic respiration was the most important process contributing to the greenhouse gas budget of these vegetable farms (Fig. 2.4; Table A2.2). The heterotrophic respiration from the inter-rows was consistent to that reported for a 30-year corn field on an Andosol soil (7.8 ± 1.1–10.2 ± 0.7 Mg C ha^{-1} yr^{-1}, Mukumbuta et al. 2017a; 2017b). These authors reported GWP (100-yr time frame) of 5.5 ± 4.8–18.4 ± 1.5 Mg CO_2-eq ha^{-1} yr^{-1}, which is lower than our estimated GWP from vegetable farms, partly because of the large NPP of corn that offsets the heterotrophic respiration (Mukumbuta et al. 2017a). Similarly, the GWP (100-yr time frame) of 3.1–4.2 Mg CO_2-eq ha^{-1} yr^{-1} in vegetable fields on the same soil type in Japan were lower than our values, likely ascribed to conventional tillage alongside lower N fertilization rate (130 kg N ha^{-1}) as cultivation practices (Yagioka et al. 2015). However, our GWP budget of the vegetable farms was in agreement to that from a newly established oil palm plantation on Acrisol soil in Jambi, Indonesia (38 Mg CO_2-eq ha^{-1} yr^{-1}; Meijide et al. 2020). These other studies as well as our present estimate of GHG footprint of smallholder vegetable production revealed the need for converted land uses to employ sustainable management practices in order to prevent soil degradation and thus avoiding further forest conversion. As microbial decomposition of soil organic matter was the largest contributor to the GHG footprint of our vegetable farms and C losses were substantial (as illustrated by the NEE in Fig. 2.4), the intensively managed soils currently continue to lose large amount of C every year. It is likely that these losses will become less with time, when a new steady state between C input and output will be reached. However, this will probably come at the costs of serious soil degradation, which will likely also affect the productivity of these soils. Management practices should thus be tailored towards increasing organic matter storage, which in turn enhances nutrient recycling (thereby minimizing dependency on large fertilizer inputs; Formaglio et al. 2021), erosion resistance (through aggregate stabilization), and water filtration (through recycling of excess nutrients) (Veldkamp et al. 2020).

2.6. Conclusions

The findings support our hypothesis that soil N_2O and CO_2 emissions increased while soil CH_4 uptake decreased in vegetable farms compared to the secondary forest. These soil GHG patterns were attributed to large N fertilization rates, increased soil temperature, and deep soil tillage in the vegetable farms, favoring increased soil CO_2 and N_2O emissions. Additionally, increased soil bulk density in the vegetable farms may promote anaerobic microsites during the wet season and limit CH_4 diffusion from the atmosphere to the soil, resulting in reduced soil CH_4 uptake. The large stock of mineral N down to 1-m depth, dominated by NO_3^-, also suggests susceptibility to leaching; this, along with excessive pesticide applications, can have deleterious impact on water quality – an environmental effect that remains uninvestigated in our study area. There is an urgent need for knowledge support to these vegetable farmers on sustainable management practices, which should be geared towards conserving soil fertility and minimizing environmental impact in order to prevent further forest conversion. The supports may include field-based trials for improving soil organic matter storage and efficient cycling of nutrients: e.g., mulching (which also reduces herbicide use; Formaglio et al. 2021), perennial buffer strips (to intercept leached nutrients; McKergow et al. 2004), reduce soil tillage, and crop rotations between deep- and shallow-rooted vegetables or between high and low nutrient-demanding vegetables. These management practices, overall, can serve as tools to offset the current estimated GWP in small-scale vegetable farms. In addition, qualitative soil analysis must be accessible to farmers as an integrative approach in fertilizer use management (e.g., as reference for synchronized split applications of fertilizers). Most importantly, our findings served as primary contribution to the data gaps and inconsitencies of available data in the agriculture sector's GHG inventory of the Philippines (Kawanishi et al. 2019). Lastly, we would like to stress that strategies and policies to reduce GHG emissions should aim at incentivizing smallholders in employing sustainable crop management practices.

2.7. References

Achard F, Beuchle R, Mayaux P et al (2014) Determination of tropical deforestation rates and related carbon losses from 1990 to 2010. Glob Chang Biol 20(8):2540–2554. doi: 10.1111/gcb.12605

Allen K, Corre MD, Kurniawan S et al (2016) Spatial variability surpasses land-use change effects on soil biochemical properties of converted lowland landscapes in Sumatra, Indonesia. Geoderma 284:42–50. doi: 10.1016/j.geoderma.2016.08.010

Anda M, Dahlgren RA (2020) Long-term response of tropical Andisol properties to conversion from rainforest to agriculture. CATENA 194:104679. doi: 10.1016/j.catena.2020.104679

Andriesse JP, Schelhaas RM (1987) A monitoring study on nutrient cycles in soils used for shifting cultivation under various climatic conditions in tropical Asia. III. The effects of land clearing through burning on fertility level. Agric Ecosyst Environ 19(4):311–332. doi: 10.1016/0167-8809(87)90059-4

Asio VB, Jahn R, Stahr K, Margraf J (1998) Soils of the tropical forests of Leyte, Philippines II: Impact of differrent land uses on status of organic matter and nutrient availability. In: Schulte A, Ruhiyat D (eds) Soils of tropical forest ecosystems. Springer Verlag, Berlin, pp 37-44

Bartels R (1982) The rank version of von Neumann's ratio test for randomness. Journal of the American Statistical Association 77:40–46. doi: 10.1080/01621459.1982.10477764

Bates D, Mächler M, Bolker B, Walker S (2015) Fitting linear mixed-effects models using lme4. J Stat Soft 67(1):1–48. doi: 10.18637/jss.v067.i01

Beheshti A, Raiesi F, Golchin A (2012) Soil properties, C fractions and their dynamics in land use conversion from native forests to croplands in northern Iran. Agric Ecosyst Environ 148:121–133. doi: 10.1016/j.agee.2011.12.001

Blake GR, Hartge KH (1986) Bulk density. In Klute (ed) Methods of Soil Analysis: Part 1 - Physical and mineralogical methods. American Society of Agronomy, Inc., Madison, pp 363–375

Bodelier PL, Laanbroek HJ (2004) Nitrogen as a regulatory factor of methane oxidation in soils and sediments. FEMS Microbiol Ecol 47(3):265–277. doi: 10.1016/S0168-6496(03)00304-0

Briones RM (2009) Agricultural diversification and the fruits and vegetables subsector: Policy issues and development constraints in the Philippines. Philippine Institute for Development Studies, Discussion Paper Series No. 2009-02:1–32

Briones RM (2014) The role of mineral fertilizers in transforming Philippine agriculture. Philippine Institute for Development Studies, Discussion Paper Series No. 2014-14:1–24

Briones RM (2016) The fertilizer industry and Philippine agriculture: Policies, problems, and priorities. Philippine Institute for Development Studies 43(1):29–49

Carandang AP, Bugayong LA, Dolom PC et al (2013) Analysis of key drivers of deforestation and forest degradation in the Philippines. Deutsche Gesellschaft für Internationale Zusammenarbeit. Bonn and Eschborn, Germany

Cinco TA, de Guzman RG, Ortiz AMD et al (2016) Observed trends and impacts of tropical cyclones in the Philippines. Int J Climatol 36(14):4638–4650. doi: 10.1002/joc.4659

Corre MD, Sueta JP, Veldkamp E (2014) Nitrogen-oxide emissions from tropical forest soils exposed to elevated nitrogen input strongly interact with rainfall quantity and seasonality. Biogeochemistry 118(1-3):103–120. doi: 10.1007/s10533-013-9908-3

Crawley MJ (2013) The R book. Wiley, Chichester West Sussex United Kingdom

Cusack DF, Macy J, McDowell WH (2016) Nitrogen additions mobilize soil base cations in two tropical forests. Biogeochemistry 128(1-2):67–88. doi: 10.1007/s10533-016-0195-7

Cusack DF, Silver WL, Torn MS et al (2011) Changes in microbial community characteristics and soil organic matter with nitrogen additions in two tropical forests. Ecology 92(3):621–632. doi: 10.1890/10-0459.1

Dahlgren RA, Saigusa M, Ugolini FC (2004) The nature, properties and management of volcanic soils. Adv Agron 82:113–182. doi: 10.1016/S0065-2113(03)82003-5

Davidson EA, Keller M, Erickson HE et al (2000) Testing a conceptual model of soil emissions of nitrous and nitric oxides. BioScience 50(8):667. doi: 10.1641/0006-3568(2000)050[0667:TACMOS]2.0.CO;2

de Blécourt M, Brumme R, Xu J et al (2013) Soil carbon stocks decrease following conversion of secondary forests to rubber (*Hevea brasiliensis*) plantations. PloS one 8(7):e69357. doi: 10.1371/journal.pone.0069357 de Koning GHJ, Veldkamp E, López-Ulloa M (2003) Quantification of carbon sequestration in soils following pasture to forest conversion in northwestern Ecuador. Glob Biogeochem Cycles 17(4):1098. doi: 10.1029/2003GB002099

Dechert G, Veldkamp E, Anas I (2004) Is soil degradation unrelated to deforestation? Examining soil parameters of land use systems in upland Central Sulawesi, Indonesia. Plant Soil 265(1-2):197–209. doi: 10.1007/s11104-005-0885-8

Department of Environment and Natural Resources (1981) Land Classification No. 2949 Forestry Administrative Order No. 4-1576. Tacloban City, Leyte, Philippines

FAOSTAT (2021) FAOSTAT Online. Food and Agriculture Organization of the United Nations. Rome, Italy

Formaglio G, Veldkamp E, Damris M et al (2021) Mulching with pruned fronds promotes the internal soil N cycling and soil fertility in a large-scale oil palm plantation. Biogeochemistry 154(1):63–80. doi: 10.1007/s10533-021-00798-4

Formaglio G, Veldkamp E, Duan X, Tjoa A, Corre MD (2020) Herbicide weed control increases nutrient leaching compared to mechanical weeding in a large-scale oil palm plantation. Biogeosciences 17(21):5243–5262. doi: 10.5194/bg-17-5243-2020

Fox J, Weisberg S (2019) An R companion to applied regression. Sage, Thousand Oaks California, USA

Friedlingstein P, Jones MW, O'Sullivan M et al (2019) Global carbon budget 2019. Earth Syst Sci Data 11(4):1783–1838. doi: 10.5194/essd-11-1783-2019

Giraudoux P (2022) pgirmess: Spatial analysis and data fining for field ecologists. https://CRAN.R-project.org/package=pgirmess

Hassler E, Corre MD, Tjoa A et al (2015) Soil fertility controls soil–atmosphere carbon dioxide and methane fluxes in a tropical landscape converted from lowland forest to rubber and oil palm plantations. Biogeosciences 12(19):5831–5852. doi: 10.5194/bg-12-5831-2015

Hirono Y, Nonaka K (2012) Nitrous oxide emissions from green tea fields in Japan: contribution of emissions from soil between rows and soil under the canopy of tea plants. Soil Sci Plant Nutr 58(3):384–392. doi: 10.1080/00380768.2012.686434

Hothorn T, Bretz F, Westfall P (2008) Simultaneous inference in general parametric models. Biometrical Journal 50(3):346–363. doi: 10.1002/bimj.200810425

Hou M, Ohkama-Ohtsu N, Suzuki S et al (2015) Nitrous oxide emission from tea soil under different fertilizer managements in Japan. CATENA 135:304–312. doi: 10.1016/j.catena.2015.07.014

Iddris NA, Corre MD, Straaten O et al (2021) Substantial stem methane emissions from rainforest and cacao agroforest partly negate soil uptake in the Congo Basin. J Geophys Res Biogeosci 126(10). doi: 10.1029/2021JG006312

Iddris NA, Corre MD, Yemefack M et al (2020) Stem and soil nitrous oxide fluxes from rainforest and cacao agroforest on highly weathered soils in the Congo Basin. Biogeosciences 17(21):5377–5397. doi: 10.5194/bg-17-5377-2020

IPCC Guidelines for National Greenhouse Gas Inventories (2006) Chapter 11: N_2O emissions from managed soils, and CO_2 emissions from lime and urea application

Ishizuka S, Tsuruta H, Murdiyarso D (2002) An intensive field study on CO_2, CH_4, and N_2O emissions from soils at four land-use types in Sumatra, Indonesia. Global Biogeochem Cycles 16(3):1049. doi: 10.1029/2001GB001614

ISRIC (2002) Procedures for soil analysis. LP van Reeuwijk (ed). Wageningen, The Netherlands

Itoh M, Kosugi Y, Takanashi S et al (2012) Effects of soil water status on the spatial variation of carbon dioxide, methane and nitrous oxide fluxes in tropical rain-forest soils in Peninsular Malaysia. J Trop Ecol 28(6):557–570. doi: 10.1017/S0266467412000569

Iwasaki S, Endo Y, Hatano R (2017) The effect of organic matter application on carbon sequestration and soil fertility in upland fields of different types of Andosols. Soil Sci Plant Nutr 63(2)(2):200–220. doi: 10.1080/00380768.2017.1309255

Jahn R, Asio VB (1998) Soils of the tropical forests of Leyte, Philippines I: Weathering, soil charcateristics, classification and site qualities. In: Schulte A, Ruhiyat D (eds) Soils of tropical forest ecosystems. Springer Verlag, Berlin, pp 29–36

Jia G, Shevliakova E, Artaxo P et al (2019) Land-climate interactions. In: Shukla PR, Skea J, Calvo Buendia E et al (eds) Climate Change and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. pp 131–247

Kawanishi M, Kato M, Matsuda E, Fujikura R (2019) Comparative study of reporting for transparency under international agreements on climate change and ozone protection: the case of the Philippines. Int J Environ Sci Technol 10(1):1–8. doi: 10.18178/ijesd.2019.10.1.1137

Kawanishi M, Kato M, Matsuda E et al (2020) Comparative study on institutional designs and performance of national greenhouse gas inventories: the cases of Vietnam and the Philippines. Environ Dev Sustain 22(6):5947–5964. doi: 10.1007/s10668-019-00460-y

Koehler B, Corre MD, Steger K et al (2012) An in-depth look into a tropical lowland forest soil: nitrogen-addition effects on the contents of N_2O, CO_2 and CH_4 and N_2O isotopic signatures down to 2-m depth. Biogeochemistry 111(1-3):695–713. doi: 10.1007/s10533-012-9711-6

Koehler B, Corre MD, Veldkamp E, Sueta JP (2009a) Chronic nitrogen addition causes a reduction in soil carbon dioxide efflux during the high stem-growth period in a tropical montane forest but no response from a tropical lowland forest on a decadal time scale. Biogeosciences 6(12):2973–2983. doi: 10.5194/bg-6-2973-2009

Koehler B, Corre MD, Veldkamp E et al (2009b) Immediate and long-term nitrogen oxide emissions from tropical forest soils exposed to elevated nitrogen input. Glob Chang Biol 15(8):2049–2066. doi: 10.1111/j.1365-2486.2008.01826.x

Koga N, Shimoda S, Shirato Y et al (2020) Assessing changes in soil carbon stocks after land use conversion from forest land to agricultural land in Japan. Geoderma 377:114487. doi: 10.1016/j.geoderma.2020.114487

Kummer DM (1992) Upland agriculture, the land frontier and forest decline in the Philippines. Agroforest Syst 18:31–46. doi: 10.1007/BF00114815

Kurniawan S, Corre MD, Matson AL, Schulte-Bisping H, Utami SR, van Straaten O, Veldkamp E (2018) Conversion of tropical forests to smallholder rubber and oil palm plantations impacts nutrient leaching losses and nutrient retention efficiency in highly weathered soils. Biogeosciences 15(16):5131–5154. doi: 10.5194/bg-15-5131-2018

Librero AR, Rola AC (2000) Philippines. In: Ali M (ed) Dynamics of vegetable production, distribution and consumption in Asia. AVRDC Publication No. 00-498. Shanhua, Tainan, pp 303–347

Maier RM (2009) Biogeochemical Cycling. In: Maier RM, Pepper IL, Gerba CP (eds) Environmental Microbiology, 2nd edn. Elsevier, pp 287–318. doi: 10.1016/B978-0-12-370519-8.00014-6

Malhi Y, Baldocchi DD, Jarvis PG (1999) The carbon balance of tropical, temperate and boreal forests. Plant Cell Environ 22:715–740. doi: 10.1046/j.1365-3040.1999.00453.x

Margraf J, Milan PP (1996) Ecology of dipterocarp forests and its relevance for island rehabilitation in Leyte, Philippines. In: Schulte A, Schöne D (eds) Dipterocarp forest ecosystems: towards sustainable management. World Scientific Singapore, pp 124–154

Matson AL, Corre MD, Langs K, Veldkamp E (2017) Soil trace gas fluxes along orthogonal precipitation and soil fertility gradients in tropical lowland forests of Panama. Biogeosciences 14(14):3509–3524. doi: 10.5194/bg-14-3509-2017

McKergow LA, Prosser IP, Grayson RB, Heiner D (2004) Performance of grass and rainforest riparian buffers in the wet tropics, Far North Queensland. 2. Water quality. Soil Res. 42(4):485. doi: 10.1071/SR02156

Meijide A, de la Rua C, Guillaume T et al (2020) Measured greenhouse gas budgets challenge emission savings from palm-oil biodiesel. Nat Commun 11(1):1089. doi: 10.1038/s41467-020-14852-6

Mori N, Kato M, Kim S et al (2014) Local amplification of storm surge by Super Typhoon Haiyan in Leyte Gulf. Geophysical research letters 41(14):5106–5113. doi: 10.1002/2014GL060689

Mosier A, Wassmann R, Verchot L et al (2004) Methane and nitrogen oxide fluxes in tropical agricultural soils: Sources, sinks and mechanisms. Environ Dev Sustain 6:11–49. doi: 10.1023/B:ENVI.0000003627.43162.ae

Mukumbuta I, Shimizu M, Hatano R (2017a) Mitigating global warming potential and greenhouse gas intensities by applying composted manure in cornfield: A 3-year field study in an Andosol soil. Agriculture 7(2):13. doi: 10.3390/agriculture7020013

Mukumbuta I, Shimizu M, Jin T et al (2017b) Nitrous and nitric oxide emissions from a cornfield and managed grassland: 11 years of continuous measurement with manure and fertilizer applications, and land-use change. Soil Sci Plant Nutr 63(2):185–199. doi: 10.1080/00380768.2017.1291265

Murty D, Kirschbaum MUF, Mcmurtrie RE, Mcgilvray H (2002) Does conversion of forest to agricultural land change soil carbon and nitrogen? a review of the literature. Glob Chang Biol 8(2):105–123. doi: 10.1046/j.1354-1013.2001.00459.x

Navarrete IA, Tsutsuki K, Kondo R, Asio VB (2008) Genesis of soils across a late Quaternary volcanic landscape in the humid tropical island of Leyte, Philippines. Soil Res 46(5):403. doi: 10.1071/SR08012

Ogle SM, Buendia L, Butterbach-Bahl K et al (2013) Advancing national greenhouse gas inventories for agriculture in developing countries: improving activity data, emission factors and software technology. Environ Res Lett 8(1):15030. doi: 10.1088/1748-9326/8/1/015030

Paul S, Veldkamp E, Flessa H (2008) Soil organic carbon in density fractions of tropical soils under forest – pasture – secondary forest land use changes. Eur J Soil Sci 59(2):359–371. doi: 10.1111/j.1365-2389.2007.01010.x

Piñeiro G, Oesterheld M, Batista WB, Paruelo JM (2006) Opposite changes of whole-soil vs. pools C:N ratios: a case of Simpson's paradox with implications on nitrogen cycling. Glob Chang Biol 12(5):804–809. doi: 10.1111/j.1365-2486.2006.01139.x

Powers JS, Corre MD, Twine TE, Veldkamp E (2011) Geographic bias of field observations of soil carbon stocks with tropical land-use changes precludes spatial extrapolation. Proc Natl Acad Sci USA 108(15):6318–6322. doi: 10.1073/pnas.1016774108

Purbopuspito J, Veldkamp E, Brumme R, Murdiyarso D (2006) Trace gas fluxes and nitrogen cycling along an elevation sequence of tropical montane forests in Central Sulawesi, Indonesia. Global Biogeochem Cycles 20(3):GB3010. doi: 10.1029/2005GB002516

R Core Team (2020) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria

Raich JW, Tufekcioglu A (2000) Vegetation and soil respiration: Correlations and controls. Biogeochemistry 48:71–90. doi: 10.1023/A:1006112000616

Ravishankara AR, Daniel JS, Portmann RW (2009) Nitrous oxide (N_2O): The dominant ozone-depleting substance emitted in the 21st century. Science 326(5949):123–125. doi: 10.1126/science.1176985

Rezaei Rashti M, Wang W, Moody P et al (2015) Fertiliser-induced nitrous oxide emissions from vegetable production in the world and the regulating factors: A review. Atmos Environ 112:225–233. doi: 10.1016/j.atmosenv.2015.04.036

Sauerbeck DR (2001) CO_2 emissions and C sequestration by agriculture - perspectives and limitations. Nutr Cycl Agroecosyst 60:253–266. doi: 10.1023/A:1012617516477

Schlesinger WH, Bernhardt ES (2013) Biogeochemistry: an analysis of global change, 3rd edn. Academic Press, Amsterdam

Schneider T, Ashton MS, Montagnini F, Milan PP (2014) Growth performance of sixty tree species in smallholder reforestation trials on Leyte, Philippines. New Forests 45(1):83–96. doi: 10.1007/s11056-013-9393-5

Silver WL, Scatena FN, Johnson AH et al (1996) Temporal disturbance affecting belowground nutrient pools. Biotropica 28:441–457. doi: 10.2307/2389087

Sotta ED, Veldkamp E, Schwendenmann L et al (2007) Effects of an induced drought on soil carbon dioxide (CO_2) efflux and soil CO_2 production in an Eastern Amazonian rainforest, Brazil. Glob Biogeochem Cycles 13(10):2218–2229. doi: 10.1111/j.1365-2486.2007.01416.x

Stolk PC, Hendriks RFA, Jacobs CMJ et al (2011) Modelling the effect of aggregates on N_2O emission from denitrification in an agricultural peat soil. Biogeosciences 8(9):2649–2663. doi: 10.5194/bg-8-2649-2011

Takagi H, Esteban M, Shibayama T et al (2017) Track analysis, simulation, and field survey of the 2013 Typhoon Haiyan storm surge. J Flood Risk Manag 10(1):42–52. doi: 10.1111/jfr3.12136

Tate KR, Ross DJ, Saggar S et al (2007) Methane uptake in soils from *Pinus radiata* plantations, a reverting shrubland and adjacent pastures: Effects of land-use change, and soil texture, water and mineral nitrogen. Soil Biol Biochem 39(7):1437–1449. doi: 10.1016/j.soilbio.2007.01.005

Tchiofo Lontsi R, Corre MD, Iddris NA, Veldkamp E (2020) Soil greenhouse gas fluxes following conventional selective and reduced-impact logging in a Congo Basin rainforest. Biogeochemistry 151(2-3):153–170. doi: 10.1007/s10533-020-00718-y

Tchiofo Lontsi R, Corre MD, van Straaten O, Veldkamp E (2019) Changes in soil organic carbon and nutrient stocks in conventional selective logging versus reduced-impact logging in rainforests on highly weathered soils in Southern Cameroon. For Ecol Manag 451:117522. doi: 10.1016/j.foreco.2019.117522

UNFCCC (1999) The Philippines' initial national communication on climate change. https://unfccc.int/documents/139218. Accessed 10 November 2021

UNFCCC (2014) Second national communication to the United Nations Framework Convention on Climate Change: Philippines. https://unfccc.int/documents/139241. Accessed 10 November 2021

van Breemen N, Mulder J, Driscoll CT (1983) Acidification and alkalinization of soils. Plant Soil 75(3):283–308. doi: 10.1007/BF02369968

van Straaten O, Corre MD, Wolf K et al (2015) Conversion of lowland tropical forests to tree cash crop plantations loses up to one-half of stored soil organic carbon. Proc Natl Acad Sci USA 112(32):9956–9960. doi: 10.1073/pnas.1504628112

van Straaten O, Veldkamp E, Corre MD (2011) Simulated drought reduces soil CO_2 efflux and production in a tropical forest in Sulawesi, Indonesia. Ecosphere 2(10)(10):119. doi: 10.1890/ES11-00079.1

Veldkamp E (1994) Organic carbon turnover in three tropical soils under pasture after deforestation. Soil Sci Soc Am J 58(1):175–180. doi: 10.2136/sssaj1994.03615995005800010025x

Veldkamp E, Keller M, Nuñez M (1998) Effects of pasture management on N_2O and NO emissions from soils in the humid tropics of Costa Rica. Glob Biogeochem Cycles 12(1):71–79. doi: 10.1029/97GB02730

Veldkamp E, Koehler B, Corre MD (2013) Indications of nitrogen-limited methane uptake in tropical forest soils. Biogeosciences 10(8):5367–5379. doi: 10.5194/bg-10-5367-2013

Veldkamp E, Purbopuspito J, Corre MD et al (2008) Land use change effects on trace gas fluxes in the forest margins of Central Sulawesi, Indonesia. J Geophys Res 113(G2):n/a-n/a. doi: 10.1029/2007JG000522

Veldkamp E, Schmidt M, Powers JS, Corre MD (2020) Deforestation and reforestation impacts on soils in the tropics. Nat Rev Earth Environ 1(11):590–605. doi: 10.1038/s43017-020-0091-5

Venables WN, Ripley BD (2002) Modern applied statistics with S. Springer, New York

Wickham H (2016) ggplot2: Elegant graphics for data analysis. Springer International Publishing, AG Switzerland

Wolf K, Flessa H, Veldkamp E (2012) Atmospheric methane uptake by tropical montane forest soils and the contribution of organic layers. Biogeochemistry 111(1-3):469–483. doi: 10.1007/s10533-011-9681-0

World Health Organization (2010) WHO recommended classification of pesticides by hazard and guidelines to classification 2009. World Health Organization, Geneva, Switzerland

Wuebbles DJ, Hayhoe K (2002) Atmospheric methane and global change 57:177–210. doi: 10.1016/S0012-8252(01)00062-9

Yagioka A, Komatsuzaki M, Kaneko N, Ueno H (2015) Effect of no-tillage with weed cover mulching versus conventional tillage on global warming potential and nitrate leaching. Agric Ecosyst Environ 200:42–53. doi: 10.1016/j.agee.2014.09.011

Zhao JF, Peng SS, Chen MP et al (2019) Tropical forest soils serve as substantial and persistent methane sinks. Scientific reports 9(1):16799. doi: 10.1038/s41598-019-51515-z

Zuur AF, Ieno EN, Walker NJ et al (2009) Mixed effects models and extensions in ecology with R. Springer, New York

2.8. Appendices

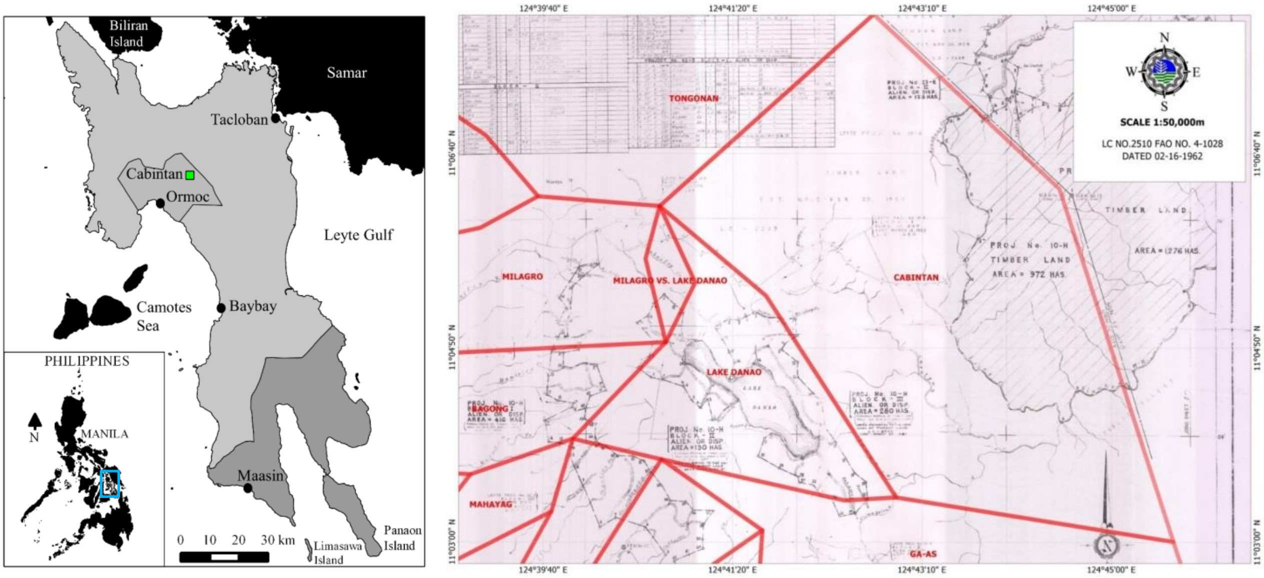

Fig. A2.1 The study area at Cabintan, Ormoc, Leyte, Philippines (a), and the first land classification map of Cabintan in the 1960s that had still timberland (b; red lines indicate local administration area; Department of Environment and Natural Resources 1962)

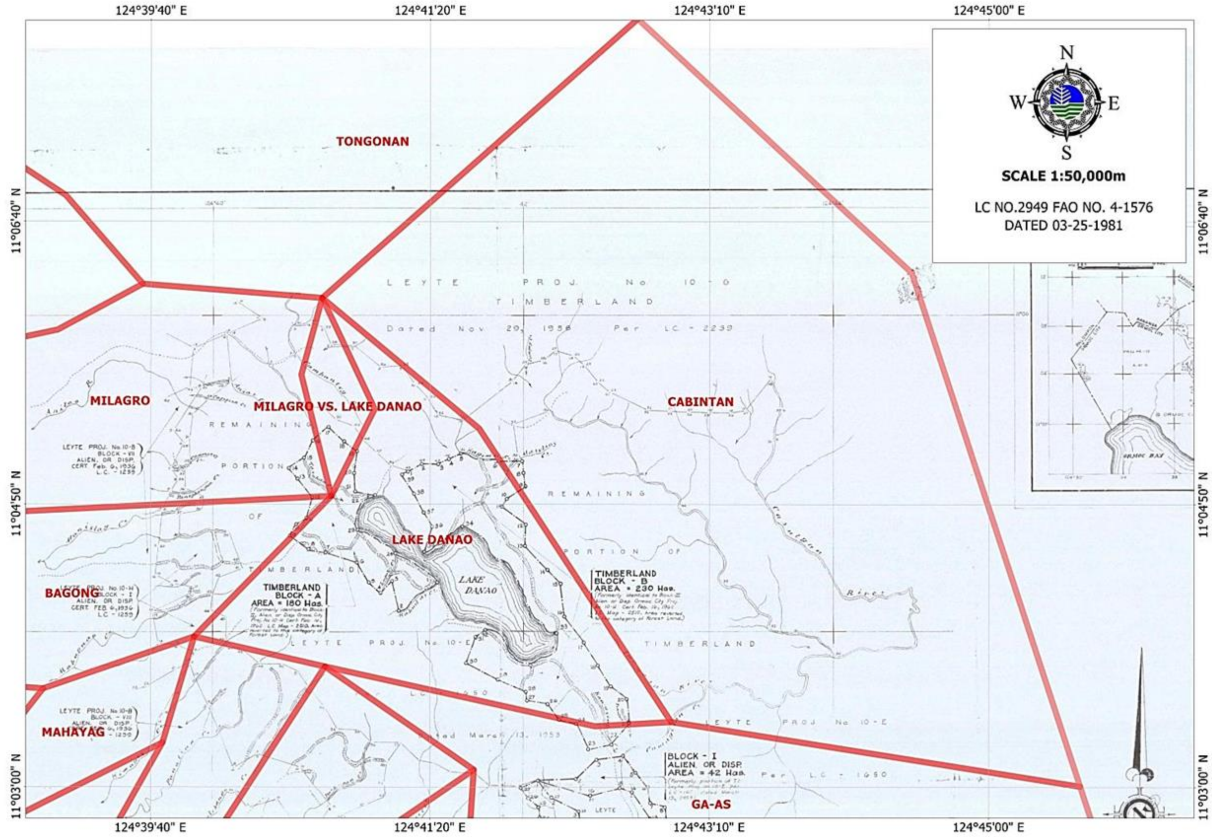

Fig. A2.2 The second land classification map of Cabintan, Ormoc, Leyte, Philippines in the 1980s, showing the disappearance of the earlier timberland and attesting to increased populace intrusion in the area (red lines indicate local administration area; Department of Environment and Natural Resources 1981)

Table A2.1

Land-use history of Cabintan, Ormoc, Leyte, Philippines. This is an amalgamation of information gathered from personal interviews with farmer collaborators and locals, communication with government agencies, values displayed in land classification maps, knowledge from earlier studies conducted in the area, and other supporting materials

Year	Significant events on land-use conversion and change of priority crops during each decade
1950s	▪ Philippines' deforestation rates demonstrated a continuous decline in forest areas since the 1950s (Kummer 1992). Deforestation and land degradation were mainly caused by unregulated logging and agricultural expansion – the latter partly linked to upland migration (Pulhin et al. 2006) and consequently resulting to further encroachment into forested areas. ▪ Cabintan is a typical example of this land-use pressure caused by the displacement of the increasing population in the lowlands, who were searching for agricultural land. This area was vastly covered by old-growth dipterocarp forest in the 1950s (Asio et al. 1998; Margraf and Milan 1996) prior to populace intrusion that started shortly after World War II and began subsistence agriculture on an Andosol soil.
1960–1970	▪ The first land classification (LC) map of Cabintan (LC No. 2510, Forestry Administrative Order (FAO) No. 4–1028; dated February 16, 1962) showed the extent of its land uses: 970 ha on forests and 825 ha for other purposes (Department of Environment and Natural Resources 1962) (Fig. A2.1). The national government initiated the first National Forest Inventory of the country in 1965 until 1969 (Food and Agriculture Organization of the United Nations 2007) and produced this map, indicating an earlier settlement in Cabintan since the 1960s. A relatively small community, practicing subsistence farming, cultivated root crops and banana as staple crops as well as a commercial crop, coconut (*Cocos nucifera* L.). The demand for copra and other coconut products has encouraged small-scale farmers in Cabintan to grow this perennial crop.

Table A2.1 continuation…

Year	Significant events on land-use conversion and change of priority crops during each decade
1960–1970	It was in the 1960s onwards, when the height of expansive cultivation of coconut was promoted to support global demand (i.e. from 1.6 million ha planted to coconut in 1960, it increased to 2.3 million ha in 1975 and generated parallel increase of total copra production from 1.6 to 2.3 × 10^6 Mg yr^{-1} (Philippine Coconut Authority; https://pca.gov.ph/index.php/about-us/pca-history) in succeeding years.
1980–1990	▪ The abundance of subsistence crops in the 1980s gathered farmers in a competition for the highest harvests of root crops (sweet potato, *Ipomea batatas*; cassava, *Manihot esculenta*; banana, *Musa sp.*). This seasonal activity for entertainment embraced winners who bagged the most abundant and large-sized harvests. It was during this height of subsistence farming, the name “Victory” was used before its official community name “Cabintan” (farmer collaborator Mr. Antonio Luyao, personal communication). ▪ The second nationwide forest inventory in 1978–1988 which produced the LC map No. 2949, FAO No. 4–1576 on March 25, 1981 (Department of Environment and Natural Resources 1981) (Fig. A2.2) further attested to the populace entry in Cabintan and subsequently to continuing agricultural cultivation of coconut and corn as priority crops. Corn cultivation became a replacement for lowland rice. The production of corn has instigated more clearing and burning of forests. Farmers had noticed how corn grew well in newly cleared initially fertile soil. However, its production dwindled markedly until the late 1980s, as corn manifested nutrient deficiencies (yellowing, purpling, and stunted growth) with age of cultivated land, presumably due to continued reduction in soil fertility. This led to abandoning of exhausted fields and clearing of new forest areas.

Table A2.1 continuation…

Year	Significant events on land-use conversion and change of priority crops during each decade
1990 to the early years of 2000	▪ The declining returns of subsistence crops (root crops and corn) encouraged farmers to venture on a fiber crop, abaca or Manila hemp (*Musa textiles* Née). Its cultivation as a third phase crop in nutrient-drained Andosol soils deemed lucrative and went extensive in the early 1990s, widely replacing corn. Abaca has a good fiber quality and is utilized as raw material for various purposes (Armecin and Gabon 2008) and has been a premier export commodity, similar with coconut. ▪ However, almost a decade after its initial cultivation the virulent bunchy top virus jeopardized the fiber's marketable quality and consequently reduced its harvests. This led in farmers' shift to vegetable production.
Early 2000–present	▪ Cultivation of seasonal vegetable crops begun, which mostly included tomato (*Solanum lycopersicum* L.), spring onion (*Allium fistulosum* L.), beans (*Phaseolus lunatus* L.), eggplant (*Solanum melongena* L.), pechay (*Brassica chinensis* L.) and chayote (*Sechium edule* (Jacq). Sw.) (Szinicz et al. 2005). ▪ In succeeding years, farmers were learning to grow more high-value vegetables, such as cabbages (*Brassica* sp.), sweet pepper (*Capsicum* sp.), broccoli (*Brassica oleracea* var. *italica*), squash (*Cucurbita* sp.), and white radish (*Raphanus sativus*). Many farmers claimed that the very first vegetable that Cabintan learned to cultivate skillfully was head cabbage (Mr. A. Luyao, personal communication). ▪ More farmers were encouraged to grow vegetables from a backyard scale (5–50 m^2) to an upscale, eventually adopting this as their means of income. However, increased vegetable production brought a parallel increase in clearing and burning of forests. ▪ Combined application of mineral fertilizers and chicken manure was based on rough estimation and rarely based on recommended rates.

Table A2.1 continuation…

Year	Significant events on land-use conversion and change of priority crops during each decade
Early 2000–present	▪ Hence, most fertilization rates are above suggested rates. The same holds for crop protection practices, whereby varied mixtures of pesticides comprised active ingredients that were moderately to highly hazardous. ▪ The total population in Cabintan in 2017 was 2300 residents, equivalent to ~ 500 households and projected to increase in 2020 to about 2460 individuals or 540 households (City Planning and Development Office 2017). More than 90% of this community was engaged into intensively managed vegetable production on small-scale land area. Currently, three farmer associations are recognized – namely, Citio Cabintan Vegetable Farmers Association (CICAVFA), Cabintan Farmers' Association (CAFA) and Cabintan Livelihood Community Association (CALCOA). These associations are either under the supervision of the local government units through the Agriculture Office of Ormoc City in collaboration with the Agriculture Training Institute of the regional government, or the private sector Energy Development Corporation (EDC), the largest producer of geothermal energy-generated electricity in the Philippines. This collaboration rendered support to small-scale farmers of Cabintan either through technical assistance related to vegetable production or by the input of corn-sheller and post-harvest facilities. ▪ Overall, vegetable production remained economically attractive for the community and had resulted in more clearing and burning of forests at elevations higher than 700 m above sea level (personal observation during the study period).

Table A2.2

Soil greenhouse gas balance in small-scale vegetable production (n = 10 farms) on an Andosol soil in Leyte, Philippines

Farm and Crop	Plant biomass (Mg ha^{-1} cropping^{-1}) [a]	NPP (Mg C ha^{-1} yr^{-1}) [b]	Chicken manure (Mg C ha^{-1} yr^{-1})	Heterotrophic respiration (Mg C ha^{-1} yr^{-1})	NEE (Mg CO_2 ha^{-1} yr^{-1}) [c]	Vegetable harvested yield (Mg CO_2 ha^{-1} yr^{-1})	NEP (Mg CO_2 ha^{-1} yr^{-1}) [d]	Ann. soil N_2O flux (Mg CO_2-eq ha^{-1} yr^{-1}) [e]	Ann. soil CH_4 flux (Mg CO_2-eq ha^{-1} yr^{-1}) [f]	GWP (Mg CO_2-eq ha^{-1} yr^{-1}) [g]
Farm 1		1.0	2.5	7.5	15.0	2.3	17.3	16.0	–0.03	33.2
B. rapa subsp. *pekinensis* (first)	1.7									
B. oleracea var. *capitata* (second)	0.7									
B. rapa subsp. *pekinensis* (third)	0.1									
Farm 2		1.7	3.1	8.2	12.3	3.9	16.2	3.2	–0.05	19.3
B. rapa subsp. *pekinensis* (first)	1.8									
B. rapa subsp. *pekinensis* (second)	0.7									
B. rapa subsp. *pekinensis* (third)	2.2									
Farm 3		1.0	3.1	13.1	33.1	2.1	35.2	6.4	–0.03	41.5
S. lycopersicum L. (first)	1.3									
B. oleracea var. *capitata* (second)	1.1									
Farm 4		0.6	2.6	8.9	20.8	1.5	22.3	3.5	–0.04	25.8
S. lycopersicum L. (first)	0.2									
B. oleracea var. *capitata* (second)	0.6									
B. oleracea var. *capitata* (third)	0.6									

Table A2.2 continuation…

Farm and Crop	Plant biomass (Mg ha^{-1} cropping^{-1}) [a]	NPP (Mg C ha^{-1} yr^{-1}) [b]	Chicken manure (Mg C ha^{-1} yr^{-1})	Heterotrophic respiration (Mg C ha^{-1} yr^{-1})	NEE (Mg CO_2 ha^{-1} yr^{-1}) [c]	Vegetable harvested yield (Mg CO_2 ha^{-1} yr^{-1})	NEP (Mg CO_2 ha^{-1} yr^{-1}) [d]	Ann. soil N_2O flux (Mg CO_2-eq ha^{-1} yr^{-1}) [e]	Ann. soil CH_4 flux (Mg CO_2-eq ha^{-1} yr^{-1}) [f]	GWP (Mg CO_2-eq ha^{-1} yr^{-1}) [g]
Farm 5		2.2	2.9	8.5	12.5	2.5	14.9	3.2	–0.01	18.1
S. lycopersicum L. (first)	1.1									
Cucurbita sp. (second)	0.4									
C. annuum L. (third)	1.8									
Farm 6		0.7	1.3	10.1	29.8	1.1	30.9	6.1	–0.04	37.0
C. annuum L. (first)	1.1									
S. lycopersicum L. (second)	0.4									
Farm 7		0.9	3.7	12.0	27.1	2.6	29.7	4.8	–0.04	34.4
A. fistulosum L. (first)	0.6									
A. fistulosum L. (second)	0.4									
B. rapa subsp. *pekinensis* (third)	1.3									
Farm 8		0.9	3.9	10.6	21.2	1.6	22.8	3.3	–0.02	26.1
S. lycopersicum L. (first)	0.4									
S. melongena L. (second)	1.9									
Farm 9		1.1	0.9	11.0	33.2	2.1	35.4	6.6	–0.06	41.9
B. rapa subsp. *pekinensis* (first)	0.3									
S. melongena L. (second)	2.9									

Table A2.2 continuation…

Farm and Crop	Plant biomass (Mg ha^{-1} cropping^{-1}) [a]	NPP (Mg C ha^{-1} yr^{-1}) [b]	Chicken manure (Mg C ha^{-1} yr^{-1})	Heterotrophic respiration (Mg C ha^{-1} yr^{-1})	NEE (Mg CO_2 ha^{-1} yr^{-1}) [c]	Vegetable harvested yield (Mg CO_2 ha^{-1} yr^{-1})	NEP (Mg CO_2 ha^{-1} yr^{-1}) [d]	Ann. soil N_2O flux (Mg CO_2-eq ha^{-1} yr^{-1}) [e]	Ann. soil CH_4 flux (Mg CO_2-eq ha^{-1} yr^{-1}) [f]	GWP (Mg CO_2-eq ha^{-1} yr^{-1}) [g]
Farm 10		1.9	1.9	10.4	24.5	3.3	27.7	6.2	–0.04	33.9
B. rapa subsp. *pekinensis* (first)	1.3									
B. rapa subsp. *pekinensis* (second)	0.1									
Capsicum sp. (third)	2.9									
Mean ± SE		1.2 ± 0.2	2.6 ± 0.3	10.0 ± 0.6	23.0 ± 2.5	2.3 ± 0.3	25.2 ± 2.4	6.0 ± 1.2	–0.04 ± 0.01	31.1 ± 2.7

[a] Includes aboveground and root biomass calculated using harvest index (HI) and root:shoot ratio (R/S), respectively. *B. rapa* subsp. *pekinensis*: 0.7 (Jölli D and Giljum S 2005; Kastner 2007), 0.1 (Murakami et al. 2002); *B. oleracea* var. *capitata*: 0.8 (Roa 2007), 0.1 (Murakami et al. 2002); *S. lycopersicum* L. : 0.5 (Apilar 2002), 0.4 (Somraj et al. 2018); *Cucurbita* sp. : 0.2 (Amer 2011), 0.1 (Lin et al. 2020); *C. annuum* L. : 0.5 (Gutierrez 1998), 0.1 (average R/S ratio from the values of Lacostales 2015 and Salas 2008); *A. fistulosum* L. : 1.0 (HI estimated from this study and encompasses both aboveground and root biomass); *S. melongena* L. : 0.7 (Mangalao 2003), 0.3 (Kirnak et al. 2002); *Capsicum* sp. : 0.5 (Gutierrez 1998), 0.1 (average R/S ratio from the values of Lacostales 2015 and Salas 2008)

[b] NPP is net primary production; conversion of plant biomass to C was based on the C analysis of each vegetable.

[c] NEE is net ecosystem C exchange = heterotrophic respiration – (NPP + chicken manure-C) (Malhi et al. 1999); heterotrophic respiration was represented by the soil CO_2-C emissions from the inter-rows, as this cultivation zone did not have plant roots

[d] NEP is net ecosystem productivity = NEE + C exported by harvested yield (Meijide et al. 2020). NEP was multiplied by 3.67 to convert C to CO_2

[e] Conversion factor of N_2O to CO_2 equivalent (CO_2-eq) is 298 for 100-year time frame (IPCC Guidelines for National Greenhouse Gas Inventories 2006)

[f] Conversion factor of CH_4 to CO_2-eq is 25 for 100-year time frame (IPCC Guidelines for National Greenhouse Gas Inventories 2006)

[g] Global Warming Potential = d + e + f

Table A2.3

Mean (± SE) annual soil N_2O, CH_4, and CO_2 fluxes from forests on mineral soils in Southeast Asia [a]

Location	Forest type	Elevation (m above sea level)	Soil type	Annual soil greenhouse gas fluxes			Reference
				Soil N_2O (kg N ha^{-1} yr^{-1})	Soil CH_4 (kg C ha^{-1} yr^{-1})	Soil CO_2 (Mg C ha^{-1} yr^{-1})	
Lampung, Indonesia (04° 55' S, 104° 34' E)	Upland	992	Andosol	< 2			Verchot et al. 2006[b]
Jambi, Indonesia (01° 05.2' S, 102° 05.7' E)	Lowland	117–120	Ferralsol	0.3	–0.8	6.9	Ishizuka et al. 2002[c]
Jambi, Indonesia (1° 04' 36.3'' S, 102° 6' 3.6'' E)	Lowland	104	Ferralsol	1.7 ± 0.5			Aini et al. 2015
Jambi, Indonesia (1.94° S, 102.85° E)	Lowland	35–95	Clay Acrisol	1.0 ± 0.4	–3.6 ± 0.9	16.9 ± 1.2	Hassler et al. 2015, 2017
Jambi, Indonesia (1.79° S, 103.36° E)	Lowland	35–95	Loam Acrisol	0.9 ± 0.2	–0.18 ± 1.6	16.2 ± 1.2	Hassler et al. 2015, 2017
Central Sulawesi, Indonesia (01° 16' S, 120° 18' E)	Montane	2470	Cambisol	1.0 ± 0.2	–1.5 ± 0.2		Purbopuspito et al. 2006

Table A2.3 continuation…

Location	Forest type	Elevation (m above sea level)	Soil type	Annual soil greenhouse gas fluxes			Reference
				Soil N_2O (kg N ha^{-1} yr^{-1})	Soil CH_4 (kg C ha^{-1} yr^{-1})	Soil CO_2 (Mg C ha^{-1} yr^{-1})	
Central Sulawesi, Indonesia (01° 19' S, 120° 18' E)	Montane	1800	Cambisol	0.3 ± 0.02	–3.3 ± 0.7		Purbopuspito et al. 2006
Central Sulawesi, Indonesia (01° 25' S, 120° 17' E)	Montane	1190	Regosol	1.1 ± 0.2	–2.5 ± 0.9		Purbopuspito et al. 2006[d]
Central Sulawesi, Indonesia (1.5° S, 120.1° E)	Sub-montane	1050	Nitisol			11.7 ± 1.1	van Straaten et al. 2011
Negeri Sembilan, Peninsular Malaysia (2.0° 59' N, 102° 18' E)	Lowland	120–150	Acrisol	8.7	–1.3	17.7	Itoh et al. 2012[e]
Leyte, Philippines (11° 03–06' N, 124° 42–45' E)	Secondary	700–900	Andosol	0.10 ± 0.02	–2.0 ± 0.2	8.2 ± 0.7	This study

[a] Include studies with at least one year of measurements using vented or closed static chamber technique and the annual means ± SE are provided in the text, table, figure or calculated from mean flux rates. This list is not meant to be complete but only for providing an overview of the range of published data for comparison with our present study

[b] Average soil N_2O flux was estimated from Figure 3 of the study's results

[c] Average soil N_2O, CH_4, and CO_2 fluxes were calculated from two forest sites

[d] Regosol, the nearest FAO soil classification equivalent to Entisol; the latter soil order was mentioned in the study

[e] Average fluxes were estimated from serial calculations of the mean soil N_2O, CH_4, and CO_2 flux rates

Table A2.4

Soil N_2O, CH_4, and CO_2 fluxes from annual and perennial croplands on Andosol soil [a]

Location	Land use/ crop	Measurement duration (months)	N fertilization rate		Soil greenhouse gas fluxes			Reference
			(kg N ha^{-1})	(kg N ha^{-1} yr^{-1})	Soil N_2O (µg N m^{-2} hr^{-1})	Soil CH_4 (µg C m^{-2} hr^{-1})	Soil CO_2 (mg C m^{-2} hr^{-1})	
Tsukuba, Japan (36° 01' N, 140° 07' E)	Chinese cabbage	2.7	200		23.4			Cheng et al. 2002[b]
Tsukuba, Japan (36° 01' N, 140° 07' E)	Chinese cabbage	2.7	250		26.7			Cheng et al. 2002[b]
Tsukuba, Japan (36° 01' N, 140° 07' E)	Chinese cabbage	2.7	250		26.3			Cheng et al. 2006[c]
Tsukuba, Japan (36° 01' N, 140° 07' E)	Chinese cabbage	6.5	250		10.2			Hou and Tsuruta 2003[d]
Tsukuba, Japan (36° 01' N, 140° 07' E)	*Brassica rapa*	2.7	120		4.5			Yamamoto et al. 2012[e]
Hokkaido, Japan (42° 26' N, 142° 29' E)	Corn field	4	184			–10 to 40	3 to 230	Hu et al. 2001[f]
Hokkaido, Japan (43° 0' N, 141° 24' E)	Corn field	24	160		280		*Plant row*: 130; *Inter-row*: 95	Kusa et al. 2006

Table A2.4 continuation…

Location	Land use/ crop	Measurement duration (months)	N fertilization rate		Soil greenhouse gas fluxes			Reference
			(kg N ha^{-1})	(kg N ha^{-1} yr^{-1})	Soil N_2O (µg N m^{-2} hr^{-1})	Soil CH_4 (µg C m^{-2} hr^{-1})	Soil CO_2 (mg C m^{-2} hr^{-1})	
Heredia Province, Costa Rica (10° 26' N, 84° 0' W)	Banana plantation	12		360	314			Veldkamp and Keller 1997
Heredia Province, Costa Rica (10° 2' N, 84° 55' W)	Pasture	12		300	258			Veldkamp et al. 1998
Heredia Province, Costa Rica (10° 20' N, 84° 55' W)	Pasture	12		300		–10.6		Veldkamp et al. 2001[g]
Leyte, Philippines (11° 03–06' N, 124° 42–45' E)	Vegetable farm	13	360	930	133.4 ± 19.7	–12.9 ± 0.9	130.3 ± 5.0	This study

[a] Include studies that employed vented or closed static chamber technique, whereby flux rates in means (with or without ± SE) or range are provided in the text, table or calculated from its total fluxes during a given period. This list is not meant to be complete but only for providing an overview of the range of published data for comparison with our present study

[b] Total emission (mg N m^{-2}) from four modes of urea application (broadcast, band, and coated applied in band mode) under two N fertilization rates were converted with 81 days cropping period, averaged, and then subtracted with the flux rate from the control plot

[c] Total emission (mg N m^{-2}) from four modes of urea application (broadcast, band, and controlled-release urea applied in band mode) were converted with 82 days cropping period, averaged, and then subtracted with the flux rate from the control plot

[d] Total emission (mg N m^{-2}) from four modes of urea application (broadcast, band, and coated applied in band mode) were

converted with 193 days cropping period, averaged, and then subtracted with the flux rate from the control plot

[e] Cumulative N_2O emissions (mg N_2O m^{-2}) from treatments consisting of N fertilizer forms (chemical compound, 100% lime N, 50% lime N, compound fertilizer with dicyandiamide) were converted with 80 days cropping period and then averaged

[f] Soil CH_4 flux was a conversion from mg C m^{-2} hr^{-1}

[g] Soil CH_4 flux was a conversion from mg CH_4 m^{-2} hr^{-1}

References used for the supplementary tables and figures

Aini FK, Hergoualc'h K, Smith JU, Verchot L (2015) Nitrous oxide emissions along a gradient of tropical forest disturbance on mineral soils in Sumatra. Agric Ecosyst Environ 214:107–117. doi: 10.1016/j.agee.2015.08.022

Amer KH (2011) Effect of irrigation method and quantity on squash yield and quality. Agric Water Manag 98(8):1197–1206. doi: 10.1016/j.agwat.2011.03.003

Apilar EG (2002) Horticultural and physiological responses of two tomato (*Lycopersicon esculentum* Mill) varities to open field. PhD thesis, Visayas State University, Leyte, Philippines

Armecin RB, Gabon FM (2008) Biomass, organic carbon and mineral matter contents of abaca (*Musa textilis* Nee) at different stages of growth. Ind Crops Prod 28(3):340–345. doi: 10.1016/j.indcrop.2008.03.014

Asio VB, Jahn R, Stahr K, Margraf J (1998) Soils of the tropical forests of Leyte, Philippines II: Impact of differrent land uses on status of organic matter and nutrient availability. In: Schulte A, Ruhiyat D (eds) Soils of tropical forest ecosystems. Springer Verlag, Berlin, pp 37-44

Cheng W, Nakajima Y, Sudo S et al (2002) N_2O and NO emissions from a field of Chinese cabbage as influenced by band application of urea or controlled-release urea fertilizers. Nutr Cycl Agroecosys 63:231–238. doi: 10.1023/A:1021119319439

Cheng W, Sudo S, Tsuruta H et al (2006) Temporal and spatial variations in N_2O emissions from a Chinese cabbage field as a function of type of fertilizer and application. Nutr Cycl Agroecosyst 74(2):147–155. doi: 10.1007/s10705-005-5965-x

City Planning and Development Office (2017) Ormoc City ecological profile 2017. http://www.ormoc.gov.ph/ormocweb/transparency/ecoprofile. Accessed 09 May 2019

Department of Environment and Natural Resources (1962) Land Classification No. 2510 Forestry Administrative Order No. 4-1028. Tacloban City, Leyte, Philippines

Department of Environment and Natural Resources (1981) Land Classification No. 2949 Forestry Administrative Order No. 4-1576. Tacloban City, Leyte, Philippines

Food and Agriculture Organization of the United Nations (2007) Brief on national forest inventory Philippines. MAR-SFM Working Paper 26/2007. FAO, Rome, Italy

Gutierrez MG (1998) Response of sweet pepper (*Capsicum annuum*) to organic (chicken dung) and inorganic fertilizers and and their combination. BSc. thesis, Visayas State University, Leyte, Philippines

Hassler E, Corre MD, Kurniawan S, Veldkamp E (2017) Soil nitrogen oxide fluxes from lowland forests converted to smallholder rubber and oil palm plantations in Sumatra, Indonesia. Biogeosciences 14(11):2781–2798. doi: 10.5194/bg-14-2781-2017

Hassler E, Corre MD, Tjoa A et al (2015) Soil fertility controls soil–atmosphere carbon dioxide and methane fluxes in a tropical landscape converted from lowland forest to rubber and oil palm plantations. Biogeosciences 12(19):5831–5852. doi: 10.5194/bg-12-5831-2015

Hou AX, Tsuruta H (2003) Nitrous oxide and nitric oxide fluxes from an upland field in Japan: effect of urea type, placement, and crop residues. Nutr Cycl Agroecosyst 65:191–200. doi: 10.1023/A:1022149901586

Hu R, Kusa K, Hatano R (2001) Soil respiration and methane flux in adjacent forest, grassland, and cornfield soils in Hokkaido, Japan. Soil Sci Plant Nutr 47(3):621–627. doi: 10.1080/00380768.2001.10408425

IPCC Guidelines for National Greenhouse Gas Inventories (2006) Chapter 11: N_2O emissions from managed soils, and CO_2 emissions from lime and urea application

Ishizuka S, Tsuruta H, Murdiyarso D (2002) An intensive field study on CO_2, CH_4, and N_2O emissions from soils at four land-use types in Sumatra, Indonesia. Global Biogeochem Cycles 16(3):1049. doi: 10.1029/2001GB001614

Itoh M, Kosugi Y, Takanashi S et al (2012) Effects of soil water status on the spatial variation of carbon dioxide, methane and nitrous oxide fluxes in tropical rain-forest soils in Peninsular Malaysia. J Trop Ecol 28(6):557–570. doi: 10.1017/S0266467412000569

Jölli D, Giljum S (2005) Unused biomass extraction in agriculture, forestry and fishery. Sustainable Europe Research Institute, Vienna, Austria. pp 1-40

Kastner T (2007) Human appropriation of net primary production (HANPP) in the Philippines 1910-2003: A socio-ecological analysis. Social Ecology Working Paper 92, Vienna, Austria. pp 1-107

Kirnak H, Tas I, Kaya C, Higgs D (2002) Effects of deficit irrigation on growth, yield and fruit quality of eggplant under semi-arid conditions. Aust J Agric Res 53(12):1367. doi: 10.1071/AR02014

Kummer DM (1992) Measuring forest decline in the Philippines: An exercise in historiography. Forest and Conservation History 36(4):185–189. doi: 10.2307/3983680

Kusa K, Hu R, Sawamoto T, Hatano R (2006) Three years of nitrous oxide and nitric oxide emissions from silandic andosols cultivated with maize in Hokkaido, Japan. Soil Sci Plant Nutr 52(1)(1):103–113. doi: 10.1111/j.1747-0765.2006.00009.x

Lacostales LE (2015) Influence of mulching on the growth and yield of sweet pepper (*Capsicum annuum* L.) grown in two types of cultivation systems. MSc. thesis, Visayas State University, Leyte, Philippines

Lin HH, Lin KH, Huang M, Su YR (2020) Use of non-destructive measurements to identify cucurbit species (*Cucurbita maxima* and *Cucurbita moschata*) tolerant to waterlogged conditions. Plants 1226(9). doi: 10.3390/plants9091226

Malhi Y, Baldocchi DD, Jarvis PG (1999) The carbon balance of tropical, temperate and boreal forests. Plant Cell Environ 22:715–740. doi: 10.1046/j.1365-3040.1999.00453.x

Mangalao EL (2003) The influence of pruning on the growth and yield of eggplant (*Solanum melongena* L.). BSc. thesis, Visayas State University, Leyte, Philippines

Margraf J, Milan PP (1996) Ecology of dipterocarp forests and its relevance for island rehabilitation in Leyte, Philippines. In: Schulte A, Schöne D (eds) Dipterocarp forest ecosystems: towards sustainable management. World Scientific Singapore, pp 124–154

Meijide A, de la Rua C, Guillaume T et al (2020) Measured greenhouse gas budgets challenge emission savings from palm-oil biodiesel. Nat Commun 11(1):1089. doi: 10.1038/s41467-020-14852-6

Murakami T, Yamada K, Yoshida S (2002) Root distribution of field-grown Chinese cabbage (*Brassica campestris* L.) under different fertilizer treatment. Soil Sci Plant Nutr 48(3):393–400. doi: 10.1080/00380768.2002.10409217

Pulhin JM, Chokkalingam U, Peras RJJ et al (2006) Historical Overview. In: Chokkalingam U, Carandang AP, Pulhin JM et al (eds) One century of forest rehabilitation in the Philippines: Approaches, outcomes, and lessons. Center for International Forestry Research, Bogor Indonesia, pp 6-41

Purbopuspito J, Veldkamp E, Brumme R, Murdiyarso D (2006) Trace gas fluxes and nitrogen cycling along an elevation sequence of tropical montane forests in Central Sulawesi, Indonesia. Global Biogeochem Cycles 20(3):GB3010. doi: 10.1029/2005GB002516

Roa FMG (2007) Performance of cabbage (*Brassica oleracea* var. *capitata* L.) genotypes under fine nets and in open field. BSc. thesis, Visayas State University, Leyte, Philippines

Salas RA (2008) Influence of irrigation methods and net barrier in chili pepper (*Capsicum annuum* L.) production. PhD thesis, Visayas State University, Leyte, Philippines

Somraj B, Reddy R, Reddy KR et al (2018) Generation mean analysis of yield components and yield in tomato (*Solanum lycopersicum* L.) under high temperature conditions. J Pharmacogn Phytochem 7(6):1704–1708

Szinicz G, Martin K, Sauerborn J (2005) Abundance of selected insect species in natural and agricultural habitats of a tropical upland (Leyte, Philippines). Agric Ecosyst Environ 111(1-4):104–110. doi: 10.1016/j.agee.2005.05.008

van Straaten O, Veldkamp E, Corre MD (2011) Simulated drought reduces soil CO_2 efflux and production in a tropical forest in Sulawesi, Indonesia. Ecosphere 2(10)(10):119. doi: 10.1890/ES11-00079.1

Veldkamp E, Keller M (1997) Nitrogen oxide emissions from a banana plantation in the humid tropics. J Geophys Res 102(D13):15889–15898. doi: 10.1029/97JD00767

Veldkamp E, Keller M, Nuñez M (1998) Effects of pasture management on N_2O and NO emissions from soils in the humid tropics of Costa Rica. Glob Biogeochem Cycles 12(1):71–79. doi: 10.1029/97GB02730

Veldkamp E, Weitz AM, Keller M (2001) Management effects on methane fluxes in humid tropical pasture soils. Biol Biochem 33:1493–1499. doi: 10.1016/S0038-0717(01)00060-8

Verchot LV, Hutabarat L, Hairiah K, van Noordwijk M (2006) Nitrogen availability and soil N_2O emissions following conversion of forests to coffee in southern Sumatra. Global Biogeochem Cycles 20(4):GB4008. doi: 10.1029/2005GB002469

Yamamoto A, Akiyama H, Naokawa T, Yagi K (2012) Effect of lime-nitrogen application on N_2O emission from an Andosol vegetable field. Soil Sci Plant Nutr 58(2)(2):245–254. doi: 10.1080/00380768.2012.667766

CHAPTER 3

YIELD RESPONSE AND PROFIT IN INTENSIVELY FERTILIZED VEGETABLE FARMS ON AN ANDOSOL SOIL IN LEYTE, PHILIPPINES

To be submitted to *Journal of the Science of Food and Agriculture*

Cecille Marie O. Quiñones[1], Edzo Veldkamp, Suzette B. Lina[2], Arwin O. Arribado[3], Marife D. Corre[1]

[1] Soil Science of Tropical and Subtropical Ecosystems, Faculty of Forest Sciences and Forest

Ecology, University of Goettingen, Buesgenweg 2, 37077 Goettingen, Germany

[2] Department of Soil Science, College of Agriculture and Food Science, Visayas State University Main Campus, Baybay City, 6521 Leyte, Philippines

[3] College of Agricultural and Environmental Sciences, Visayas State University Alangalang Campus, Alangalang, 6517 Leyte, Philippines

3.1. Abstract

Excessively fertilized vegetable farms are widespread in the Philippines; however, yield and profit remain below optimum while high crop production costs penalize farmers. The optimum levels of extant plant-available N and fertilization rates for N, P and K were determined in 10 intensively fertilized vegetable farms on an Andosol soil in Leyte, Philippines. Estimates for materials and labor costs, revenue, and profit were also evaluated covering a year of successive cropping periods. The optimum limits per cropping period for the extant mineral N was 230 kg N ha^{-1} and the fertilization rates for N, P and K were 290 kg N ha^{-1}, 200 kg P ha^{-1}, and 340 kg K ha^{-1}, respectively. These limits produced the ideal yield response of Chinese cabbage and solanaceous vegetables, its corresponding N response efficiency, and partial productivity factor from applied P and K. Temporary soil adsorption of nitrate was likely as indicated by its least dissolved concentration in drainage water at 0.3 m soil depth. Materials cost charged higher than labor cost to the total crop production cost, with variations dictated by fertilizer cost. Higher profit from solanaceous vegetables than cabbages was influenced by higher farm-gate price. The identified optimum nutrient and fertilizer limits provided the bases for potentially reducing both crop production costs and negative environmental consequences, while obtaining the ideal harvested yield and profit in intensively fertilized farms. These limits may also serve as initial step in promoting sustainability in heavily fertilized vegetable production systems.

Keywords: *vegetable yield response, optimum N-P-K fertilization rates, cost-benefit analysis, Andosol soil, Philippine agriculture*

3.2. Introduction

The vegetable industry is an essential component of the Philippines’ agriculture sector. Vegetables are produced from 6% of the country’s total agricultural area and contributed roughly 30% to total agricultural production (Briones 2009; FAOSTAT 2021). Eggplant, tomato, and cabbages are consistently among the highly cultivated vegetables, whereby in 2015–2019 these respectively corresponded to a production volume of 241000 ± 3, 218000 ± 2, and 124000 ± 1 Mg yr^{-1} with an equivalent value (0.0173 Euro per Php exchange rate) of 100 ± 9, 60 ± 3, and 43 ± 2 million Euros (Philippine Statistics Authority 2020). Since vegetable production generally occurs year-round, this has supported perennial vegetable availability, although more production is still encouraged, in stride of a rapidly increasing population, to secure nutrition and food supply in the country (Keatinge et al. 2011; Zamora et al. 2013). Economically, vegetable farming as livelihood is attractive and provides employment for a majority of upland migrants; however, this resulted to clearing more intact forests, creating agricultural expansion which instigates economic activities, and promoted shifts in land uses (Carandang et al. 2013; Coxhead et al. 2002; Pulhin et al. 2006).

Vegetable farms can be found country-wide, typically fragmented, and mainly engaged in small-scale production (Dikitanan et al. 2017). These sit either on relatively nutrient-rich soils with favorable soil physical attributes or on nutrient-exhausted soils, and commonly associated by a densely inhabited farming community. In a small farmed parcel, expansion of cultivation is performed through intensive management practices such as absence of fallow to allow multiple cropping episodes, high fertilization and pesticide application rates, and frequent tillage and irrigation during vegetable production periods

(Librero and Rola 2000). Among these, intensive application of fertilizers is most accessible to farmers in insuring marketable crop yield against unwarranted loss, which in many cases, rates are beyond the crop's actual nutrient demand (Tei et al. 2020). Subsequently, this long-term practice inculcates losses not only in terms of capital resources allocated for labor and crop production inputs (e.g., fertilizers, pesticides, seeds), but it also offsets optimal profit. More importantly, intensive fertilization increases the occurrence of nutrient leaching (i.e., N and P) which harbors groundwater contamination and increased soil N_2O emissions (Quiñones et al. 2022).

In smallholder farms which are generally overly fertilized for many years, the working capital for production inputs, largely meant for fertilizers, is commonly availed from loans (Cramb et al. 1999; Eder 2006; Laborte et al. 2009). Adjacent to this key constraint to farming, harvested marketable yield and profit remain below optimum despite intensive cultivation practices, consequently penalizing farmers. Harvested yield of crops beyond its maximum potential is not achieved following excessive fertilization because yield does not proportionally increase with nutrient inputs towards nutrient saturation (Keuter et al. 2013; Pastor and Bridgham 1999; Schmidt et al. 2021). Considering this, the application of fertilizers more than the crop's nutrient requirement is a repeated practice by farmers and the expenditure encompassing this only generate unnecessary burden to the working capital. The farmer's sought profit, therefore, is not attained, ascribed to inferior harvested yield, large fertilizer cost, and combined with strong variations in farm-gate prices of crops (Laborte et al. 2009). Since prolonged intensively fertilized smallholder farms are widespread in the Philippines, there is a need of identifying the optimum limits of plant-available nutrients and fertilization rates and its corresponding optimum yield response. Moreover, the association of yield response to actual costs of production and profit are equally important. Information on these will provide bases in obtaining ideal crop yield at optimum nutrient levels that will potentially reduce both crop production costs and negative environmental impacts, while it will serve as initial step in promoting sustainable vegetable production systems.

This study aimed to 1) identify the optimum yield response and optimum limits of plant-available N and fertilization rates for P and K in intensively fertilized vegetables farms on an Andosol soil in Leyte, Philippines, and 2) ascertain the relationship of yield response to actual costs of crop production and fam-gate profit. Our collection of vegetable harvested yield and the rates of N, P, and K fertilization rates, including the estimates for materials cost, labor, and profit covered a year of simultaneous cropping periods in small-scale farms which typically represent intensive production practices. We addressed the hypothesis that our identified optimum levels of plant-available and fertilization rates P and K will produce the optimum yield response of vegetables (Pastor and Bridgham 1999; Schmidt et al. 2021), and the farmer's profit will vary according to the choice of vegetable type, the vegetable's farm-gate price (Laborte et al. 2009), and will also be largely influenced by fertilizer cost (Cramb et al. 1999).

3.3. Materials and methods

3.3.1. Site description

This study was performed in Cabintan (11° 03– 06' N, 124° 42– 45' E, 500–900 m above sea level), a vegetable-producing community, in Ormoc, Leyte, Philippines, from May 2018 to May 2019. The mean annual precipitation was 3000 ± 390 (mean ± standard error;

SE) mm and the annual air temperature was 28 ± 0.2 °C (2014–2017 data from the Department of Science and Technology–Philippine Atmospheric, Geophysical and Astronomical Services Administration (DOST PAG–ASA), Tacloban City, Leyte). During the study period, the annual rainfall was 2730 mm, with the highest monthly rainfall in December to February (360 mm–485 mm month^{-1}) and the lowest in March until May (110–130 mm month^{-1}). Mean monthly air temperature was between 23° C and 32° C (2018–2019 data from weather stations at the Department of Agriculture, Ormoc City and DOST PAG–ASA, Tacloban City). The soil of the area is Typic Hapludand (FAO classification) that developed on trachytic basalt-andesite rocks and characterized by low soil bulk density, acidic soil pH, high P fixing capacity (Table 1), and dominance of non-crystalline allophane and imogolite minerals (Asio et al. 1998; Jahn and Asio 1998). The relatively mild upland weather, alongside intensive fertilization practices, supported year-round vegetable farming activities. Cabintan is catering to the vegetable demands in Leyte province and neighboring islands, including the country's capital in the north and cities in the southern provinces.

3.3.2. Experimental design and vegetable cropping practices

This study had 10 replicate farms that represented the common management practices of vegetable production system in the study area. The farms, all located on the same geology and climate, were each managed by small-scale farmers and apportioned ≤ 0.30 ha for vegetable production. The distance between our studied farms was ~ 2 km. Vegetable cultivation practices commonly varied in fertilization rates, vegetable crops, and the frequency of cropping periods in a year, depending on the farmers' preferences. Based on farmers' interviews, we have determined the fertilization rates and the commonly applied fertilizers (Table A3.1), including urea (46% N), muriate of potash (50% K), ammonium phosphate (16% N–9% P), ammonium sulfate (21% N), diammonium phosphate (18% N–20% P), complete (14% N–6% P–12% K), and occasionally in combination with air-dried and partly decomposed chicken manure (containing 288 ± 10 g C kg^{-1}, 51 ± 3 g N kg^{-1}, 30 ± 2 g P kg^{-1}, 15 ± 1 g Mg kg^{-1}, 54 ± 5 g Ca kg^{-1}, 56 ± 2 g K kg^{-1}). These vegetable farms, which practiced two to three cropping periods in a year, clearly showed distinct zones, i.e., plant row and inter-row, which are interchangeable for each grown vegetable in each cropping period. Plant rows were where fertilizer application was done, whereas inter-rows were where access for weeding, watering, and harvesting was conducted. On average, plant rows were 70% and inter-rows were 30% of areal coverage of the farms. Soil preparation was carried out using animal-drawn (*Bubalus bubalis carabenesis*) plow with a depth of ~ 0.6 m. Leafy (i.e., Chinese and head cabbages) and fruit-bearing vegetables (i.e., tomato, eggplant, sweet pepper, chili pepper; hereafter referred to as solanaceous vegetables) suited to the mild upland weather were planted year-round (Table A3.1). For pest and disease controls, the farmers used combinations of insecticide, molluscicide, and fungicide, which can be highly harmful (Methomyl in Scorpio 40 SPTM, Lannate 40 SPTM, Check Mate 40 SP®), moderately hazardous (Cypermethrin in Magnum®, Metaldehyde in Stop®, Cartap hydrochloride in Contract 50 SP®, Difenoconazole in Montana®) or least hazardous (Chlorothalonil in Rover®) (based on LD_{50} test; World Health Organization 2010). To prepare the farm for the succeeding cropping, farmers preferred to eliminate weeds using broad-spectrum herbicides (Glyphosate IPA in Tekweed 480 SL®, Sharp Shooter 480 SL®, Mower 48 SL®) as a cheaper option than manual weeding. In brief, the cropping practices in our studied vegetable farms included wide fertilization rates, land preparation, planting, weed and pest controls, and harvesting that all involved manual labor.

3.3.3. General soil characteristics

Soil properties were assessed in the top 0.6 m depth for each vegetable farm (Table 1). Soil bulk density was determined using the core method (Blake and Hartge 1986) at depth intervals of 0–0.1, 0.1–0.3, 0.3–0.5, and 0.5–0.6 m by digging a 1 m × 1 m × 1 m pit in each vegetable farm. Separate soil samples were taken from five sampling points within each farm for the same depth intervals using an auger, and the five samples were composited to represent each farm. Soil samples were air-dried, sieved through 2-mm sieve and analyzed for particle size distribution using the hydrometer method (ISRIC 2002) at the Visayas State University, Leyte, Philippines. The rests of the soil samples were transported to the laboratory in Institute Soil Science of Tropical and Subtropical Ecosystems (SSTSE), University of Goettingen, Germany for biochemical analyses. Soil pH was measured from 1:2.5 soil-to-water ratio. Effective cation exchange capacity (ECEC) was analyzed by percolating the soils with unbuffered 1 mol L^{-1} NH_4Cl solution and the exchangeable cations (Mg, Ca, K, Na, Al, Fe, Mn) in percolates was analyzed using the inductively coupled plasma-atomic emission spectrometer (ICP-AES; iCAP 6300 Duo VIEW ICP Spectrometer, Thermo Fischer Scientific GmbH, Dreieich, Germany). Base and aluminum saturations were calculated as the percentage of exchangeable base cations (Mg, Ca, K, Na) and Al on ECEC, respectively. Soil organic carbon (SOC) and total N were analyzed from finely ground soil samples using a CN analyzer (Vario EL cube, Elementar Analysis Systems GmbH, Hanau, Germany). SOC and total N stocks were calculated using the measured soil bulk densities in the top 0.6 m and presented as the sum of the three depth intervals (0–0.1, 0.1–0.3, 0.3–0.5, and 0.5–0.6 m), whereas the rests of the soil properties as presented as depth-weighted averages (Table 3.1).

Table 3.1

Soil characteristics in the top 0.6 m of small-scale vegetable farms (mean ± SE, n = 10 farms) on an Andosol soil in Leyte, Philippines

Soil physical and biochemical properties [a]	Mean ± SE
Sand (%)	59 ± 2
Silt (%)	17 ± 1
Clay (%)	10 ± 2
Bulk density (g cm^{-3})	0.44 ± 0.02
pH (1: 2.5 soil-H_2O ratio)	4.3 ± 0.1
ECEC ($cmol_c$ kg^{-1})	2.2 ± 0.3
Base saturation (%)	55 ± 6
Al saturation (%)	27 ± 5
C:N ratio	9.2 ± 0.2
SOC stock (Mg C ha^{-1})	64 ± 6
Total soil N stock (Mg N ha^{-1})	6 ± 1

[a] Values in the top 0.6 cm for each replicate farm are weighted average of the sampled depth intervals at 0–0.1, 0.1–0.3, 0.3–0.5, and 0.5–0.6 m, except for element stocks which are the sum of the entire depth

3.3.4. Plant-available N in the soil

The extant net production of mineral N in the soil, i.e., net N mineralization rate that is used as an index of plant-available N, and the oxidation of nitrite to nitrate, i.e., nitrification rate (Hart et al. 1994), were measured in the top 0.05 m depth at monthly interval (May 2018–May 2019) using the buried bag method (Keuter et al. 2013; Schmidt et al. 2021). In each farm during monthly measurement, six intact cores were taken randomly. The three soil cores were thoroughly mixed into one composite sample and extracted immediately by adding soils into prepared extraction bottles containing 150 ml 0.5 mol L^{-1} K_2SO_4 (T_0 samples). The T_0 samples were shaken for an hour by a mechanical shaker, filtered, and the extracts were frozen immediately for later analysis of mineral N. The remaining three intact soil cores were individually put inside plastic bags that were loosely close for aeration, and inserted back into the soil to incubate in-situ for six days (T_1 samples). These T_1 samples were then composited and extracted for mineral N as described above. To determine the dry mass of the extracted soil, gravimetric moisture content was measured from each of the remaining soil samples by oven-drying the soils at 105 °C for one day. In-situ soil net N mineralization rate and moisture content were also determined in 0.05–0.3 m soil depth once during the dry and wet seasons in 2019 in the same manner described above. The frozen soil extracts were transported via airfreight from the field to SSTSE, Germany for analyses of NH_4^+ and NO_3^- concentrations using continuous flow injection colorimetry (SEAL Analytical AA3, SEAL Analytical GmbH, Norderstedt, Germany); NH_4^+ was determined by salicylate and dichloroisocyanuric acid reaction and NO_3^- by cadmium reduction method with NH_4Cl buffer. Soil net N mineralization rate was calculated as the mineral N (NH_4^+ and NO_3^-) concentrations at T_1 minus at T_0 divided by six days. Similarly, net nitrification rate was calculated as the differences in NO_3^- concentrations between T_1 and T_0 (Hart et al. 1994). These rates were expressed from soil mass basis to area basis using the measured soil bulk densities of 0.55 g cm^{-3} for the top 0.05 m and 0.53 g cm^{-3} for the 0.05–0.3 m. The index of total plant-available N was the sum of the soil net N mineralization rate and the N fertilization rate, as was used by Keuter et al (2013) and Schmidt et al (2021). Soil net N mineralization rate for the entire cropping period was calculated as: kg N ha^{-1} cropping $period^{-1}$ = mean of monthly net N mineralization rates in each farm × number of days from germination to harvest, specific for a vegetable crop (i.e., Chinese cabbage = 80 days, head cabbage = 110 days, tomato = 120 days, squash = 170 days, sweet pepper = 180 days, spring onion = 100 days, eggplant = 260 days, and chili pepper = 240 days).

3.3.5. Resin-exchangeable P, soil microbial biomass, and dissolved N concentrations in drainage water

The Andosol soil in the study area has extremely high P adsorption capacity (> 95% of P added can be adsorbed onto the soil due to the dominance of allophane, imogolite, and goethite minerals; Jahn and Asio 1998). Thus, the commonly used index of available P in the soil, using the resin-exchange method (Tiessen et al. 1984), can only indicate a fraction of potentially available P at a measurement period in this Andosol soil. Given this limitation, resin-exchangeable P level in the studied farms was measured once during the dry and wet seasons in 2019 for the top 0.05 m and 0.05–0.3 m depths. In each farm and soil depth, composite soil samples were taken, as described above for the general soil characteristics. In short, 1 g soil and 1 g anion exchange resin (analytical grade, 20–50 mesh DOWEX_1X8; SERVA Electrophoresis GmbH, Heidelberg, Germany) were shaken overnight with 30 ml distilled water, and the anion exchange resin was extracted with 20 ml 0.5 mol L^{-1} HCl. The P concentrations in the extracts were analyzed using ICP-AES. These values were converted from soil mass basis to area basis using the measured soil bulk densities (0.55 g cm^{-3} for the top 0.05 m depth and 0.53 g cm^{-3} for 0.05–0.3 m depth).

Microbial biomass C and N were measured once during the dry and wet seasons in 2019, using $CHCl_3$ fumigation-extraction method (Brookes et al. 1985). In each farm, five soil samples were taken in the top 0.05 m depth separately the plant rows and inter-rows, and the five soil samples were composited into one sample for each of these cultivation zones. From the composited soil of each plant row and inter-row, ~ 50 g were extracted right away with 150 ml 0.5 mol L^{-1} K_2SO_4 , shaken for one hour, filtered and the extracts were frozen immediately. Another part of the same composited soil (~ 30 g) was fumigated with $CHCl_3$ inside a 50-L desiccator for five days, followed by extraction and immediate freezing of the extracts. The frozen soil extracts were transported by air to SSTSE, Germany for analysis. Extractable organic C in extracts was analyzed by ultraviolet-enhanced persulfate oxidation using a Total Organic Carbon analyzer (TOC-Vwp, Shimadzu Europa GmbH, Duisburg, Germany). Total extractable N was analyzed by continuous flow injection colorimetry (see above) after ultraviolet-persulfate digestion and hydrazine sulfate reduction. Microbial C and N were calculated as the difference of C and N concentrations between fumigated and unfumigated soils, divided by $k_C = 0.45$ (Brookes et al. 1985) and $k_N = 0.68$ (Shen et al. 1984) for five-day fumigated samples. The plant row and inter-row did not differ in microbial C and N ($P = 0.51$–0.80) and these values were area-weighted (70% plant rows and 30% inter-rows) to represent each farm. The values were converted from soil mass basis to area basis using the measured soil bulk density of 0.55 g cm^{-3} for the top 0.05 m depth.

Finally, as further indicators of the movement of dissolved N under high fertilization regimes in these vegetable production systems, we also measured dissolved N concentrations at 0.3 m depth by sampling the drainage water using suction cup lysimeters (P80 ceramic, maximum pore size 1 μm; CeramTec AG, Marktredwitz, Germany). In May 2018, lysimeters were installed at 0.3 m depth in the 10 vegetable farms and in the nine plots of the secondary forest (serving as a reference of an unfertilized system). The forest was on the same soil, geology and climate as the vegetable farms. Due to the relatively dry condition in 2018 (Wang and Cai 2020), the lysimeters sampling of drainage water was only for four months at the height of the wet season (i.e., September to December 2018). Drainage water was collected for two weeks at monthly interval, frozen immediately and transported by air to SSTSE, Germany for analysis of NH_4^+, NO_3^-, and dissolved organic N concentrations (i.e., total dissolved N minus mineral N) as described above.

3.3.6. Nutrient uptake in harvested yield, N response efficiency, and partial factor productivity for applied P and K

We measured the above-ground (except for spring onions which included both above- and below ground biomass) dry biomass (DM) of harvested yield during each cropping period by collecting sample of harvestable grade within a 10 m × 10 m area in each farm and oven-dried the tissue samples at 70 °C for at least three days or until stable mass was attained (Table A3.1). The harvestable grade was according to the farmer’s standard for the vegetable’s marketable quality in terms of size, shape, and color. Moisture content of the vegetables ranged between 90% and 98%. Oven-dried tissue samples were brought to SSTE, Germany for total N, P, and K analyses. Total N concentration was measured from finely ground tissue sample using the CN analyzer mentioned above. The finely ground tissue samples were digested in concentrated HNO_3 under high pressure and extracts were analyzed for P and K concentrations using ICP-AES.

Nutrient uptake in harvested yield was calculated as follows: kg N, P or K cropping period^{-1}) = N concentration (% ÷100 or kg N kg$^{-1}_{\text{tissue sample}}$) × harvested yield (kg DM ha^{-1} cropping period^{-1}) or P or K concentration (kg P or K kg$^{-1}_{\text{tissue sample}}$) × harvested yield (kg DM ha^{-1} cropping period^{-1}) (Keuter et al. 2013; Schmidt et al. 2020). Nitrogen response efficiency (NRE) was calculated as the ratio of harvested yield (kg DM ha^{-1} cropping period^{-1}) to plant-available N (soil net N mineralization rate + N fertilization rate, kg N ha^{-1} cropping period^{-1}) (Bridgham et al. 1995; Keuter et al. 2013; Pastor and Bridgham 1999; Schmidt et al. 2021). Partial productivity factor from the applied P (PFP_P) or K (PFP_K) was calculated as the ratio of harvested yield (kg DM ha^{-1} cropping period^{-1}) to P or K fertilization rate (kg P or K ha^{-1} cropping period^{-1}), as used by Cassman et al (2002). The use of PFP_P and PFP_K are considered appropriate indices of yield response to applied P and K fertilizers without adding the resin-extractable P or exchangeable K because these latter values are nutrient concentrations and not process rates, unlike that for net N mineralization rates. The ranges of NRE, PFP_P, and PFP_K over cropping periods and across farms can provide simple indications for optimum yield response under optimum plant-available N, and P and K fertilization rates in the studied smallholder vegetable production systems.

3.3.7. Labor and materials costs, revenue, and profit

We estimated the cost and benefit of production during each cropping period for each vegetable type in the following:

Profit = Revenue - total production cost

Revenue = harvested yield, kg ha^{-1} cropping $period^{-1}$ × farm-gate price kg^{-1}. This price was based on the province- or country-standard farm-gate price kg^{-1} for each vegetable type (https://openstat.psa.gov.ph/Metadata/Prices; farm gate prices kg^{-1} of vegetables were: Chinese cabbage Philippine peso (PhP)15 = 0.26 Euro; head cabbage Php 20 = 0.35 Euro; tomato Php 30 = 0.52 Euro; spring onion Php 50 = 0.87 Euro; sweet pepper Php 40=0.69 Euro; squash Php 15 = 0.26 Euro; eggplant Php 30 = 0.52 Euro; chili pepper Php 110 = 1.91 Euro). The total production cost comprised of labor costs (i.e., number of man-days × current salary for land preparation, planting, weeding, spraying pest control, and harvesting) and the material costs (i.e., fertilizers, seeds, herbicides, and pesticides). We report the cost-benefit analysis both in Euros (conversion from Philippine peso to Euro used the exchange rate of 1 Php = 0.0173 Euro, which was the average for the years enclosing our study period (2018–2020; https://www1.oanda.com/currency/converter/) and in Philippine peso (Table A3.2).

3.3.8. Statistical Analysis

Each parameter was first evaluated for normal distribution and equality of variance using Shapiro Wilk's test and Levene's test, respectively. Net N transformation rates did not follow a normal distribution, and hence were log-transformed. We used the linear mixed-effects (LME) models (Crawley 2013) with Fisher's least significant difference test (LSD) for repeatedly measured parameters (i.e., net N transformation rates and dissolved N concentrations in drainage water). For assessing differences in net N transformation rates between dry and wet seasons or differences in dissolved N concentrations between vegetable farms and forest, the LME models had season for the former or land use for the latter was considered as a fixed effect while measurement day and replicate plots were random effects. The LME model includes either 1) a variance function that allows different variances of the response variable for the fixed effect (Crawley 2013), 2) a first-order temporal autoregressive process that assumes the correlation between measurements decreases with increasing time distance (Zuur et al. 2009). The fitting LME model was selected based on the least Akaike information criterion. For variables measured once (i.e., rates of soil net N mineralization and nitrification, resin-exchangeable P in the 0.05–0.3 m depth, and soil microbial biomass in the top 0.05 depth), the difference between seasons was assessed by either paired *T* test (normal distribution) or the non-parametric Wilcoxon signed-rank test (non-normal distribution). All statistical tests were considered significant at $P \leq 0.05$ and carried out using R version 4.0.2 (R Core Team 2020). Values of parameters are expressed as mean ± standard error (SE).

To evaluate the pattern of yield response with net income, the relationship of NRE, $\mathrm{PFP_P}$, and $\mathrm{PFP_K}$ with profit was carried out for leafy vegetables, Chinese and head cabbages, and the solanaceous vegetables. The number of cropping periods across 10 farms were: for Chinese cabbage = 6, head cabbage = 4, and solanaceous vegetables = 7 (combination from tomato = 2, sweet pepper = 2, eggplant = 2, and chili pepper = 1).

3.4. Results

3.4.1. Plant-available nutrients, soil microbial biomass, and soil water N

In both soil depths (0–0.05 m and 0.05–0.3 m), the rates of net N mineralization and nitrification were similar between seasons (*P* = 0.11–0.78; Table 3.2; Fig. A3.1). Average across 10 farms, the combined N fertilization rates (Table A3.1) and extant net N

Table 3. 2

Mean (± SE, n = 10 farms) rates of soil net N mineralization and net nitrification, resin-exchangeable P (within depths of 0–0.05 m and 0.05–0.3 m), soil microbial biomass (within 0–0.05 m depth), and dissolved N concentrations of soil-pore water (at 0.3 m depth) during the dry and wet seasons in small-scale vegetable farms on an Andosol soil in Leyte, Philippines

Depth and parameters	Season	
	dry	wet
0–0.05 m soil depth:		
Net N mineralization (kg N ha^{-1} day^{-1})	1.8 ± 1.0a	1.4 ± 0.5a
Net N nitrification (kg N ha^{-1} day^{-1})	1.7 ± 0.9a	0.9 ± 0.2a
Resin-exchangeable P (kg P ha^{-1})	11 ± 3b	61 ± 12a
Microbial C (kg C ha^{-1})	167 ± 11a	156 ± 9a
Microbial N (kg N ha^{-1})	20 ± 2a	19 ± 2a
Microbial C:N	8.5 ± 0.6a	8.4 ± 0.5a
0.05–0.3 m soil depth:		
Net N mineralization (kg N ha^{-1} day^{-1})	6.1 ± 3.6a	2.0 ± 1.0a
Net N nitrification (kg N ha^{-1} day^{-1})	6.0 ± 3.6a	2.0 ± 1.0a
Resin-exchangeable P (kg P ha^{-1})	309 ± 69a	45 ± 9.4b

Table 3.2 continuation…

Dissolved N concentrations at 0.3 m depth of lysimeters [§]:	
Vegetable farms	
NH_4^+ (mg NH_4^+–N L^{-1})	37 ± 36A
NO_3^- (mg NO_3^-–N L^{-1})	2.6 ± 2.4A
Dissolved organic N (mg N L^{-1})	1.8 ± 0.3A
Secondary forest	
NH_4^+ (mg NH_4^+–N L^{-1})	1.6 ± 1.3B
NO_3^- (mg NO_3^-–N L^{-1})	0.3 ± 0.1B
Dissolved organic N (mg N L^{-1})	0.6 ± 0.2A

Means followed by different lowercase letters within a row indicate significant differences between seasons for net N transformation rates (linear mixed-effects models with Fisher's LSD test), resin-exchangeable P, and soil microbial biomass (Paired *T* test or Wilcoxon signed-rank test) at $P \leq 0.05$. The conversion of units from mass basis to area basis was calculated by using the soil bulk densities of 0.55 g cm^{-3} for the top 0.05 m and 0.53 g cm^{-3} for 0.05–0.3 m soil depth

[§] Lysimeter sampling of soil water was only for four months (September to December 2018) during the wet season. Dissolved N concentrations in the secondary forest were measured to serve as reference land use (see Chapter 2). Means followed by different uppercase letters within a column display significant differences between land uses for dissolved NH_4^+, NO_3^-, and dissolved organic N concentrations (linear mixed-effects models with Fisher's LSD test) mineralization rates in the top 0.05 m soil depth was 761 ± 116 kg N ha^{-1} cropping period^{-1}, whereby N fertilization rates accounted 56 ± 7 % and soil N mineralization rates constituted 44 ± 7% (i.e., 379 ± 97 kg N ha^{-1} cropping period^{-1}). Soil net nitrification rate was 48 ± 4% of net N mineralization (Table 3.2). Stocks of resin-exchangeable P in the top 0.05 m depth was higher in the wet than the dry season while it was the converse in 0.05–0.3 m ($P < 0.01$; Table 3.2). Exchangeable K was 32 ± 4 kg K ha^{-1} in the top 0.05 m depth and was 133 ± 26 kg K ha^{-1} in the 0.05–0.3 m depth. Microbial C and N were comparable between seasons (P = 0.37–0.54; Table 3.2). Dissolved NH_4^+ and NO_3^- in drainage water were higher in vegetable farms than in the secondary forest ($P \leq 0.05$; Table 3.2). Dissolved NH_4^+ was the largest concentration followed by NO_3^- and dissolved organic N concentrations.

3.4.2. Vegetables' harvested yield response and nutrient uptake

During the study period, the optimum (indicated by vertical dash lines) plant-available N was 520 kg N ha^{-1} cropping period^{-1} (N fertilization was 290 kg N ha^{-1} and extant net N mineralization rate was 230 kg N ha^{-1}), whereby at this rate the optimum yield and NRE were exhibited, particularly in farms with Chinese cabbage (Fig. 3.1a, b). The optimum P and K fertilization rates of 200 kg P ha^{-1} and 340 kg K ha^{-1}, respectively, showed the optimum yields (Fig. 1c, e), PFP_P and PFP_K (Fig. 3.1d, f), largely in farms with Chinese cabbage and some farms with eggplant and chili pepper. Moreover, the optimum N, P, and K uptake in the harvested yield of vegetables corresponded with the optimum plant-available N, and optimum P and K fertilization rates; the nutrient uptake, in turn, determined the patterns of NRE, PFP_P, and PFP_K (Fig. A3.2).

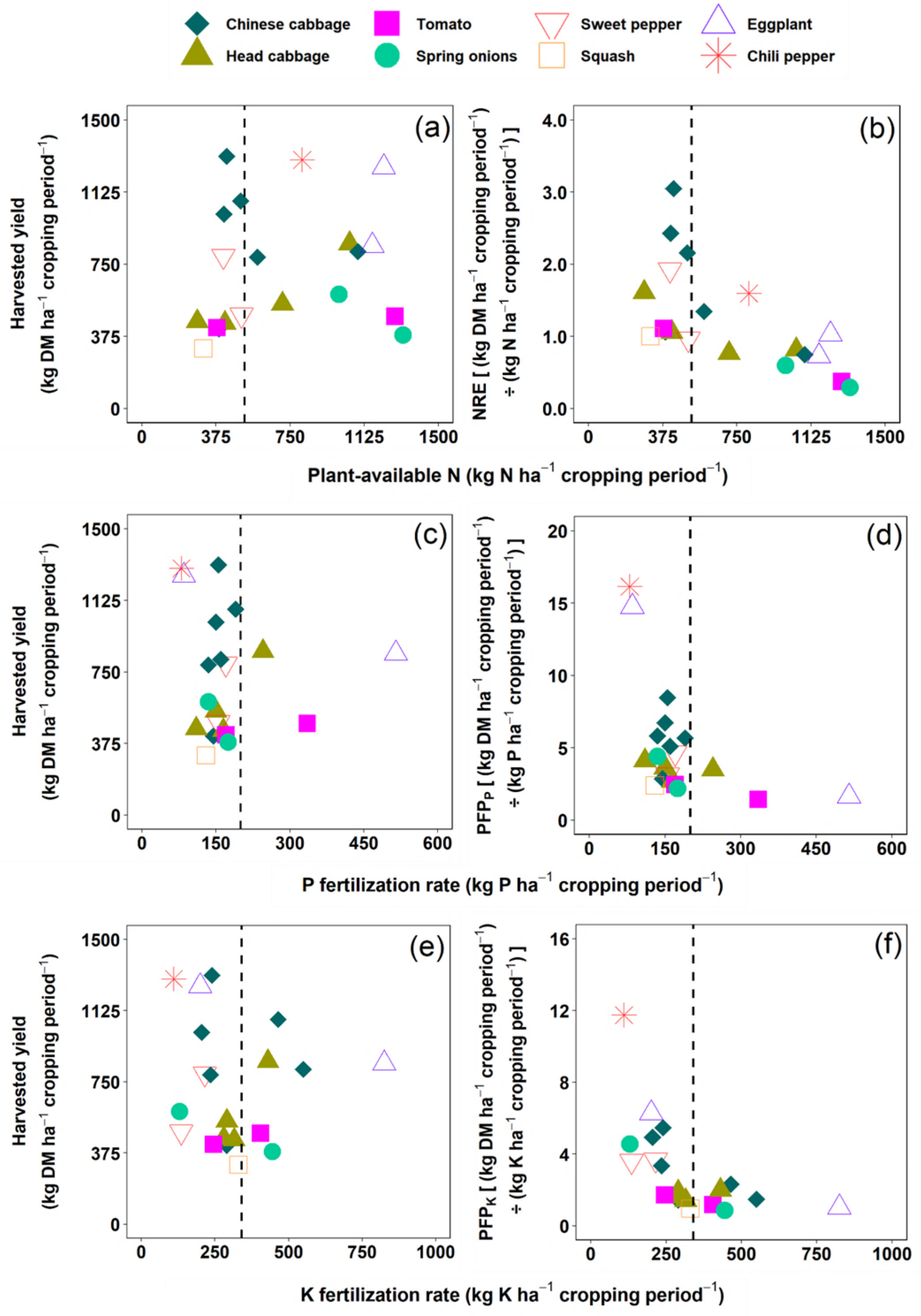

Fig. 3.1 Relationships of vegetable yield with plant-available N (N fertilization rate + net N mineralization rate within the top 0.05 m soil depth) (a), P, and K fertilization rates (c,

e). N response efficiency (NRE = yield ÷ plant-available N) (b) and partial factor productivity ($PFP_{P\ or\ K}$ = yield ÷ P or K fertilization rate) from the applied P (d) and K fertilizers (PFP_K) (f) in small-scale vegetable farms on an Andosol soil in Leyte, Philippines (n = 20 vegetable cropping periods). The dash lines are our subjective delimitation for the optimum yield response to optimum N, P and K fertilization rates. About 56 ± 7 % of plant-available N is contributed by N fertilization rate and the remaining was contributed by the extant soil net N mineralization rate.

3.4.3. Cost-benefit analysis

The total production cost (labor + materials costs) varied minimally across vegetable cropping periods (Fig. 3.2a). Labor cost accounted 6–13% of the total production cost or equivalent to 187–265 Euros ha^{-1} cropping $period^{-1}$ (Table A3.2). Land preparation accounted 39–56% of the labor cost, while farm activities planting, weeding, and pest control spraying each comprised 10–14%, and harvesting imparted 3–31%. The materials cost constituted 87–94% of the production cost or an expenditure of 1747–3530 Euros ha^{-1} cropping $period^{-1}$ (Table A3.2). Of this material cost, 21–61%, 25 – 50%, and 15 – 30% were allocated for procurements of N-P-K fertilizers, seeds, and herbicides + pesticides, respectively. Cropping for eggplant has the highest cost of production while chili pepper has the lowest (Fig. 3.2a). Overall, labor cost was generally a stable expenditure across vegetable cropping periods, whereas materials cost accounted the largest fraction of the total production cost with its fluctuations dictated largely by fertilizer cost (Table A3.2).

Compared with the cabbages, higher revenue and profit were obtained from the cropping of solanaceous vegetables (Fig. 3.2b) with chili pepper producing the highest profit at 30763 Euros ha^{-1} from a single cropping period, followed by eggplant and sweet pepper that generated profits between 2340 and ~ 8590 Euros ha^{-1} cropping period^{-1}. Cabbages, however, were more frequently cultivated than solanaceous vegetables, wherein Chinese and head cabbage delivered profits between ~ 2700 and 4362 Euros ha^{-1} cropping period^{-1}. The least profits were from cultivation of tomatoes and squash (Fig. 3.2b; Table A3.2).

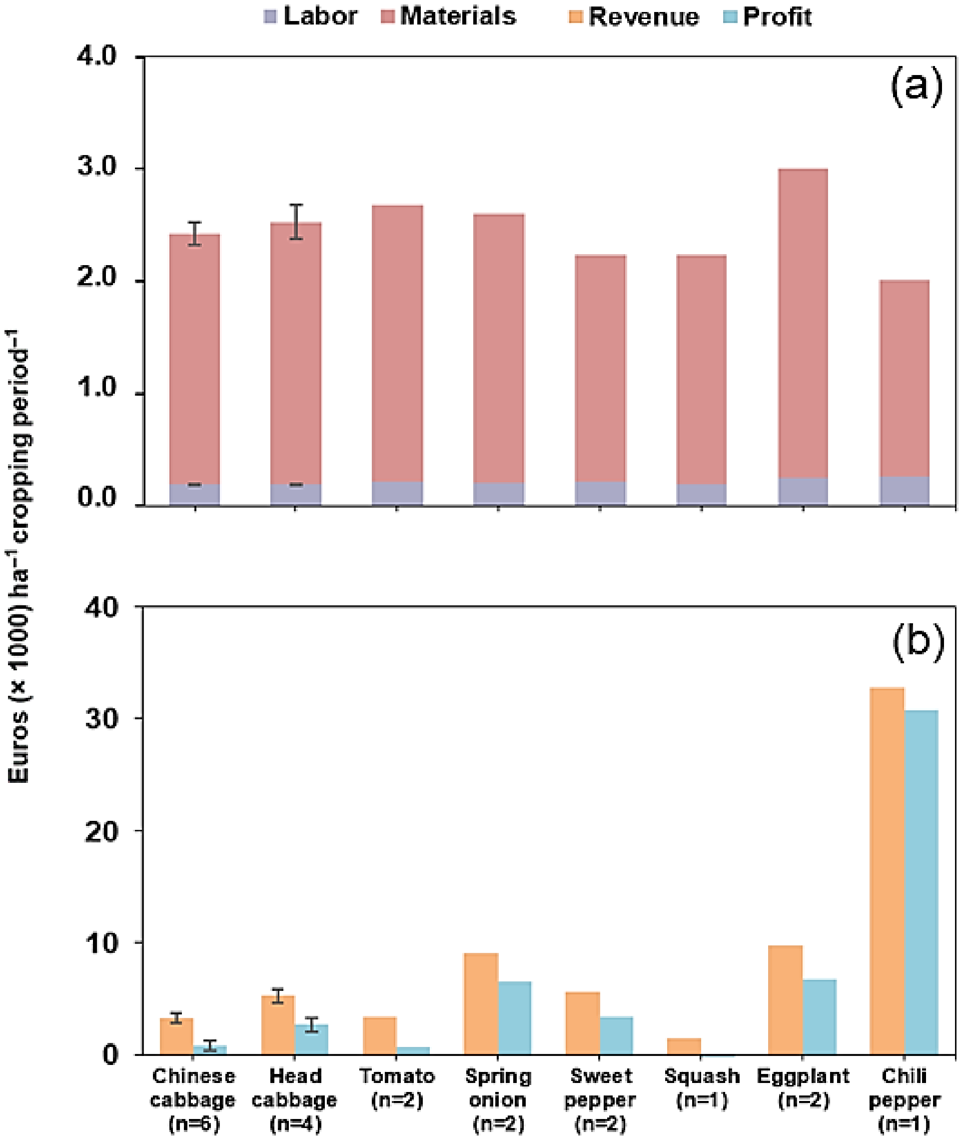

Fig. 3.2 Labor and materials costs (a), revenue, and profit (b) in small-scale vegetable farms on an Andosol soil in Leyte, Philippines (mean ± SE, n = vegetable cropping periods)

An opposing relationship between NRE and profit was displayed by the cabbages and solanaceous vegetables: the highest NRE from Chinese cabbage displayed the lowest profit, while the lowest NRE from solanaceous vegetables showed the highest profit (Fig. 3.3a). Briefly, the NRE of the latter group ranged between 0.37 and 1.92 coming from tomato and peppers, respectively, which brought profits between 682–30868 Euros ha^{-1} cropping period^{-1} (Table A3.2). The highest PFP$_P$, PFP$_K$, and profit were demonstrated similarly from the solanaceous vegetables, particularly from chili pepper and eggplant, whereas the cabbages had low PFP$_P$, PFP$_K$, and profit (Fig. 3.3b, c).

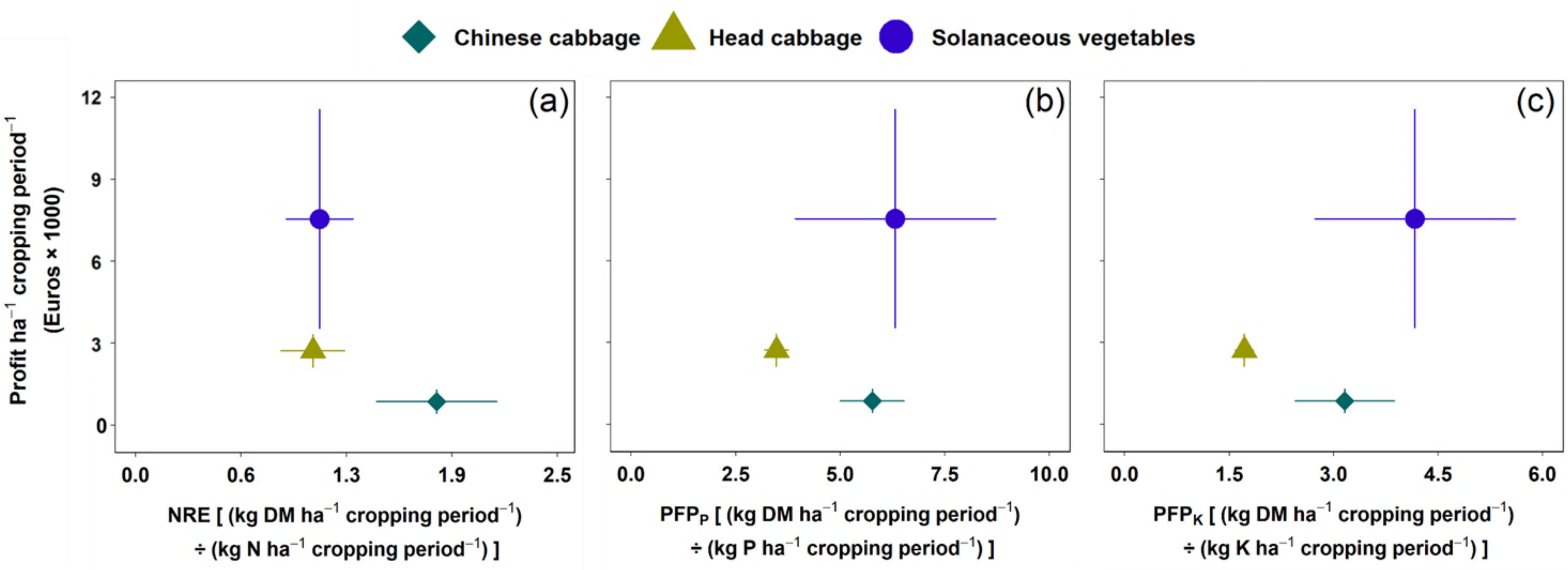

Fig. 3.3 Relationships of profit (revenue – total cost) with N response efficiency (NRE, a) and partial factor productivity from applied P (PFP_P, b) and K fertilizers (PFP_K, c) in small-scale vegetable farms on an Andosol soil in Leyte, Philippines (mean ± SE, n = vegetable cropping periods, for Chinese cabbage = 6, head cabbage = 4, and solanaceous vegetables = 7 (combined for tomato = 2, sweet pepper = 2, eggplant = 2, and chili pepper = 1)

3.5. Discussion

3.5.1. Intensively fertilized small-scale vegetable farms on an Andosol soil

To my knowledge, no studies have yet measured and described the net N transformation rates using the buried bag method in intensively fertilized smallholder farms. The invariable rates of soil net N mineralization in the top 0.05 m and 0.05–03 m depths (Table 3.2) across cropping periods or between seasons, were probably due to the N-saturated soil resulting from intensive, high N fertilization rates. Since the 2000s, vegetable farming was an agricultural activity in the study area, and farmers had commonly applied high N fertilization rates between 150 and 825 kg N ha^{-1} cropping $period^{-1}$ with two to three cropping periods in a year (Table A3.1). The large net N transformation rates in the 0.05–0.3 m soil depth was consistent with the concentrations of dissolved N concentrations of drainage water at 0.3 m depth in the vegetable farms, which were larger than in the secondary forest, suggesting increased N leaching losses common to intensively fertilized agricultural systems (Dechert et al. 2005; Formaglio et al. 2020; Kurniawan et al. 2018). Moreover, the pattern of dissolved N concentration wherein dissolved NO_3^- was lesser than NH_4^+, indicated the adsorption of NO_3^- to the positive charges of non-crystalline allophane and imogolite clay minerals, common in this Andosol soil (Navarrete et al. 2008) with acidic pH in the study area (Table 3.1). These positive charges of clay minerals have led to the temporary adsorption of NO_3^- in deeper depths (Table 2.5; Quiñones et al. 2022), retarding its leaching with drainage water (Sansoulet et al. 2007). However, chronic Cl^- addition from either K fertilizers or sea spray can potentially replace the NO_3^- on the soil's adsorption sites, and thereby possibly subjecting NO_3^- to further leaching down to lower depths (Formaglio et al. 2020). The large resin-exchangeable P stock in the top 0.3 m depth was indicative of high and repeated P fertilizer application (Table 3.2). The repeated application of P fertilizers (Table A3.1), despite the large stock of resin-exchangeable P in the soil, could be in excess from the vegetables' P requirement, and the released P from fertilizers are strongly sorbed to non-crystalline minerals such as allophane, imogolite and Al hydroxide (Beck et al. 1999; Parfitt 2009). In sum, the smallholder vegetable farms were intensively fertilized, a management practice that instigated N and P saturation, including its temporary nutrient adsorption in deeper soil depth.

3.5.2. Optimum N-P-K fertilization rates and yield response

Given the long-term, intensive fertilization, and nutrient-saturated conditions of these vegetable farms, it is helpful to delineate the optimum levels of fertilization rates that produced the optimum yield response of vegetables. The optimum plant-available N at 520 kg N ha^{-1} cropping period^{-1} (comprising a fertilization rate of 290 kg N ha^{-1} and an extant net N mineralization rate of 230 kg N ha^{-1} cropping period^{-1}) had shown optimum yield of leafy vegetable (Fig. 3.1a). The N fertilization rate at this optimum plant-available N value was approximately close to the rates applied in Chinese cabbage fields on Andosol soils in Japan (i.e., 200–250 kg N ha^{-1}, Cheng et al. 2002; Cheng et al. 2006; Hou and Tsuruta 2003); however, this was about twice higher than the general recommended N fertilization rate for Chinese cabbage (i.e., 120 kg N ha^{-1}; Kalb and Chang 2005). The optimum N fertilization rate, included in the delineated optimum plant-available N with optimum NRE (Fig. 3.1b) were the actual farmer's practices in our study area, and their practices were neither based on prior mineral N level determination in the soil nor by any recommended rate. N, as a nutrient, is the primary driver for the growth and development of photosynthetically less active and immature inner leaves for a head-forming crop, such as cabbages (van Lammerts Bueren and Struik 2017). The optimum N fertilization rate as well as the extant N mineralization in the soil, both included in my index of plant-available N, reflected the farmers' experience that such fertilization rate had shown increases in the number of leaves, plant height, and overall crop quality, and ultimately dictated the optimum harvested yield of Chinese cabbage. This delineation for optimum plant-available N and NRE across cropping seasons and farms can aid in simple approximation of optimum N fertilization rate that can minimize negative environmental impacts (e.g. greenhouse gas footprint – Fig. 2.4; Quiñones et al. 2022; N leaching losses; Formaglio et al. 2020), arising from excessive N fertilizer inputs beyond the crop's demand.

The delineated optimum fertilization rates for P and K at 200 kg P ha^{-1} (Fig. 3.1c, d) and 340 kg K ha^{-1} (Fig. 3.1e, f), respectively, were about four times higher than the recommended fertilization rates for Chinese cabbage (i.e., 60 kg P ha^{-1} and 90 kg K ha^{-1}; Kalb and Chang 2005) and for solanaceous vegetables eggplant, sweet pepper, and tomato (i.e., 60 kg P ha^{-1} and 130 kg K ha^{-1}; Berke et al. 2003; Chen et al. 2002; Hanson et al. 2000). As fruit-bearing deep-rooted vegetables and mostly grown in hybrid varieties, optimum P and K levels are vital for overall fruit yield and subsequently dictate the quantity and quality of harvested yield. In particular, sufficient P is key for root formation, fruit and seed development, and plant disease resistance (Zhu et al. 2017), whereas adequate K is vital for the synthesis and transport of photosynthates to plant reproductive and storage organs, and hence promotes fruit size, color, taste, and peel thickness (Havlin et al. 2014). The delineated optimum P and K fertilization rates (Fig. 3.1c–f), which the farmers practiced based on these abovementioned yield quality indicators and yield size, were also reflective of the nutrient demands of these vegetables, as supported by the optimum P and K nutrient uptake of the harvested yield (Fig. A3.2) as well as PFP_P and PFP_K (Fig. 3.1 d, f).

Under those delineated optimum plant-available N and P and K fertilization rates across cropping periods in the studied farms, the uptake of these nutrients in the harvested yield were also at the optimum (Fig. A3.2). For example, the ratio of the optimum N uptake in the harvested yield (60 kg N ha^{-1} cropping $period^{-1}$) to the optimum plant-available N (e.g., 520 kg N ha^{-1} cropping $period^{-1}$) was ~ 12%, a value higher than the < 1% from an intensively managed grassland (Keuter et al. 2013) and comparable with the 10-20% from intensively managed croplands in Germany (Schmidt et al. 2021). The practical take away from this delineated optimum plant-available N (largely contributed by that rate of N fertilization) and optimum P and K fertilization rates was that addition of excess N, P and fertilizers beyond this optimum levels will not generate proportional increases in nutrient uptake and yield (Fig. A3.2a–f) (Cassman et al. 2002; Keuter et al. 2013; Schmidt et al. 2021). Conversely, a reduction of the excessive fertilization rates in the studied smallholder vegetable farms from the maximum rate to these delineated optimum limits can generate optimum harvestable yield of vegetables, while nutrient uptake is optimized, losses via leaching and gaseous emissions may be reduced, and unnecessary expenditures on fertilizers can be minimized.

3.5.3. Costs of small-scale vegetable production system on an Andosol soil

To present a simple partial economic analysis of small-scale vegetable production in our studied farms, the production cost covered the major components labor and materials costs, and the revenue or profit estimated from harvested yield at farm-gate price (i.e., selling price upon disposal of vegetables after price bargaining between the farmer and the buyer; Jaleta and Gardebroek 2007). Although vegetable production systems can be labor-demanding, key farm activities land preparation charged the highest and harvesting the least to labor cost. Land preparation in our studied farms can customarily entail two weeks utmost and it comprised expenses for the service rendered from employed labor and for the hired utility of draught animal. While the use of draught animal for plowing and harrowing remains to be a common practice in most small-scale farms in the Philippines, keeping one as family-owned for farm use is less adopted (Cramb et al. 1999; Kirchhof et al. 2000; Magcale-Macandog et al. 2010). Instead, hiring a draught animal is a regular practice. Similarly common able members of the farming household engage in cultivation activities in place for hired labor in cases that farm activities should be hastened (Eder 2006). This can, however, vary according to the farmer's capacity to employ assistance from other farms to his. Reliance to family labor was still practiced but wage-work was availed during the overlap of farm activities; this created off-farm income to hired individuals from neighboring farms (Eder 2006; Poudel et al. 1998; Shively and Pagiola 2004). The farming household's involvement to most cropping activities practically minimized labor cost, thereby contributing a stable component to total crop production cost (Fig. 3.2a; Table A3.2).

The materials cost imparted higher expenses than labor cost to overall crop production cost (Fig. 3.2a; Table A3.2). This was mainly regulated by the outlays for fertilizers and seeds, wherein purchased quantities of fertilizers mostly larger than the recommended rate for the crop's nutrient demand, was habitually perceived by farmers as attainable security against harm to harvested yield (Cramb et al. 1999; Tei et al. 2020). This approach appeared behavior-dependent and actually rooted to the farmer's payment obligation loans mainly allocated for fertilizers (Cramb et al. 1999). The payment of an existing loan, as insured by the revenue from harvested yield, assured farmers of a profit they believed to be secured by applying high fertilization rates (Table A3.1). Moreover, farmers also regard their economic losses from pests and diseases and thus, they avoid yield damage by mainly relying on massive application of synthetic agricultural chemicals (Schreinemachers et al. 2015). These expenses on farm inputs integral to cropping practices have encouraged farmers to rely on borrowed capital, resulting for material costs as the largest fraction to total crop production cost.

3.5.4. Yield and profit from small-scale production of cabbages and solanaceous vegetables

Apart from the favorable climate and soil properties that support the recurrent cultivation of vegetables, other pressing factors considered by farmers as to which vegetables to grow were cropping productivity (affected by seasons and capital) and profitability (influenced by yield, market demand, and farm-gate price). Although profit can be lower relative to solanaceous vegetables, cabbages were frequently grown (utmost three cropping periods in a year) because of its harvested yield across generated income year-round (Fig. 3.2b; Tables A3.1, A3.2). Yield of leafy cabbages and also fruit vegetables may be compromised by climate-related detriments during the wet season (i.e., last quarter of the year), however, this is balanced around better profit during off-season cultivation since the farm-gate price is higher than during dry months of production (Armenia et al. 2013; Librero and Rola 2000). Moreover, cultivation for cabbages was also viewed by farmers as less intensive as this entailed less capital, due to a shorter growing period compared with solanaceous vegetables. Apart from this, bringing the farm for cabbage production convinced farmers as more profitable than leaving the farm fallowed.

The overall preference for production of solanaceous vegetables was considerably justified by factors pertaining to capital, market price, and profit (Figs. 3.2, 3.3). Cultivating for these vegetables for a single cropping, which covered the initial phase towards complete establishment, was capital-demanding and labor-intensive (Tables A3.1, A3.2). Capital for fertilizers and high-yielding varieties were the farmers' main consideration, whereas labor was secondary. However, farmers take the risk of cultivating these vegetables because of its longer cropping period which delivered recurrent marketable harvests valuated at higher farm-gate price than cabbages (Johnson et al. 2008b; Librero and Rola 2000). Despite lower NRE compared with cabbages, profit from cropping for solanaceous vegetables delivered the highest profit and likely dictated by market price and offset the materials costs for production (Figs. 3.2, 3.3; Tables A3.1, A3.2).

3.6. Conclusions

The results support that our identified optimum limits of plant-available N and fertilization rates for P and K, produced the optimum yield response of vegetables in intensively fertilized vegetable farms. In particular, optimum plant-available N corresponded for optimum yield to Chinese cabbage, while optimum fertilization rates for P and K delivered optimum yield to solanaceous vegetables. Beyond the optimum levels, harvested yield of these vegetables did not increase further, suggesting that nutrients from fertilizers were beyond crop requirement and highly subjected to losses. High dissolved N concentration at 0.3 m soil depth was indicative for N leaching, as wells as the temporary NO_3^- adsorption to the soil, whereas P and K leaching were less likely to occur. NO_3^-, however, can potentially undergo leaching to deeper soil depth considering the high precipitation in the study area and the repeated application of Cl-containing fertilizers during cropping periods. Moreover, high N application causes vegetables' susceptibility to pest and fungi and thus, more pesticide and fungicide applications may be needed. Significant monetary losses are, therefore, incurred from unnecessary expenditure on fertilizers and even pest control products, which subsequently offset optimum revenue and profit. The choice for solanaceous vegetables to grow was mainly driven by its higher market price over leafy cabbages. Cropping for the latter, however, was beneficial in terms of N input reduction, NRE improvement, and N retention, which at the same time optimum harvested yield and profit were achieved. Increasing profit through minimized nutrient and monetary losses arising from intensive fertilizer input in small-scale vegetable production systems is feasible, if adherence to optimum limits of nutrient inputs would be recommended, in parallel with application of sustainable management practices. During cropping periods, these practices may include N management (i.e, right amount, timing, rate, and application method; Tei et al. 2020), inoculation of arbuscular mycorrhiza fungi that may liberate adsorbed P (Tawaraya et al. 2012), adoption of effective microorganisms in the pest and disease management strategies, apart from cultural and mechanical techniques (Olle and Williams 2013; Timprasert et al. 2014). All together, these can substantially reduce dependence to excessive fertilizer application and to reliance on synthetic pest control measures, thereby potentially enhancing farmer's profit and promote sustainable vegetable production systems in the Philippines.

3.7. References

Armenia PT, Menz KM, Rogers GS et al (2013) Economics of vegetable production under protected structures in the Eastern Visayas, Philippines. In: Oakeshot J, Hall D (eds) Smallholder HOPES—horticulture, people and soil. Proceedings of the ACIAR-PCAARRD Southern Philippines Fruits and Vegetables Program meeting, 03 July 2012, Cebu, Philippines. ACIAR Proceedings 139. Australian Centre for International Agricultural Research, Canberra, pp 112-121

Asio VB, Jahn R, Stahr K, Margraf J (1998) Soils of the tropical forests of Leyte, Philippines II: Impact of different land uses on status of organic matter and nutrient availability. In: Schulte A, Ruhiyat D (eds) Soils of tropical forest ecosystems. Springer Verlag, Berlin, pp 37-44

Beck MA, Robarge WP, Buol SW (1999) Phosphorus retention and release of anions and organic carbon by two Andisols. European Journal of Soil Science 50(1):157–164. doi: 10.1046/j.1365-2389.1999.00213.x

Berke TG, Black LL, Morris RA et al (2003) Suggested cultural practices for sweet pepper. AVRDC Publication No. 99-497R. Shanhua, Taiwan, pp 1–5

Blake GR, Hartge KH (1986) Bulk density. In: Klute (ed) Methods of Soil Analysis: Part 1 - Physical and mineralogical methods. American Society of Agronomy, Inc., Madison, pp 363–375

Bridgham SD, Pastor J, McClaugherty CA, Richardson CJ (1995) Nutrient-use efficiency: A litterfall index, a model, and a test along a nutrient-availability gradient in North Carolina peatlands. Am Nat 145(1):1–21. doi: 10.1086/285725

Briones RM (2009) Agricultural diversification and the fruits and vegetables subsector: Policy issues and development constraints in the Philippines. Philippine Institute for Development Studies, Discussion Paper Series No. 2009-02:1–32

Brookes PC, Landman A, Pruden G, Jenkinson DS (1985) Chloroform fumigation and the release of soil nitrogen: A rapid direct extraction method to measure microbial biomass nitrogen in soil. Soil Biol Biochem 17(6):837–842. doi: 10.1016/0038-0717(85)90144-0

Carandang AP, Bugayong LA, Dolom PC et al (2013) Analysis of key drivers of deforestation and forest degradation in the Philippines. Deutsche Gesellschaft für Internationale Zusammenarbeit. Bonn and Eschborn, Germany, pp 1–110

Cassman KG, Dobermann A, Walters DT (2002) Agroecosystems, nitrogen-use efficiency, and nitrogen management. Ambio 31(2):132–140. doi: 10.1579/0044-7447-31.2.132

Chen NC, Kalb T, Talekar N et al (2002) Suggested cultural practices for eggplant. AVRDC Training Guide. Shanhua, Taiwan, pp 1-8

Cheng W, Nakajima Y, Sudo S et al (2002) N_2O and NO emissions from a field of Chinese cabbage as influenced by band application of urea or controlled-release urea fertilizers. Nutr Cycl Agroecosys 63:231–238. doi: 10.1023/A:1021119319439

Cheng W, Sudo S, Tsuruta H et al (2006) Temporal and spatial variations in N_2O emissions from a chinese cabbage field as a function of type of fertilizer and application. Nutr Cycl Agroecosyst 74(2):147–155. doi: 10.1007/s10705-005-5965-x

Coxhead I, Shively G, Shuai X (2002) Development policies, resource constraints, and agricultural expansion on the Philippine land frontier. Envir Dev Econ 7(2):341–363. doi: 10.1017/S1355770X02000219

Cramb RA, Garcia JNM, Gerrits RV, Saguiguit GC (1999) Smallholder adoption of soil conservation technologies: evidence from upland projects in the Philippines. Land Degrad Dev 10(5):405–423. doi: 10.1002/(SICI)1099-145X(199909/10)10:5<405:AID-LDR334>3.0.CO;2-J

Crawley MJ (2013) The R book. Wiley, Chichester West Sussex United Kingdom

Dechert G, Veldkamp E, Brumme R (2005) Are Partial Nutrient Balances Suitable to Evaluate Nutrient Sustainability of Land use Systems? Results from a Case Study in Central Sulawesi, Indonesia. Nutr Cycl Agroecosyst 72(3):201–212. doi: 10.1007/s10705-005-1546-2

Dikitanan R, Grosjean G, Leyte J (2017) Climate-resilient agriculture in the Philippines. CSA Country Profiles for Asia Series. International Center for Tropical Agriculture (CIAT); Department of Agriculture -Adaptation and Mitigation Initiatives in Agriculture, Government of the Philippines. Manila, Philippines, pp 1–24

Eder JF (2006) Land use and economic change in the post-frontier upland Philippines. Land Degrad Dev 17(2):149–158. doi: 10.1002/ldr.721

FAOSTAT (2021) FAOSTAT Online. Food and Agriculture Organization of the United Nations. Rome, Italy. http://faostat.fao.org/default.aspx.

Formaglio G, Veldkamp E, Duan X, Tjoa A, Corre MD (2020) Herbicide weed control increases nutrient leaching compared to mechanical weeding in a large-scale oil palm plantation. Biogeosciences 17(21):5243–5262. doi: 10.5194/bg-17-5243-2020

Hanson P, Chen JT, Kuo CG et al (2000) Suggested cultural practices for tomato. AVRDCPublication No. 00-508. Shanhua, Taiwan, pp 1-8

Hart SC, Stark JM, Davidson EA, Firestone MK (1994) N mineralization, immobilization and nitrification. In: Methods of Soil Analysis, Part 2-Microbiological and biochemical properties. SSSA Book Series No. 5, pp 985-1018. doi: 10.2136/sssabookser5.2.c42

Havlin J, Tisdale SL, Nelson WL, Beaton JD (2014) Soil fertility and fertilizers: An introduction to nutrient management. Pearson, Upper Saddle River, N.J.

Hou AX, Tsuruta H (2003) Nitrous oxide and nitric oxide fluxes from an upland field in Japan: effect of urea type, placement, and crop residues. Nutr Cycl Agroecosyst 65:191–200. doi: 10.1023/A:1022149901586

ISRIC (2002) Procedures for soil analysis. LP van Reeuwijk (ed). Wageningen, The Netherlands

Jahn R, Asio VB (1998) Soils of the tropical forests of Leyte, Philippines I: Weathering, soil charcateristics, classification and site qualities. In: Schulte A, Ruhiyat D (eds) Soils of tropical forest ecosystems. Springer Verlag, Berlin, pp 29-36

Jaleta M, Gardebroek C (2007) Farm-gate tomato price negotiations under asymmetric information. Agric Econ 36(2):245–251. doi: 10.1111/j.1574-0862.2007.00202.x

Johnson GI, Weinberger K, Wu MH (2008b) Vegetable industry in tropical Asia: The Philippines (An overview of production and trade). AVRDC Exploration Series No. 1. Shanhua, Taiwan, pp 1–84

Kalb T, Chang LC (2005) Suggested cultural practices for heading chinese cabbage. AVRDC Publication No. 05-642. Shanhua, Taiwan, pp 1–6

Keatinge JDH, Yang RY, Hughes Jd’A et al (2011) The importance of vegetables in ensuring both food and nutritional security in attainment of the Millennium Development Goals. Food Sec 3(4):491–501. doi: 10.1007/s12571-011-0150-3

Keuter A, Hoeft I, Veldkamp E, Corre MD (2013) Nitrogen response efficiency of a managed and phytodiverse temperate grassland. Plant Soil 364(1-2):193–206. doi: 10.1007/s11104-012-1344-y

Kirchhof G, Priyono S, Utomo WH et al (2000) The effect of soil puddling on the soil physical properties and the growth of rice and post-rice crops. Soil Tillage Res 56(1-2):37–50. doi: 10.1016/S0167-1987(00)00121-5

Kurniawan S, Corre MD, Matson AL, Schulte-Bisping H, Utami SR, van Straaten O, Veldkamp E (2018) Conversion of tropical forests to smallholder rubber and oil palm plantations impacts nutrient leaching losses and nutrient retention efficiency in highly weathered soils. Biogeosciences 15(16):5131–5154. doi: 10.5194/bg-15-5131-2018

Laborte AG, Schipper RA, Van Ittersum MK et al (2009) Farmers' welfare, food production and the environment: a model-based assessment of the effects of new technologies in the northern Philippines. NJAS: Wageningen Journal of Life Sciences 56(4):345–373. doi: 10.1016/S1573-5214(09)80004-3

Librero AR, Rola AC (2000) Philippines. In: Ali M (ed) Dynamics of vegetable production, distribution and consumption in Asia. AVRDC Publication No. 00-498. Shanhua, Taiwan, pp 303–347

Magcale-Macandog DB, Rañola FM, Rañola RF et al (2010) Enhancing the food security of upland farming households through agroforestry in Claveria, Misamis Oriental, Philippines. Agroforest Syst 79(3):327–342. doi: 10.1007/s10457-009-9267-1

Navarrete IA, Tsutsuki K, Kondo R, Asio VB (2008) Genesis of soils across a late Quaternary volcanic landscape in the humid tropical island of Leyte, Philippines. Soil Res 46(5):403. doi: 10.1071/SR08012

Olle M, Williams IH (2013) Effective microorganisms and their influence on vegetable production – a review. J Hortic Sci Biotechnol 88(4):380–386. doi: 10.1080/14620316.2013.11512979

Parfitt RL (2009) Allophane and imogolite: role in soil biogeochemical processes. Clay miner. 44(1):135–155. doi: 10.1180/claymin.2009.044.1.135

Pastor J, Bridgham SD (1999) Nutrient efficiency along nutrient availability gradients. Oecologia 118(1):50–58. doi: 10.1007/s004420050702

Philippine Statistics Authority (2020) Selected Statistics on Agriculture,. Republic of the Philippines, ISSN-2012-0362

Poudel DD, Midmore DJ, Hargrove WL (1998) An analysis of commercial vegetable farms in relation to sustainability in the uplands of Southeast Asia. Agric Syst 58(1):107–128. doi: 10.1016/S0308-521X(98)00052-3

Pulhin JM, Chokkalingam U, Peras RJJ et al (2006) Historical Overview. In: Chokkalingam U, Carandang AP, Pulhin JM et al (eds) One century of forest rehabilitation in the Philippines: Approaches, outcomes, and lessons. Center for International Forestry Research, Bogor Indonesia, pp 6-41

Quiñones CMO, Veldkamp E, Lina SB et al (2022) Soil greenhouse gas fluxes from tropical vegetable farms, using forest as a reference. Nutr Cycl Agroecosyst 124(1):59–79. doi: 10.1007/s10705-022-10222-4

R Core Team (2020) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria

Sansoulet J, Cabidoche YM, Cattan P (2007) Adsorption and transport of nitrate and potassium in an Andosol under banana (Guadeloupe, French West Indies). Eur J Soil Science 58(2):478–489. doi: 10.1111/j.1365-2389.2007.00904.x

Schmidt M, Corre MD, Kim B et al (2021) Nutrient saturation of crop monocultures and agroforestry indicated by nutrient response efficiency. Nutr Cycl Agroecosyst 119(1):69–82. doi: 10.1007/s10705-020-10113-6

Schreinemachers P, Balasubramaniam S, Boopathi NM et al (2015) Farmers' perceptions and management of plant viruses in vegetables and legumes in tropical and subtropical Asia. Crop Prot 75:115–123. doi: 10.1016/j.cropro.2015.05.012

Shen SM, Pruden G, Jenkinson DS (1984) Mineralization and immobilization of nitrogen in fumigated soil and the measurement of microbial biomass nitrogen. Soil Biol Biochem 16(5):437–444. doi: 10.1016/0038-0717(84)90049-X

Shively G, Pagiola S (2004) Agricultural intensification, local labor markets, and deforestation in the Philippines. Envir Dev Econ 9(2):241–266. doi: 10.1017/S1355770X03001177

Tawaraya K, Hirose R, Wagatsuma T (2012) Inoculation of arbuscular mycorrhizal fungi can substantially reduce phosphate fertilizer application to *Allium fistulosum* L. and achieve marketable yield under field condition. Biol Fertil Soils 48(7):839–843. doi: 10.1007/s00374-012-0669-2

Tei F, De Neve S, de Haan J, Kristensen HL (2020) Nitrogen management of vegetable crops. Agric Water Manag 240:106316. doi: 10.1016/j.agwat.2020.106316

Tiessen H, Stewart JWB, Cole CV (1984) Pathways of phosphorus transformations in soils of differing pedogenesis. Soil Sci Soc Am J 48:853–858. doi: 10.2136/sssaj1984.03615995004800040031x

Timprasert S, Datta A, Ranamukhaarachchi SL (2014) Factors determining adoption of integrated pest management by vegetable growers in Nakhon Ratchasima Province, Thailand. Crop Prot 62:32–39. doi: 10.1016/j.cropro.2014.04.008

van Lammerts Bueren ET, Struik PC (2017) Diverse concepts of breeding for nitrogen use efficiency. A review. Agron Sustain Dev 37(50). doi: 10.1007/s13593-017-0457-3

Wang G, Cai W (2020) Two-year consecutive concurrences of positive Indian Ocean Dipole and Central Pacific El Niño preconditioned the 2019/2020 Australian “black summer” bushfires. Geosci Lett 7(1):1–9. doi: 10.1186/s40562-020-00168-2

World Health Organization (2010) WHO recommended classification of pesticides by hazard and guidelines to classification 2009. World Health Organization, Geneva, Switzerland

Zamora OB, de Guzman LEP, Saguiguit SLC et al (2013) Leveraging agriculture to improve nutrition in the Philippines. Food Sec 5(6):873–886. doi: 10.1007/s12571-013-0306-4

Zhu Q, Ozores-Hampton M, Li Y, Morgan K et al (2017) Effect of phosphorus rates on growth, yield, and postharvest quality of tomato in a calcareous Soil. HortScience 52(10):1406–1412. doi: 10.21273/HORTSCI12192-17

Zuur AF, Ieno EN, Walker NJ et al (2009) Mixed effects models and extensions in ecology with R. Springer, New York

3.8. Appendices

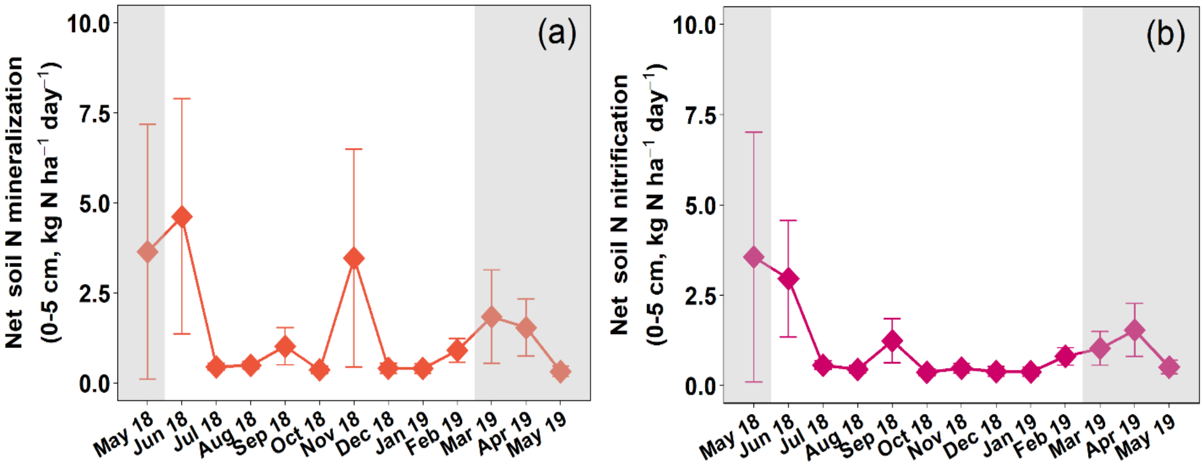

Fig. A3.1 Mean (± SE) rates of soil net N mineralization (a) and net nitrification (b) in the top 0.05 m of small-scale vegetable farms (n = 10 farms), with commonly varied fertilization regimes (Table A3.1), on an Andosol soil in Leyte, Philippines. Gray shadings mark the dry season (< 150 mm rainfall month^{-1})

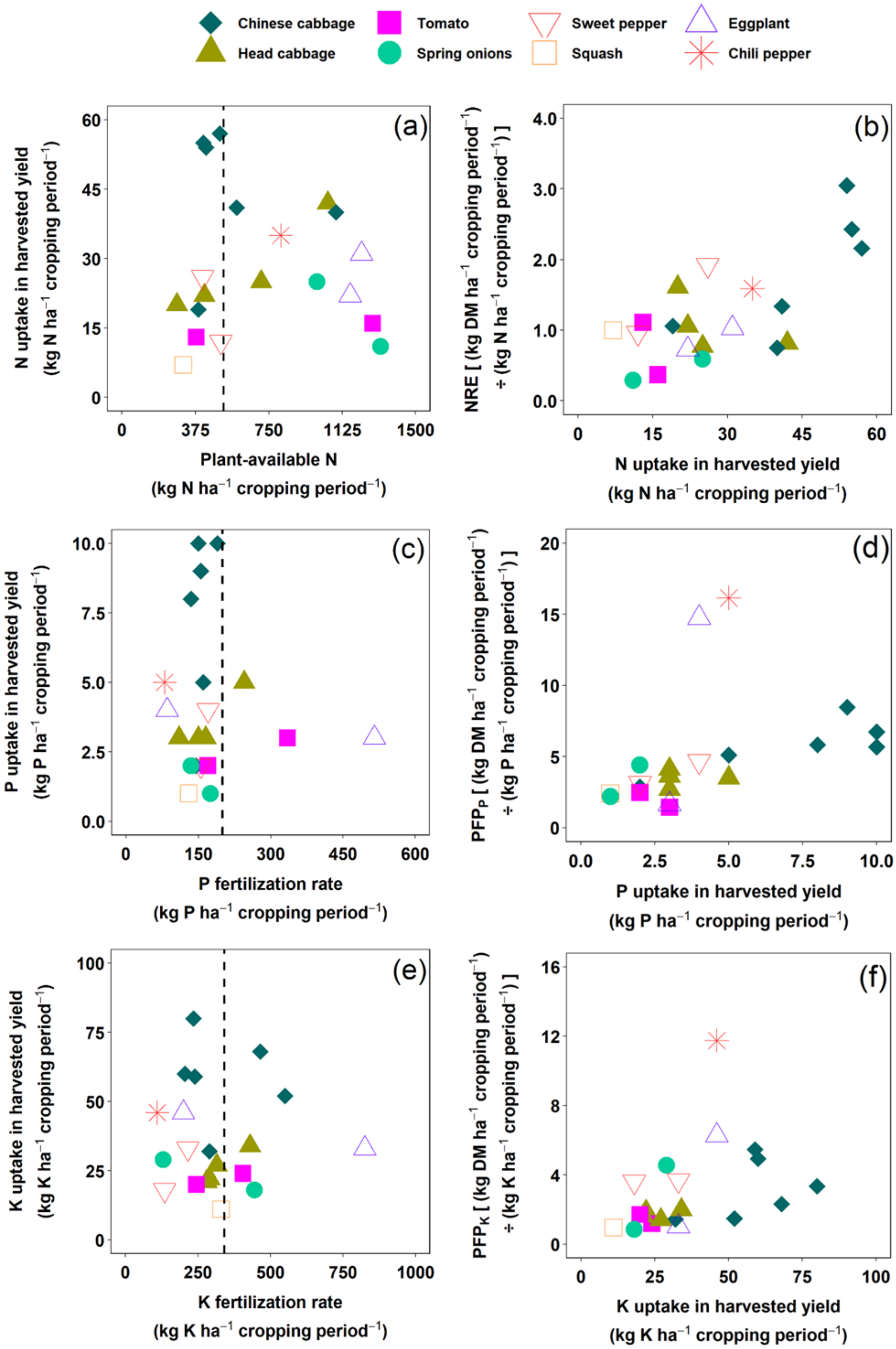

Fig. A3.2. Relationships of N, P, and K uptake in vegetable yield with plant-available N (a; sum of N fertilization rates and extant net N mineralization rates during the cropping period), and P and K fertilization rates (c, e). N response efficiency (NRE) = yield ÷

plant-available N (b), and partial factor productivity from the applied P (PFP_P) and K fertilizers (PFP_K) = yield ÷ P or K fertilization rate (d, f) in small-scale vegetable farms on an Andosol soil in Leyte, Philippines (n = 20 vegetable cropping periods). The dashed lines are my subjective delimitation for optimum N, P, and K uptake in harvested yield to optimum N, P and K fertilization rates. Nutrient uptake in harvested yield showed similar patterns with NRE (b), PFP_P (d), and PFP_K (f)

Table A3.1

Cultivated crops and corresponding harvested yield and fertilization rates in small-scale vegetable farms (n = 10 farms) on an Andosol soil in Leyte, Philippines

Vegetable farm	Crops	Harvested yield [a]		Fertilization rate		
		Fresh weight	Dry matter	N	P	K
		(kg ha^{-1} cropping period^{-1})		(kg ha^{-1} cropping period^{-1})		
Farm 1	Chinese cabbage (*B. rapa* subsp. *pekinensis*)	13840	1010	335	150	205
	Head cabbage (*B. oleracea* var. *capitata*)	17000	540	600	150	290
Farm 2	Chinese cabbage (*B. rapa* subsp. *pekinensis*)	9890	1080	330	190	465
	Chinese cabbage (*B. rapa* subsp. *pekinensis*)	9400	415	220	145	290
	Chinese cabbage (*B. rapa* subsp. *pekinensis*)	19000	1310	260	155	240
Farm 3	Tomato (*S. lycopersicum* L.)	7050	480	570	335	405
	Head cabbage (*B. oleracea* var. *capitata*)	12600	860	400	245	430
Farm 4	Head cabbage (*B. oleracea* var. *capitata*)	12330	445	355	165	315
	Head cabbage (*B. oleracea* var. *capitata*)	18830	450	215	110	280

Table A3.1 continuation...

Vegetable farm	Crops	Harvested yield [a]		Fertilization rate		
		Fresh weight	Dry matter	N	P	K
		(kg ha^{-1} cropping period^{-1})		(kg ha^{-1} cropping period^{-1})		
Farm 5	Tomato (*S. lycopersicum* L.)	6000	420	325	170	245
	Squash (*Cucurbita* sp.)	6000	310	235	130	330
	Sweet pepper (*C. annuum* L.)	9900	790	330	170	215
Farm 6	Sweet pepper (*C. annuum* L.)	6400	490	210	155	135
Farm 7	Spring onion (*A. fistulosum* L.)	6900	590	280	135	130
	Spring onion (*A. fistulosum* L.)	14150	380	605	175	445
	Chinese cabbage (*B. rapa* subsp. *pekinensis*)	16000	820	520	160	550
Farm 8	Eggplant (*S. melongena* L.)	16920	850	825	515	825
Farm 9	Eggplant (*S. melongena* L.)	20900	1255	260	85	200
Farm 10	Chinese cabbage (*B. rapa* subsp. *pekinensis*)	8100	790	365	135	235
	Chili pepper (*Capsicum* sp.)	17220	1290	150	80	110

[a] Dry matter of harvested yield during each cropping period was measured by collecting fresh harvestable sample and oven-drying it at 70 °C for at least three days

Table A3.2

Cost-benefit analysis of small-scale vegetable farms on an Andosol soil in Leyte, Philippines (n = 20 vegetable cropping periods)

Vegetable crops/ number of cropping periods	Production cost ha^{-1} cropping period^{-1} (range; mean ± SE) [a]						Revenue ha^{-1} cropping period^{-1} (range; mean ± SE) [b]		Profit ha^{-1} cropping period^{-1} (range; mean ± SE) [c]	
	Labor		Materials		Total					
	Philippine peso	Euro equivalent	Philippine peso	Euro equivalent	Philippine peso	Euro equivalent	Philippine peso	Euro equivalent	Philippine peso	Euro equivalent
Chinese cabbage (*B. rapa* subsp. *pekinensis*, n=6)	10800 – 11100 (10850 ± 50)	187 – 192 (188 ± 1.0)	115403 –154800 (129200 ± 5775)	1996 – 2678 (2235 ± 100)	126503 – 165600 (140050 ± 5751)	2189 – 2865 (2423 ± 99)	121500 – 285000 (190575 ± 26243)	2102 – 4931 (3297 ± 454)	-17816 – 155903 (50525 ± 25975)	-308 – 2697 (874 ± 449)
Head cabbage (*B. oleracea* var. *capitata*, n=4)	10800 – 11400 (11100 ± 173)	187 – 197 (192 ± 3.0)	113667 – 154953 (135060 ± 8694)	1966 – 2681 (2337 ± 150)	124467 – 166353 (146160 ± 8842)	2153 – 2878 (2529 ± 153)	246600 – 376600 (303800 ± 32359)	4266 – 6515 (5256 ± 560)	99668 – 252133 (157640 ± 35713)	1724 – 4362 (2727 ± 618)
Tomato (*S. lycopersicum* L., n=2)	12300	213	125583 – 160160 (142871)	2173 – 2771 (2472)	137883 – 172460 (155171)	2385 – 2984 (2684)	180000 – 211500 (195750)	3114 – 3659 (3386)	39040 – 42117 (40579)	675 – 729 (702)
Spring onion (*A. fistulosum* L., n=2)	11400 – 11700 (11550)	197 – 202 (200)	116514 – 160825 (138670)	2016 – 2782 (2399)	128214 – 172225 (150,220)	2218 – 2979 (2599)	345000 – 707500 (526250)	5969 – 12,240 (9104)	216786 – 535275 (376,030)	3750 – 9260 (6505)

Table A3.2 continuation...

Vegetable crops/ number of cropping periods	Production cost ha^{-1} cropping $period^{-1}$ (range; mean ± SE) [a]						Revenue ha^{-1} cropping $period^{-1}$ (range; mean ± SE) [b]		Profit ha^{-1} cropping $period^{-1}$ (range; mean ± SE) [c]	
	Labor		Materials		Total					
	Philippine peso	Euro equivalent	Philippine peso	Euro equivalent	Philippine peso	Euro equivalent	Philippine peso	Euro equivalent	Philippine peso	Euro equivalent
Sweet pepper (*C. annuum* L., n=2)	12000 – 12900	208 – 223	107837 – 125192	1886 – 2166	120737 – 137192	2089 – 2373	256000 – 396000	4429 – 6851	135263 – 258808	2340 – 4477
Squash (*Cucurbita* sp., n=1)	11400	197	117780	2038	129180	2235	90000	1557	-39180	-678
Eggplant (*S. melongena* L., n=2)	12900 – 15300 (14100)	223 – 265 (244)	115256 – 204050 (159653)	1994 – 3530 (2762)	130556 – 216950 (173753)	2259 – 3753 (3006)	507600 – 627000 (567300)	8781 – 10847 (9814)	290650 – 496444 (393547)	5028 – 8588 (6808)
Chili pepper (*Capsicum* sp., n=1)	15000	260	100985	1747	115985	2007	1894200	32770	1778215	30763

[a] Materials included fertilizers, seeds, and pesticides while labor was based on number of man-days × current salary for land preparation, planting, weeding, spraying pest control, and harvesting. Philippine peso (PhP) conversion to Euro equivalent was calculated using the exchange rate 1 Php = 0.0173 Euro (annual average between 2018–2020; https://www1.oanda.com/currency/converter/)

[b] Harvested yield at farm-gate price per kg (based on the standard farm-gate price per kg in the province or country for each vegetable, i.e. Chinese cabbage: Php 15=0.26 Euro; head cabbage: Php 20=0.35 Euro; Tomato: Php 30=0.52 Euro; spring onion: Php 50=0.87 Euro; sweet pepper: Php 40=0.69 Euro; Squash: Php 15=0.26 Euro; Eggplant: Php 30=0.52 Euro; chili pepper: Php 110 = 1.91 Euro; https://openstat.psa.gov.ph/Metadata/Prices)

[c] Profit = revenue - total production cost

CHAPTER 4

SYNTHESIS

The overall focus of this research project was to evaluate the environmental and economic impacts of an intensively managed smallholder vegetable production system on an Andosol soil. The general hypotheses tested were (1) vegetable farms will have higher soil GHG emissions, relative to the forest and (2) identified optimum levels of N-P-K fertilization rates in farms will correspond to optimum vegetables' harvested yield and fertilizer cost will largely influence the total crop production cost including the farmer's farm-gate profit. Results have supported the above hypotheses indicating that vegetable farms as a substantial source of soil N_2O, $CO_{2,}$ and weak sink of CH_4. Reducing farmers' fertilization rates to optimum limits produces optimum harvested yield and fertilizer input reduction can potentially moderate production costs, improve farm-gate profit, and can overall minimize detrimental impacts on the environment. In this chapter, I discuss the overall compromises that intensive management in smallholder vegetable production systems can contribute to the environment, economy, and society.

4.1. Probable soil degradation resulting from intensive vegetable cultivation practices

The population in the Philippines is projected to increase from 129×10^6 individuals in 2030 to about 158×10^6 in 2050 (FAOSTAT 2022). A fraction of this population will be immersed in agriculture-based occupation that may increase agricultural production and economic activity, but it may add also pressure to settlement areas. The population growth itself, alongside elevated food demand, is expected to displace part of the population migrating to rural upland areas and boosting agricultural activities, subsequently clearing forest vegetation and tillage of soils as farmlands. As cultivation practices intensify over a long period, dynamic soil properties such as bulk density, ECEC, pH, and SOC stocks undergo serious irreversible changes (Veldkamp et al. 2020). These findings are similarly gathered in this study, where secondary forests converted to intensively managed smallholder vegetable farms underwent serious changes in soil properties (Table 2.1). For example, the SOC stock in the secondary forest down to 1-m soil depth was 231 Mg C ha^{-1}, but it has noticeably decreased to 96 Mg C ha^{-1} following land-use conversion and intensive cultivation practices. Assuming that conversion of forest to vegetable farms started 20 years earlier than this research project (Table A2.1) and that the decline of SOC was constant, the SOC stock decreases at a rate of 7 Mg C ha^{-1} yr^{-1}. Although this decrease does not mean complete exhaustion of soil organic C since inputs from other sources such as manures, crop residues, and microbial biomass replenish the C supply, the SOC stock loss is likely to advance and the rate of loss can be invigorated by two activities: first, vegetable cultivation practices continue to intensify every cropping period as farmers aim to produce and earn more, at the expense of no fallow periods, and second, forest conversion and disturbance become extensive arising from growing farming activities in the area. Moreover, a major underlying factor that increasingly drives these activities is the profitability of vegetable production to the farming community. This economic advantage, however, is implemental for intensified production practices, which in turn hastened decreases of SOC stock and compromises qualities of other soil properties (Table 2.2). C stability influences overall soil fertility, productivity, and C storage and thus, serious C losses can weaken soil functions (Lal 2013; Veldkamp et al. 2020). Therefore, the soil is highly subjected to serious degradation and this occurrence can likely expand as the forest clearing-conversion-intensive cultivation-abandonment cycle is repeated. There is an urgent need to improve cultivation practices that impose soil organic matter accumulation and soil tillage reduction to salvage soil quality and minimize soil C losses.

4.2. Serious occurrence of NO_3^- leaching and NO_3^- pollution

Excessive fertilizer application for many years, creating a surplus of N, resulted in high NO_3^- accumulation in the 1-m depth of the Andosol soil (Table 2.5). This indicated that excess NO_3^- has leached and stored at a deeper soil depth since its movement is retarded from further leaching through its temporary adsorption to variable charges of the soil (Rasiah et al. 2003) and that NO_3^- in deeper depths can lengthen emissions since substrate for soil N_2O production is available. The delayed leaching of NO_3^- can be offset by Cl^- from fertilizers or sea salt spray replacing loosely held NO_3^- in exchange sites (Formaglio et al. 2020). Moreover, NO_3^- mobility below the root zone is invigorated under high precipitation, particularly for Andosol soils in the humid tropical regions where rainfall > evapotranspiration (Endo et al. 2013; Prado et al. 2011). Under such conditions, NO_3^- leaching advances and increases the risk for contamination (i.e., > 10 mg NO_3^--N L^{-1} or > 45 mg NO_3^- L^{-1}) to groundwater and freshwater bodies located in lower elevations. Leached NO_3^- can also serve as an indirect substrate for N_2O production (Tubiello et al. 2013). To corroborate NO_3^- leaching in vegetable farms, it is suggested that N leaching losses in drainage water be measured using suction lysimeters installed within the root zone and in 1-m and > 1-m soil depths.

Due to large reserves of NO_3^- in the 1-m soil depth, substantial soil N_2O emissions from vegetable farms can continue over a long duration. Assuming that the NO_3^- stock in the top 0.5 m during the wet season (~ 130 kg NO_3^--N ha^{-1}; Table 2.5) was the substrate for the N_2O-producing processes in the top 0.05 m (~ 13 kg N yr^{-1}; Table 2.5), this indicated that roughly 10% of the NO_3^- stock was emitted as soil N_2O. Since NO_3^- availability was not limited, it would entail a decade before the entire NO_3^- stock will be released as N_2O into the atmosphere. The period for emissions can even last longer if the NO_3^- down to the 1-m depth (~ 200 kg NO_3^--N ha^{-1}; Table 2.5) is counted.

4.3. Integration of soil GHG fluxes in vegetable production systems into GHG inventories

The Philippines is one of the countries most exposed to climate change-related calamities with a vulnerability intensified by localized environmental degradation (Holden and Marshall 2018). The agriculture sector, which is the country's economic lifeline, experiences serious destructive aftermath brought by stronger typhoons. Hence, it is most distressed by climate change. For instance, the super typhoon Haiyan in 2013 brought a total damage cost of US$ 440 million to agriculture in slammed areas (NDRRMC Update 2014). And yet, the agriculture sector is one of the highest sources of GHGs with an insufficient inventory due to a lack of input data (UNFCC 1999). Additionally, the agriculture GHG inventory highlights most of its emissions from rice agroecosystems (under the rice cultivation category), while the incorporation of emissions in other crop production systems (under the agricultural soils category) likely remained overlooked (UNFCC 1999; UNFCCC 2014). A major focus for one crop production system is creating bias in the inventory. Hence, the agriculture GHG inventory is highly uncertain and contains underestimated values. Given the wide coverage of vegetable farms in the entire country (Dikitanan et al. 2017) and its considerable mineral fertilizer consumption (Briones 2014; Johnson et al. 2008), patterns of soil GHG fluxes in vegetable production systems (Table 2.3; Fig. 2.4; Quiñones et al. 2022) are suggested to be integrated into the agriculture GHG inventory. As management practices are foreseen to intensify, soil CH_4 production is predicted to override CH_4 uptake due to increased soil compaction that inhibits soil aeration, whereas soil N_2O and CO_2 are projected to elevate attributed to higher NO_3^- from N inputs (as explained above) and SOC losses through heterotrophic respiration. Considering the overall GHG balance of the studied vegetable production system (Fig. 2.4), its minimal but considerable contribution to possible increases of atmospheric N_2O, CO_2, and CH_4 can convey detrimental impacts to the environment, i.e., a slight increase of these potent gases is contributory for climate change occurrence or global warming in worst case scenario – impacts that needed more serious concern over economic losses instigated by intensive vegetable production practices. Although vegetable production systems on the same soil type across the Philippines may vary and more investigations that cover cultivation practices are still necessary, soil N_2O, CO_2, and CH_4 fluxes must be measured at a farm level before their integration into agriculture-specific and national GHG inventories. This bottom-up approach can improve the GHG inventories and subsequently offer realistic GHG trends that can be used as yardsticks for improved efforts, strategies, and policies for climate change mitigation and resilience, particularly for the most vulnerable sector which is agriculture.

4.4. Environmental and economic benefits from optimization of farmer's conventional fertilization rates

Optimizing the farmers' conventional fertilization rates was practical, profitable, and advantageous with the aim of reducing the undesirable economic and environmental impacts from excessive fertilization inputs in vegetable production systems. The impacts from the abatement of fertilization rates to optimum limits can be the following: a) a considerable decrease in soil N_2O, CH_4, and CO_2 fluxes due to reduced stimulation of microbial processes responsible for the production of these gases, b) evident reduction of NO_3^- leaching and/or NO_3^- accumulation in deeper soil depths, consequently curtailing the risk of groundwater contamination and indirect soil N_2O emissions stimulated by excessive NO_3^- availability, and c) improved overall economic conditions for vegetable farmers since borrowed loans for fertilizer procurement will be reduced and profit will be not hampered by loan payments. These advantages, however, are yet projections and needed validations in future investigations in the study area.

4.5. Farmer's participation in promoting sustainable vegetable production systems

Farmers are the lifeblood of the entire vegetable industry making their involvement and cooperation vital so that the industry will fully attain its potential (Johnson et al. 2008a), in terms of sustainable production, fair market, and reduction of soil GHG footprints. In particular, the partnership of farmers with the government and private sector is vital in the formulation of specific cultivation practices that promote soil C sequestration or C persistence and other climate-change mitigation measures, so that adoption of these practices would create a higher impact than when farmers are told what management practices to apply (Davidson 2022). Moreover, farmers should be offered an honorarium for their commitment to employing practices that minimize C losses in agricultural soils. These approaches would not only be compelling but may also create a farming community that adheres to sustainable vegetable cultivation practices (e.g., use of cover crops, application of biochar, integration of manure; Schlesinger 2022), which overall may offer long-term beneficial effects.

4.6. Outlook

The results of our study have provided the much needed knowledge on the changes of soil properties and nutrient stocks, patterns of soil GHG fluxes, and optimum levels of nutrients and fertilization rates in an intensively fertilized smallholder vegetable production system. In addition, vegetable farming deemed attractive and lucrative as livelihood and thus, foreseen to increase as an agricultural activity. These science-based information are useful to policy makers, academic institutions or researchers, farmers, private organizations, and the community as a whole, for concerted efforts to reduce soil GHG emissions and water contamination, minimize crop production losses, optimize yield and profit, and to promote sustainable crop production practices. In particular, the study's data can be used by relevant government agencies and policy makers as reference in formulating agriculture-related policies and strategies that reflect sustainable cultivation practices alongside technical services (e.g., access of farmers to qualitative soil analysis, adherence to recommended fertilizer and pesticide application rates, organic sources of fertilizers and pest control, rotation of vegetable cultivation). Academic institutions can strengthen and convey these policies and strategies at student and farm levels, instill environmental protection awareness in the process, and implement monitoring. Farmers, who apply sustainable practices in their farming, should be incentivized. The transmission of information, increase of community participation, and dissemination of efforts to reduce negative impacts of intensive crop production can be re-enforced through the participation of related scientific organizations or non-government institutions. Overall, an inclusive approach supported by scientific information is essential to minimize the negative environmental effects from intensive crop production and to promote sustainable practices. It also entails the wholistic participation of the society and thus, the information generated from this research project ought to be known to various sectors.

Given the above-mentioned, more research is still required to further understanding of the effects arising from intensive vegetable cultivation on the Andosol soil of our study area and topics may include the following:

- annual nutrient leaching losses in the vegetable farms at shallow (0.30 m) and deeper (0.6–1 m) soil depths, in comparison with the secondary forest as reference land use
- soil net mineralization rate in the secondary forest to determine the magnitude of its increase following land-use conversion to vegetable farms
- the effect of unregulated pesticide application to soil GHG fluxes and soil net mineralization rates
- soil GHG budget following optimum limits of fertilization to determine the decrease of soil N_2O, CH_4, and CO_2 relative with the farmers' accustomed fertilization rates
- NO_3^- stock at >1 m soil depth to evaluate deeper NO_3^- availability that can likely promote indirect soil N_2O emissions and pollute the ground water

4.7. References

Briones RM (2014) The role of mineral fertilizers in transforming Philippine agriculture. Philippine Institute for Development Studies, Discussion Paper Series No. 2014-14:1–24

Davidson EA (2022) Is the transactional carbon credit tail wagging the virtuous soil organic matter dog? Biogeochemistry 161(1):1–8. doi: 10.1007/s10533-022-00969-x

Dikitanan R, Grosjean G, Leyte J (2017) Climate-resilient agriculture in the Philippines. CSA Country Profiles for Asia Series. International Center for Tropical Agriculture (CIAT); Department of Agriculture -Adaptation and Mitigation Initiatives in Agriculture, Government of the Philippines. Manila, Philippines, pp 1–24

Endo A, Mishima SI, Kohyama K (2013) Nitrate percolation and discharge in cropped Andosols and Gray lowland soils of Japan. Nutr Cycl Agroecosyst 95(1):1–21. doi: 10.1007/s10705-012-9544-7

FAOSTAT (2022) FAOSTAT Online. Food and Agriculture Organization of the United Nations. https://www.fao.org/faostat/en/#data/OA. Accessed 13 November 2022

Formaglio G, Veldkamp E, Duan X et al (2020) Herbicide weed control increases nutrient leaching compared to mechanical weeding in a large-scale oil palm plantation. Biogeosciences 17(21):5243–5262. doi: 10.5194/bg-17-5243-2020

Holden WN, Marshall SJ (2018) Climate change and typhoons in the Philippines: Extreme weather events in the anthropocene. In: Integrating Disaster Science and Management. Elsevier, pp. 407–421

Johnson GI, Weinberger K, Wu MH (2008) The vegetable industry in tropical Asia: The Philippines. AVRDC Exploration Series No. 1, pp 1-84

Lal R (2013) Soil carbon management and climate change. Carbon Manag 4(4):439–462. doi: 10.4155/cmt.13.31

NDRRMC Update (2014) Sitrep No 108 Effects of typhoon "Yolanda" (Haiyan). National Disaster Risk Reduction and Management Center, Quezon City, Philippines, pp 1-62

Prado B, Duwig C, Etchevers J et al (2011) Nitrate fate in a Mexican Andosol: Is it affected by preferential flow? Agric Water Manag 98(9):1441–1450. doi: 10.1016/j.agwat.2011.04.013

Quiñones CMO, Veldkamp E, Lina SB et al (2022) Soil greenhouse gas fluxes from tropical vegetable farms, using forest as a reference. Nutr Cycl Agroecosyst 124(1):59–79. doi: 10.1007/s10705-022-10222-4

Rasiah V, Armour JD, Menzies NW et al (2003) Nitrate retention under sugarcane in wet tropical Queensland deep soil profiles. Soil Res 41(2):1145–1161. doi: 10.1071/SR02076

Schlesinger WH (2022) Biogeochemical constraints on climate change mitigation through regenerative farming. Biogeochemistry 161(1):9–17. doi: 10.1007/s10533-022-00942-8

Tubiello FN, Salvatore M, Rossi S et al (2013) The FAOSTAT database of greenhouse gas emissions from agriculture. Environ Res Lett 8(1):15009. doi: 10.1088/1748-9326/8/1/015009

UNFCC (1999) The Philippines' initial national communication on climate change. https://unfccc.int/documents/139218. Accessed 10 November 2021

UNFCCC (2014) Second national communication to the United Nations Framework Convention on Climate Change: Philippines. https://unfccc.int/documents/139241. Accessed 10 November 2021

Veldkamp E, Schmidt M, Powers JS, Corre MD (2020) Deforestation and reforestation impacts on soils in the tropics. Nat Rev Earth Environ 1(11):590–605. doi: 10.1038/s43017-020-0091-5

ACKNOWLEDGEMENTS

My profound gratitude goes to the following organizations and personalities:

The German Academic Exchange Service (DAAD), for awarding me a scholarship that supported my PhD studies; the Institute Soil Science of Tropical and Subtropical Ecosystems (SSTSE) for hosting my PhD studies and for providing most of the funds for my thesis project (~ 2 years of fieldwork and lab analyses).

The Ulrich Stiftung (https://www.uni-goettingen.de/en/517109.html), the Faculty of Forest Sciences and Forest Ecology (c/o SSTSE), and the Graduate School of Forest and Agricultural Sciences for granting me research funds during the final year of my PhD studies.

My sincerest thanks go to Prof. Dr. Edzo Veldkamp, the Head of SSTSE, for his kind endorsement during my DAAD scholarship application in 2016, for the opportunity to occupy a PhD position in his group, and for his imparted academic expertise. Thank you very much for your continued support and guidance before and during my graduate studies (including MS) at SSTSE.

My heartfelt appreciation goes to Dr. Marife D. Corre, my immediate Supervisor, who encouraged and supported the realization of my PhD thesis project. Her unceasing all-out supervision of my work offered me opportunities to undergo thorough training in the different aspects of scientific research (i.e, good research planning, carrying out well-planned fieldwork, objective scrutiny to gathered data, and tight scientific reporting/ writing). Thank you so much, Ate Marife, for generously sharing with me your time, efforts, encouragement, life experiences, wide scientific knowledge, and passion for research. All these brought me enriching remarkable PhD training and other meaningful experiences, which I will carry forward after my time at SSTSE. I am sincerely grateful to work with an inspiring and empowered woman, like you.

Special thanks go to the other members of my thesis committee, namely Prof. Dr. Klaus Dittert and Dr. Guntars Martinson, for their constructive suggestions that further the improvement of my thesis themes.

Warm thanks are extended to the staff of SSTSE. The technical and laboratory supports from Dirk Böttger, Andrea Bauer, Martina Knaust, Kerstin Langs, and Natalia Schröder are highly appreciated. I am fortunate to have experienced assistance with urgency from the Institute secretary Sonja Gerke. I am similarly glad for the camaraderie and exchange of ideas with my officemates Jie Lou and Guadong Shao, and with other colleagues, namely Najeeb Al-Amin Iddris, Raphael Manu, Xenia Bischel, Dan Niu, Guan-tao Chen, Anike Berane, Sarah Choe Marcus Schmidt, and Oliver van Straaten. I thank you all for your support.

Much appreciation goes to the personalities and government offices, who in one way or another, were instrumental in the performance of my thesis in Cabintan, Leyte. In particular, I am thankful to Jovan A. Nayre, Jowill P. Loreto, Gretchen Mae M. Prado, Isaias A. Codilla, Olegario F. Paredes Jr., Maria Elena A. Mendoza, Judith F. Paredes, Nazi P. Embog, Dr. M. J. M. Bande and his team, Karl Vincent S. Mendez, Ma. Aneli A. Auguis, farmer collaborators, and village leaders and locals for their assistance during my series of fieldwork. Logistical and information supports rendered by the City Mayor's Office, City Agriculture Office, and Community Environment and Natural Resources Office in Ormoc City, the offices Department of Environment and Natural Resources and Department of Science and Technology Philippine Atmospheric, Geophysical and Astronomical Services Administration in Tacloban City, and the Mines and Geosciences Bureau in Palo, Leyte are likewise highly recognized and very much appreciated. Daghang salamat sa inyung kinasing-kasing nga tabang!

My sincere thanks are addressed to the Visayas State University and to the Department of Soil Science for their continued support, displayed through their approval of my requests for study leave extension.

Heaps of sincere thanks to my fellow Filipino students and friends, with whom I shared colorful moments in every season of my stay in Göttingen. Thank you for sharing with me your sincere presence.

Last but not the least, my constant gratitude and love goes to my tatay Cesar, nanay Lilia, and to my siblings Cherryl, Kristine Joyce, Sherlie, Lesle Mae, and kuya Alain for their evergreen support. I dedicate to you all this PhD thesis – a humble output of half a decade’s scientific toil.

THESIS DECLARATION

I, Cecille Marie O. Quiñones, do hereby declare that the present thesis entitled "Soil greenhouse gas balance, yield, and profit in intensively fertilized vegetable farms on an Andosol soil in Leyte, Philippines" is my work and its chapters have been independently written and completed by myself. The pieces of information, obtained from fitting published references or unreported data sources, have been duly acknowledged in the text and cited in the references section of each chapter. This thesis has not been submitted in any form for another degree at any university. I certify that the manuscript presented in Chapter 2, which is now formally published, has been written by me as the first author.

Göttingen, November 2022

(Cecille Marie O. Quiñones)

CURRICULUM VITAE

PERSONAL INFORMATION

Name **: Cecille Marie O. Quiñones**
Place of Birth **:** Baybay City, Leyte, Philippines
Gender **:** Female
E-mail Address **:** cmoquinones@gmail.com
or cecillemarie.quinones@vsu.edu.ph

EDUCATIONAL BACKGROUND

2017 - Present	PhD Student of the Soil Science of Tropical and Subtropical Ecosystems, University of Göttingen, Germany
2012 – 2014	MSc in Soil Science (minor field: Tropical Ecology) at Visayas State University, Baybay City, Leyte, Philippines MSc Thesis Title: Soil Properties of a Degraded Grassland Watershed Underlain by Ultramafic Geology in Northeastern Leyte, Philippines
2009 – 2011	MSc in Forest Sciences and Forest Ecology at Georg-August Universität of Göttingen, Germany Specialization: Tropical and International Forestry Programme MSc Thesis Title: Soil Nitrogen Cycling in Permanent Managed Grassland as Affected By Fertilization and Phytodiversity
2004 – 2008	Bachelor of Science in Agriculture at VSU, Baybay City, Leyte Major in Soil Science BSc Thesis Title: Nutrient Characteristics of Acidic and Calcareous Soils Planted to *Jatropha curcas* L. Applied with Chemical and Organic Fertilizers
2000 – 2004	VSU Laboratory High School (VSULHS), Baybay City, Leyte
1993 – 2000	Visca Foundation Elementary School (ViFES), Baybay City, Leyte

WORK / RESEARCH EXPERIENCE

Feb 2018 – Sep 2019	Field-based quantification of soil greenhouse gas fluxes, nutrient response efficiency and nutrient leaching losses in small-scale vegetable production on an Andosol soil in Leyte, Philippines, as part of the performance of a PhD research project.
Jan 2015 – Jul 2017	Instructor/ Lecturer (Regular Position) at the Department of Soil Science, Visayas State University, Visca, Baybay City, Leyte; **Duties/ Responsibilities**: teaches courses in basic soil science, soil fertility, and environmental geomorphology to BSc students; serves as thesis adviser to BSc in soil science/environmental

	management students; conducts soil researches dealing with nutrient management, soil erosion, nutrient omission experiments for vegetables, and soil characterization (funded by the Australian Center for International Agricultural Research (ACIAR) & the Philippine Commission on Higher Education (CHED); serves as resource person for farmers' trainings and seminars
Sept – Dec 2014	Project Officer of the ACIAR Soil Project at VSU
July – Aug 2014	Science Research Assistant of the Philippine Higher Education Research Network (funded by CHED) Project 1, Study 3
Aug 2013 – Feb 2014	Field and laboratory work for MSc thesis research in Northeastern Leyte and VSU
Jan 2011	Forest soil survey as part of a forest management plan in Gunung Walat Educational Forest, Bogor Agricultural University (IPB), Indonesia
Aug – Dec 2010	Field and laboratory work for MSc research in Göttingen, Niedersachsen, Germany
Sep 2008 – June 2009	Science Research Assistant under the Soil Component of the ACIAR Vegetable Project
April - Oct 2007 / Feb 2008	Laboratory work for BSc thesis research

RESEARCH PROJECTS

Involvement	Study
1. Study leader	*PhD research project*: Nutrient response efficiency, soil greenhouse gas fluxes and nutrient leaching losses in vegetable production systems on an Andosol soil in Leyte, Philippines – funded by Institute Soil Science of Tropical and Subtropical Ecosystems and by DAAD
2. Study Leader	Soil erosion and pedo-hydrological properties under various agricultural land uses in marginal uplands- funded by CHED PHERNet (January – December 2015)
3. Component Leader	Identification of macronutrient constraints through nutrient omission trials involving four soil types commonly grown to vegetables in Leyte – part of the ACIAR Soil Project (2015 – 2017)
4. Component Leader	Greenhouse study to monitor the growth and yield of eggplant (*Solanum melongena* L.) and sweetpepper (*Capsicum annuum* L.) commonly grown in acidic and calcareous soils of Leyte – part of

	the ACIAR Soil Project (2015 – 2017)
5. Co-component leader	Field survey of vegetable farmers in Leyte, Bohol, and Samar - part of the ACIAR Soil Project (2015 – 2017). The study evaluates the nutrient contents of soils and vegetables as well as the management practices of the farmers.

WORKSHOPS/ TRAININGS ATTENDED

16 – 30 Apr 2016	Training on the methods of nutrient studies and the use of research related equipment; orientation on the vegetable production and the soils and geology of the Lockyer Valley. University of Queensland and Queensland Department of Agriculture and Fisheries. Brisbane, Australia
14 – 18 Sep 2015	National Certification III: *Harnessing Agricultural Extension Workers' Capabilities on Agricrop Production*. Agriculture Training Institute –Regional Training Center VIII, Visayas State University, Visca, Baybay City, Leyte

CONFERENCES/ SEMINARS ATTENDED

19 – 30 April 2021	European Geosciences Union General Assembly 2021. Contribution: vPICO presentation about soil N2O, CH4, and CO2 fluxes between tropical secondary forest and small–scale vegetable production on an Andosol soil
23 – 24 May 2016	National Research Council of the Philippines – Visayas Regional Cluster (NRCP –VRC) Annual Scientific Conference and 13th General Membership Assembly. University of San Jose Recoletos, Cebu City. *Theme*: Research Innovation for Inclusive Development in the Visayas Region. (*Member and Participant*)
14 May 2016	DAAD – GIZ Alumni Day. Doehle Haus, Makati City. *Theme*: Harnessing the Potentials of Alumni for International Cooperation. (*Alumni*)
7 – 8 Apr 2016	Department of Science and Technology (DOST) 1st International Scholars' Conference. Philippine International Convention Center, Pasay, Manila. *Theme*: Benchmarking Science and Technology towards Enhancing Global Competitiveness. (*Poster Judge and Participant*)
16 Mar 2016	NRCP 83rd General Membership Assembly and Scientific Conference. Philippine International Convention Center, Pasay City. *Theme*: Research Innovation for Inclusive Development. (*Member and Participant*)
16 – 20 Feb 2016	2nd National Organic Agriculture Scientific Conference. Convention Center, Visayas State University. *Theme*: Go organic…for health, resiliency, and sustainability. (*Participant*)

04 Nov 2015	Soil and Plant Nutrition Seminar on 'The challenge of Predicting Metal Transfer through the soil – plant – animal continuum (by Prof. Neil Menzies, University of Queensland- Australia) and 'Field Diagnostics of Disorders in Vegetable Crops (by Dr. Stephen Harper, Queensland Department of Agriculture and Fisheries- Australia). Department of Soil Science, Visayas State University. (*Participant*)
14 – 16 Oct 2015	First Annual Regional Conference on Climate Change Research, Development, & Extension. Convention Center, Visayas State University. *Theme*: Charting the Path for Eastern Visayas' Climate Change Research, Development, & Extension Programs. (*Participant*)
30 Jul – 01 Aug 2015	Conference on Experiences and Lessons Learned in Rehabilitating Typhoon-Damaged Agriculture and the 6th Biennial PSAI Convention. Convention Center, Visayas State University. (*Participant*)
7 – 8 May 2015	4th National Department of Science and Technology –Science Education Institute Accelerated Science and Technology Human Resources Development Program – National Science Consortium (DOST – ASTHRDP) Scholars' Conference. Hotel Jen, Manila. *Theme:* Strengthening Linkages through Multi-Disciplinary Collaboration. (*Oral Presentation)*
22 – 24 Oct 2013	National Conference on Development Initiatives in the Philippine Marginal Uplands. Visayas State University. *Theme:* Enhancing Farm Productivity and Environmental Quality in the Philippine Marginal Uplands: A scan of the past and look into the future. (*Participant*)
24 Sep – 6 Oct 2012	13th International Seminar and Workshop on Tropical Ecology. Visayas State University, Visca, Baybay, Leyte. (*Participant*)
20 – 22 Jun 2011	Biodiversity Conference. University of Göttingen. *Theme:* Functions and Services of Biodiversity. (*Participant*)
14 – 16 Sep 2010	Tropentag (Tropical Day) Conference. ETH Zurich, Switzerland. *Theme:* International Research on Food Security, Natural Resource Management and Rural Development. (*Participant*)
6 – 8 Oct 2009	Tropentag (Tropical Day) Conference. University of Hamburg, Germany. *Theme:* Biophysical and Socio-economic Frame Conditions for the Sustainable Management of Natural Resources. (*Participant*)

SCIENTIFIC PUBLICATIONS

2022	Quiñones, C.M.O., E. Veldkamp, S.B. Lina et al. Soil greenhouse gas fluxes from tropical vegetable farms, using forest as a reference. *Nutr Cycl Agroecosyst* 124: 59–79. https://doi.org/10.1007/s10705-022-10222-4
2019	Zhang, J., L. A. Bruijnzeel, C. M. O. Quiñones, R et al. 2016. Soil physical characteristics of a degraded tropical grassland and a 'reforest': Implications for runoff generation. *Geoderma* 333: 163-177. https://doi.org/10.1016/j.geoderma.2018.07.022

5 – 9 Jun 2016	Zhang, J., C. M. O. Quiñones, R. Tripoli, I. H. J. van Meerveld, V. B. Asio, and L. A. Bruijnzeel. 2016. Contrasting headwater runoff generating mechanisms in fire-climax grassland and semi-mature secondary forest, Leyte, Philippines. American Geophysical Union Chapman Conference. Cuenca, Ecuador. (*Poster presentation*)
2015	Quiñones, C.M.O. and V.B. Asio. 2015. Soils derived from ophiolitic rocks in Northeastern Leyte: morphological, physical, and chemical properties. *Annals of Tropical Research* 37 (2): 35-55.
2014	Asio, V. B., S. B. Lina, D. S. Maranguit, A. B. Bolledo, R. J. T. Doguiles, C. M. O. Quiñones, J. R. Sabijon, and K. L. Demain. 2014. Characteristics of soils in the marginal uplands of Inopacan, Leyte. *Annals of Tropical Research* 36 (Supplement): 1-15.
2014	Hoeft, I., A. Keuter, C. M. Quiñones, P. Schmidt-Walter, E. Veldkamp and M. Corre. 2014. Nitrogen retention efficiency and nitrogen losses of managed and phytodiverse temperate grassland. *Basic and Applied Ecology* 15 (3): 207 – 218. (ISI Journal)

SCHOLARSHIPS AND AWARDS

• DAAD Scholarship for PhD Studies at the University of Goettingen	2017 - 2021
• Department of Science and Technology – ASTHRDP Graduate Scholarship	2012 - 2013
• DAAD Scholarship for MSc Studies at the University of Goettingen	2009 - 2011
• Philippine Agriculture Resources Research Foundation, Inc. Scholarship	2006 - 2008
• College Scholarship	2004 - 2006
• High School Scholarship	2000 - 2004
• Licensed Agriculturist – Professional Regulation Commission	Passed the board exam in 2009
• Certificate of Civil Service Eligibility	April 04, 2008
• Sen. Edgardo J. Angara Award of Excellence	April 04, 2008
• VSU Academic Award of Excellence	April 04, 2008
• Breeders Award of Excellence	April 04, 2008