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Balut egg photo by Shankar S.

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Rai MK, Carpinella C. 2006. Naturally Occurring Bioactive Compounds. Elsevier, Amsterdam.

Chapter in book:

Webb CO, Cannon CH, Davies SJ. 2008. Ecological organization, biogeography, and the phylogenetic structure of rainforest tree communities. In: Carson W, Schnitzer S (eds) Tropical Forest Community Ecology. Wiley-Blackwell, New York.

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Assaeed AM. 2007. Seed production and dispersal of *Rhazya stricta*. 50^{th} Annual Symposium of the International Association for Vegetation Science, Swansea, UK, 23-27 July 2007.

Proceeding:

Alikodra HS. 2000. Biodiversity for development of local autonomous government. In: Setyawan AD, Sutarno (eds.) Toward Mount Lawu National Park; Proceeding of National Seminary and Workshop on Biodiversity Conservation to Protect and Save Germplasm in Java Island. Universitas Sebelas Maret, Surakarta, 17-20 July 2000. [Indonesian]

Thesis, Dissertation:

Sugiyarto. 2004. Soil Macro-invertebrates Diversity and Inter-Cropping Plants Productivity in Agroforestry System based on Sengon. [Dissertation]. Universitas Brawijaya, Malang. [Indonesian]

Information from internet:

Balagadde FK, Song H, Ozaki J, Collins CH, Barnet M, Arnold FH, Quake SR, You L. 2008. A synthetic *Escherichia coli* predator-prey ecosystem. Mol Syst Biol 4: 187. www.molecularsystemsbiology.com. DOI:10.1038/msb.2008.24

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Review: Iloilo's Balut Industry (Philippines)-An exploration of the environment, social organizations, and consumer demands

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Abstract. *Vergara TID, Alejandria MC, Lustanas B. 2020. Review: Iloilo's Balut Industry (Philippines)-An exploration of the environment, social organizations, and consumer demands. Asian J Agric 4: 41-51.* The province of Iloilo has one of the highest numbers of small-scale duck farms in the country. Its agricultural landscape has allowed the rise of farmers entering duck raising practices, mainly along with rice fields throughout the province. However, continuous interventions in the agricultural sector of Iloilo are directed at boosting economic growth. This paper provides a qualitative evaluation of the efficiency of current policies and implementation of rules and regulations on both the duck and duck egg industry of the Province of Iloilo. Findings revealed the need to address issues on the production, distribution, and marketing of the duck and duck egg products of the province. Environmental conditions such as climate and water access, along with the role of social organizations, and impact of existing policies play a key role in the current trajectory of the Iloilo duck industry.

Keywords: Iloilo, balut industry, consumer demands, duck, social organizations

INTRODUCTION

Iloilo's geography (region, topography, landmarks, and geography)

The province of Iloilo is in the Western Visayas Region, also known as Region 6 of the Philippines. Western Visayas is composed of five other provinces namely: Aklan, Antique, Capiz, Guimaras, and Negros Occidental. Iloilo province is located in the southern portion of Panay island, wherein it is bounded by Capiz and Jintotolo Channel in the north; Panay Gulf and Iloilo Strait in the east; Guimaras Strait in the south; and Antique in the west.

The province has the second largest total land area of 471, 940 hectares-comprising 23% of the total land area of the Western Visayas (Department of Environment and Natural Resources 2019). An estimate of 357,857 hectares is characterized as alienable and disposable land. At present, it is composed of two cities: Iloilo city (independent) and Passi City (component), and 42 municipalities. Iloilo City, which is the capital of the province, is commonly known as the 'Heart of the Philippines,' as it lies at the central portion of the country.

A province is a place of many historical and cultural landmarks, which include the Arevalo Plaza known as the first Spanish settlement in Panay to be attacked by English privateer Sir Thomas Cavendish in 1588 (Iloilo City Government 2019). The province is also known for many natural attractions, such as the Gigantes Island or 'Isla de Gigantes,' which is located on the northern coast of Iloilo where 15th-century burial caves can also be found. Sicogon Island is a 1,104-hectare white sand island near Gigantes Island. The tallest peak in the province is Mt. Manaphag which is located on the island of Pan de Azucar. It has a height of 573 feet above sea level and is considered one of the steepest mountains in the country.

Types of agricultural activities in Iloilo

Agriculture is recognized as the principal industry in the province of Iloilo (Philippine Information Agency 2019). In 2002, it was recognized that Iloilo had the largest number of farms in the region, with 133.5 thousand farms. This is equivalent to 31.1% of the total number of farms in the Philippines (Philippine Statistics Authority 2004). Sugar farming was known to be the 'backbone of its economy' (Iloilo Metropolitan Times 2016) and was considered to be most profitable in the province, particularly in Passi City. This local industry likely started in the 19th century as it became high in demand in the market, contributing to the economic boom of the province (Philippine Star Global 2011). In 2016, Western Visayas was the top producer of sugarcane in the country, with a 15.65% contribution to the total agricultural output of the region (Philippine Statistics Authority 2019).

At present, the primary agricultural output of the region is palay, which contributes about 23.85% of the total output of the region (Philippine Statistics Authority 2019). It is ranked as the third-highest rice-producing region in the country. An estimate of 1.05 million hectares is agricultural where 35.4% is composed of rice land (National Nutritional Council 2019). The province of Iloilo is dubbed as the 'Food Basket and Rice Granary of Western Visayas' (Philippine Star Global 2011), as it is the top rice-producing province in the region. Meanwhile, Iloilo ranks as the fifth-highest rice-producing province (Iloilo Economic Development Foundation Inc 2018).

Western Visayas attained an 8.4% economic growth rate in 2017, which is higher in comparison to the 6.7% rate of the country in the same year (The Philippine Star 2018). This significant growth is primarily attributed to the recovery of the agriculture, hunting, forestry, and fishing (AHFF) sector (Iloilo Metropolitan Times 2018). The region is also recognized as the fourth fastest-growing regional economy in the Philippines (SunStar Bacolod 2018).

Types of livelihood activities in Iloilo

Around the late 18th century, the province of Iloilo was known as the ‘textile capital of the Philippines,’ as it established a large-scale commercial weaving industry (Funtecha 1981). At present, it is still known for many cottage industries including pottery, ceramics, and woodcraft. In 1855, the province opened its own international port, ‘El Puerto de MuelleLoney,’ also known as ‘Iloilo’s River Wharf,’ which encouraged trading globally; it was known as the biggest port in the Philippines (Province of Iloilo 2018). It also became a premier province of the country mainly due to its numerous economic activities. Iloilo is considered the primary commercial and trade center of Western Visayas. It is also where infrastructure, telecommunication systems, ports, and other utilities are available (Mangahas 2006). Recent increase in growth rate has been attributed to the industry and services sectors (National Economic and Development Authority 2017).

Iloilo belonged to the top ten highest fisheries producing regions in 2015-2017, garnering a 2.86% share in the total output of the country (Philippine Statistics Authority 2018b). The region has also been ranked as the second-highest producer of milkfish (Philippine Statistics Authority 2019). The province ranks 5th in poultry and livestock (Iloilo Economic Development Foundation Inc. 2018). In 2016, the Western Visayas region had the second-highest inventory of native chicken with a 9.52% contribution in the total Philippine inventory (Philippine Statistics Authority 2016a). In the same year, the region placed first in carabao production with a 15.10% contribution.

The rise of duck farming industry in Iloilo

Duck raising is being promoted for the improvement of the agricultural sector through the Integrated Rice-Duck Farming System (Pacamalan 2001). The use of ducks has been considered as a good alternative for chemical pesticides utilized in growing rice (Escobin et al. 2009). It is being implemented, as it has the potential to increase rice productivity while reducing the cost of production. One of the informants, Mary is a farmer and duck raiser located in the municipality of Barotac Viejo. She started raising ducks in 1983 since their income from rice farming was not sufficient. She explained, “*Pero saamon, iyanangnakapatapossamgaanakko*" (For us, [duck farming] helped my children to finish their education). Integrating duck farming into her livelihood has allowed her children to finish formal education. It has been recognized as a significant source of livelihood particularly in rural and low-income communities (Jha and Chakrabart 2017).

In 2001, Iloilo became the third-largest duck producing province in the Philippines; Nueva Ecija and Pampanga ranked first and second, respectively (Hui-Shung and Dagaas 2004). It has also been identified that duck farms in the provinces of Iloilo and Quezon are relatively small (Chang and Villano 2008) in comparison to farms in Nueva Ecija and Pampanga. Western Visayas has an estimate of 1.36 million backyard duck farms, the largest number of small-scale farms in the country (Philippine Statistics Authority 2016b). The top three duck producing region in 2018 were Central Luzon, SOCCSKSARGEN, and Western Visayas respectively (Philippine Statistics Authority 2018a).

Figure 1. Geographical map of Iloilo province, Philippines

RESEARCH OBJECTIVE, SIGNIFICANCE, AND METHODOLOGY

This paper explores the intersections of contexts such as the environment, social organizations, and consumer demands in situating the status and the trajectory of the duck and duck egg industry in the province of Iloilo. Through interviews and participant observations among producers, retailers, vendors, and consumers; this paper identified the key issues and adaptations that local stakeholders are participating into access and promote their interests in the industry. This paper also provides a qualitative evaluation of the efficiency of existing policies on duck and duck egg industry that are affecting the stakeholders in the province of Iloilo.

CONSUMER DEMANDS

Locations and types of production

Duck raising has been highly associated with the rice farming system. In Iloilo, the main source of income for locals is primarily rice farming complemented by raising animals such as ducks (Lavega 2007). In the province of Iloilo, the selected informants are in the municipalities of Ajuy, Barotac Viejo, and Iloilo City. The municipalities were selected to provide a narrative on the rice-duck farming system being practiced by local farmers. Meanwhile, the balut dealers identified were mainly located within the city proper where balut eggs are usually sold along the streets. Balut is a fertilized duck egg that has been part of Filipino socio-cultural history (Magat 2002). While it is also a traditional Filipino delicacy, boiled, and incubated to perfection, balut plays a major role in the duck industry in the Philippines (Escobin et al. 2009).

The identified informants included: 4 duck farmers, 1 duck farmer and balut maker, 1 balut maker, and 3 balut dealers. These key informants were selected primarily because of their geographical location. Duck farms are categorized into two types: commercial and backyard. The difference between the two lies in the number of ducks where the former requires more than 100, regardless of their sex and age (Chang and Villano 2008). The selected duck farms in the province of Iloilo are placed near rice fields with a population of 200 to 400 individuals.

Producers, distributors, and industry dynamics

The local duck industry is primarily composed of small-scale producers and traders; it was considered fragmented in comparison to commercial chicken (Hui-Shung and Dagaas 2004). Iloilo is dominated by small-scale duck farms that are unable to supply the local demand for duck eggs. As a result, local businesses rely on supplies coming from other provinces. One of the informants, Roselyn, explained her experience as a balut dealer for 7 years:

"*R: Sa Bulacannga--sa Pampanga meron pero datisa Iloilo lang.* (In Bulacan—also Pampanga but before we only get supply within Iloilo)

T: Iloilo po. Bakit po huminto sa Iloilo? (Iloilo. Why did you stop buying in Iloilo?)

R: Kasi natuklasan namin doon sa Pampanga na mas mura siya (We discovered that the eggs are cheaper in Iloilo)."

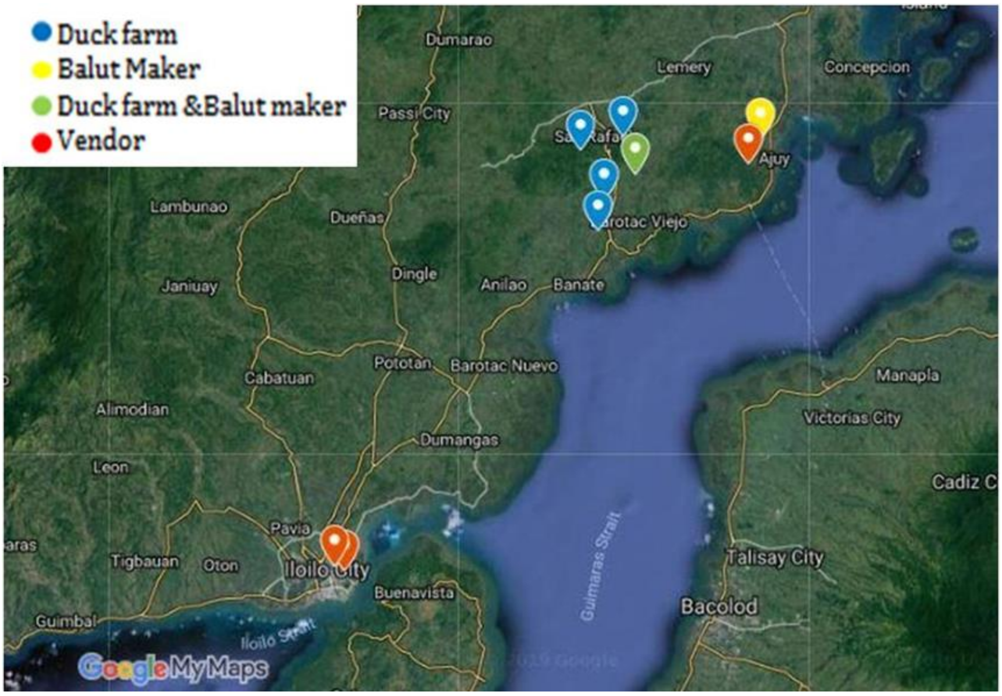

Figure 2. Location of selected informants in Iloilo, Philippines.

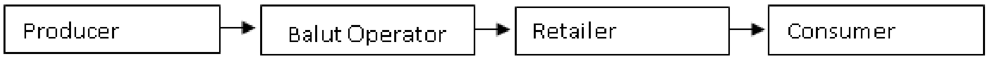

Figure 3. Processing of eggs in Iloilo, Philippines

Due to balut's high demand among Iloilo consumers, small balut dealers in Iloilo, such as Roselyn, resort to cheaper egg supplies, which are sold in other provinces like Pampanga.

Importing supplies from provinces such as Bulacan and Pampanga was seen as a better option than buying from local sources in Iloilo. While there is a limited number of local balut makers in the province, balut products are more expensive. The Philippine Council for Agriculture and Aquatic Resources Research and Development (1991) has identified marketing channels utilized in the distribution of duck eggs in the country. First, Figure 3 presents the model of the flow of distributing processed eggs (e.g., balut, penoy, salted eggs) into different actors in the industry. The informant Roselyn started off as a balut a vendor and later decided to establish her own business. She recalled, "At first, I was selling as a balut vendor and then later on we discovered that we could also sell fresh eggs." Some members of the industry, such as Roselyn who has multiple functions, allow a shortened process of the marketing and distribution of products.

Consumer demands and attitudes towards balut

Street food has been recognized by the FAO (2009b) as ready-to-eat food and beverages sold along the streets and other public spaces. This kind of food is commonly sold on makeshift stands or stalls along the sidewalks evident in both rural and urban areas (Steyn et al. 2011). Street food is known to become popular as low-cost alternative sources of nutrients (Karsavuran and Ozdemir 2017), mainly in low-and-middle-income communities. One of the common street foods found in the Philippines is balut. This snack is prepared by incubating duck eggs for about 18 days. As part of the Filipino food tradition, it has become popular among various age groups. Figure 4 below presents the current age range of consumers and the age range when they started eating balut.

Figure 4 presents that most of the selected consumers in Iloilo started eating balut among the age group of 9 to 13 years old (38%); it is closely followed by the 14 to 18-year-old age group (36%). It could be inferred that the accessibility and availability of balut as a street food has been a determining factor in its popularity among age groups. Balut vendors can be commonly found along sidewalks or roaming around the neighborhood during the afternoon until early dawn the following day (Fernandez 2002).

The consumption of street foods such as balut is determined by a variety of economic, nutritional, and cultural factors. Figure 5 includes several reasons for balut consumption among selected consumers in the province of Iloilo. The graph indicates several reasons for consumption including taste *(lasa)*, nutritional value *(sustansya)*, strength *(pampalakas)*, curiosity *(kuryosidad)*, peer influence *(pinilit)*, snack *(pulutan)*, and local beliefs *(paniniwala)*. The selected consumers in the province of Iloilo are identified according to their sex, comprising 48% male and 52% female.

Balut has been recognized in different countries for its role as a means of extreme gastronomic challenge (dela Torre 2002). It was used in various reality television shows such as Fear Factor. It has also been included in the 'disgusting and terrifying food list' (Calderon 2014) but is still considered a delicious snack for its consumers. The preference for street food among selected consumers in Iloilo is mainly reliant on its taste and nutritional content. Consumers who answered taste as their primary reason for balut consumption comprised 76% of the total selected consumers; followed by nutritional value with 42%. Balut and other duck egg products are popular because of their unique taste and high nutritional value (Boquet 2017). It is known that ducks have higher nutritional contents (Metzer 2012) compared to chicken eggs that are more widely consumed. However, duck eggs are also negatively linked to higher levels of cholesterol content than chicken eggs (Arthur et al. 2015).

The consumption of balut has also been strongly associated with the notions of strength and energy boost; 22% of the total selected consumers affirm this belief. Some consumers are patronizing this snack with the idea that it helps in strengthening their knees for more stamina and other medicinal properties (Abbugao 1985). This belief is more prevalent among the male population of the selected consumers, yielding 33.3%, while only 11.5% of the females adhere to such belief. Its consumption has been traditionally linked to the notion of 'masculinity'. As such, while considered to be exotic food, balut is also believed to be an aphrodisiac (Rijke 2008; Sanceda et al. 2007), making it more popular among men. This notion could be dated back as early as the arrival of Spanish colonizers in the Philippines in 1521 (Magat 2002) since Spaniards are known to introduce the concept of 'machismo' into the Filipino culture.

ENVIRONMENT AS A CONTEXT

Agriculture and duck farming

Agriculture is considered a crucial sector in attaining poverty reduction (Jha and Chakrabarti 2017). In 2015, it is estimated that about 56% of Filipinos are living in rural areas and are highly dependent on agricultural activities (Dikitanan et al. 2017); while farmers and fisherfolks mainly remain in poverty. In many Asian countries, integrated rice-duck farming has been implemented as a part of a sustainable agricultural movement (Suh 2014). It was introduced in Bangladesh in 2001 (Salahuddin 2005), and Cambodia also implemented a similar system (FAO

2009a). This system encourages the use of ducks as 'fertilizers' in growing rice (Pacamalan 2001), contributing to the increase in productivity and income, chemical-free rice and duck products, as well as the improvement of the quality of life of the farmers (SunStar Philippines 2014).

Duck farming and duck egg production in the province of Iloilo may be reliant on a variety of environmental factors rooted in economic and political factors. In an agricultural area such as Iloilo, the harvesting season is a determining factor in the laying period of ducks. The ducks can freely roam around fields and feed on rice husks for food during the harvesting season. Roger, a duck farmer, explained "*Problema lang diyanpag tag oras na ng tag tatanim ng palay. Pag wala kang ano ba…malalagyan ng pakawala ng mga itik. Yun…mahihinto yung pangingitlog nila*" (The problem is that when it is the planting season, and you would not have space for ducks to roam around. The egg production will stop). The lack of enough space designated for raising ducks contributes to the fluctuations of duck production. Ducks have been considered as most advantageous, as it requires inexpensive, minimal housing facilities, and less space for rearing (Chang et al. 2003) yet these problems still affect the ducks.

Climate and topography

The Western Visayas region has a Type I climate (Philippine Statistics Authority 2019). The climate of Iloilo Province is relatively dry from December to June and relatively wet from July to November. Apart from the seasonality of rice harvesting, climatic conditions may also be a determining factor in duck mortality and egg production. Changes in temperature and rainfall patterns will have an impact on agricultural production which in turn will threaten food security (Vogel et al. 2013). It may result in outbreaks of pests and diseases in plants as well as reduction in the number of fish. One of the informants, Roger, who is a duck farmer explained, "*Yung sa tiyempo rin ba…kung minsan namamatay pag init nang init tapos pag nakalabas sila satubig, mainit yung tubig. Yung parang di na makalakad…napipilay. Tapos minsan ang leeg bumabaliktad"* (In climate…sometimes the ducks also die because of too much heat and even the water is too hot for them. The ducks could not walk like they have sprained their legs). The problem is aggravated during the monsoon season and during typhoons. In a country such as the Philippines, the occurrence of several typhoons in a year is common. As Roger, who is a duck farmer, recalled "*Ah wala naman problem asa…ah yung problema lang talaga pag yung may mga bagyo…yan. Pag may bagyo ano…lalo na pag doon sa Luzon ang bagyo tapos nasisira ang mga farm nila, apektado kami dito*." (The only problem is when there is typhoon. When there is a typhoon especially in the Luzon area and their farms are destroyed, we are also affected here). The Philippines have been considered as the third most disaster-prone country according to the 2017 World Risk Index of the United Nations (Relief Web 2017). The significant decrease in GDRP of the region from 7.7% in 2011-2012 to 4.1% in 2012-2013 was primarily attributed to the effects of the Super Typhoon Yolanda (internationally known as Haiyan) in November 2013 (National Economic and Development Authority 2017). It resulted in an estimated 1.1 million houses being damaged, 33 million coconut trees destroyed, and about 5.9 million workers affected (World Vision 2013). Balbina who was a balut maker from the municipality of Ajuy since 1983, has also been affected by the typhoon. According to her, "*Wala eh, minsan nga pamangkin ko,binigyan ako noon ng pampaayos ng balutan kasi nasira ito noong Yolanda. Nasira lahat. Binigyan ako ng pamangkinko ng paggawa ng balutan kaya naka operate kami man. Maayosangbalutan, walanaman kami kapitalmabili ng itlog (laughs*)" (It was my nephew that helped me in fixing my balutan because it was damaged during the typhoon Yolanda. Everything was destroyed. My nephew gave me money to repair my balutan and that is why we were able to operate again. It was fixed but we do not have capital to buy eggs). The typhoon caused the loss of her main source of living and she was only able to regain it through the help of her relatives. However, it can be difficult for other local businesses to revive their respective source of living.

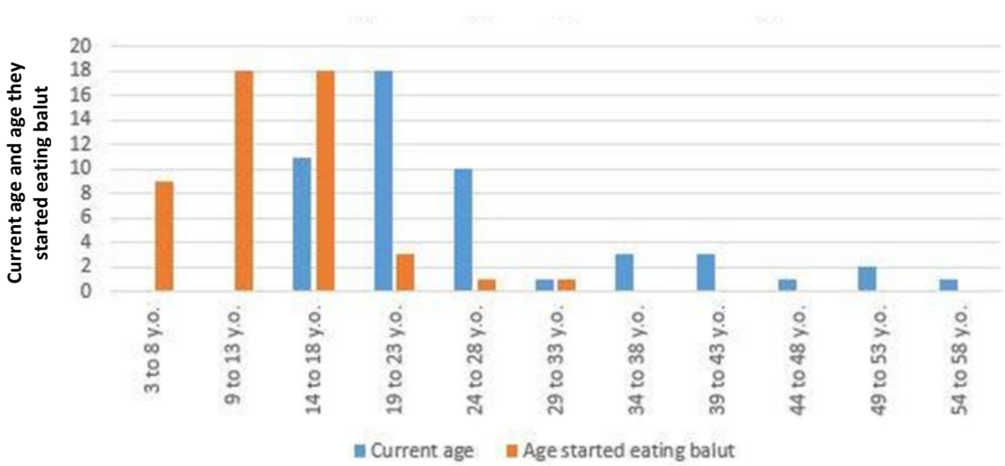

Figure 4. Age demographics of selected consumers in Iloilo, Philippines.

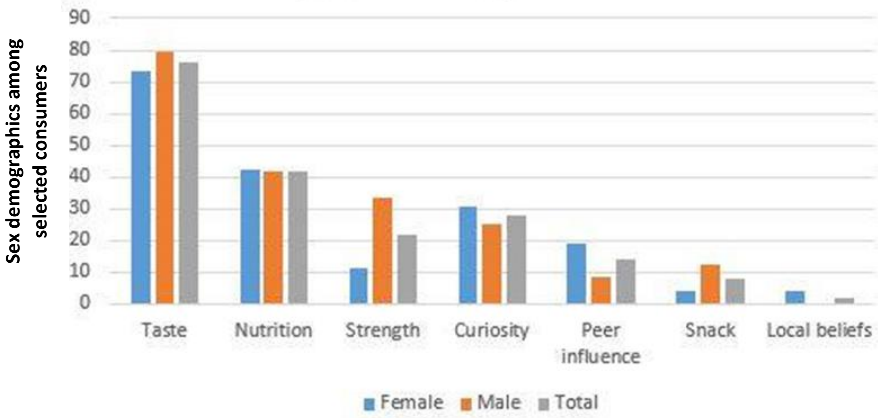

Figure 5. Sex demographics among selected consumers in Iloilo, Philippines.

Watershed and water access

Two of the largest watersheds in the province are the Maasin Watershed Forest Reserve and the Jalaur River Watershed Forest Reserve. The Maasin Watershed primarily supplies an estimate of 55% of the total potable water in Iloilo city and its adjacent municipalities through the Metro Iloilo Water District. The Tigum River is located in Sta. Barbara supplies the water in the towns of Oton, Cabatuan, Pavia, Sta. Barbara, San Miguel, and Maasin. The availability of water supply in agricultural areas is recognized as a key factor in the outcome of production. In Iloilo, water has been known as the main constraint in achieving high productivity (Philippine Institute for Development Studies & Bureau of Agricultural Research 2004). The primary system of irrigation in the province was an individual system followed by communal sources and others (Philippine Statistics Authority 2004). Dry season and droughts significantly affect the amount of water in the watersheds and dams, which will then impact irrigation systems of farmers—resulting in a decrease in agricultural production. According to an informant, Demfred, *"Hindi man tamaka init, hindi man…tubig problema diyan sa itik. Katamtaman lang ang init ng tubig. Tubig ang importante. Pag walang tubig hindi sila makatuka sa karamnan"* (The temperature is not suitable for the ducks…the water is the problem. Water is important. If there is no water, the ducks cannot eat). In duck farming, it is important to ensure that the ducks have enough water supply, especially during the dry season. The limited availability of water has also been made difficult due to the El Niño phenomenon (Greenpeace 2007).

Impacts of bird flu outbreak

Ducks have been recognized as the most resilient fowls when it comes to various environmental conditions and illnesses (Adzitey and Adzitey 2011). Still, ducks could get affected by a variety of factors. Highly pathogenic avian influenza (HPAI) is a widely recognized virus that is known to have started in southern China in 1996 (Gilbert et al. 2007). The virus has rapidly developed and has now about 102 genotypic variants (Su et al. 2015) at present; it is also known to evolve into subgroups during the breeding period (Kwon et al. 2016). In 2017, a H5N6 avian influenza or bird flu outbreak hit the municipality of San Luis in the province of Pampanga in Central Luzon. An estimated 37,000 birds died and about 600,000 birds (e.g., chicken, duck) were culled to prevent further spread of the disease. Ferdinand, who is a balut dealer in Iloilo city, has recalled:

F: Ay hindi man, diba noong nakaraan yung ano…birds flu. (Before there was a bird flu)

T: Naapektuhan po kayo noon? (Are you affected by that?)

F: Tatlong buwan kaming walang benta ditong balut. (We did not have profit for three months)

T: Tatlong buwan po? (Three months?)

F: Oo, walang benta ng balut. Tapos nag supply sila galing Maynila, luto na. Pag dating dito, baho na. Yun ang laking lugi namin noon.(Yes, we cannot sell balut. Then, when they supplied from Manila, it was cooked already. When it got here, it was already spoiled. We suffered huge losses that time)

The bird flu outbreak has caused balut dealers, such as Ferdinand, to lose profit for three months. As balut dealing is his primary source of living, he had no option but to continue his business to compensate for his economic losses. The Department of Agriculture (DA) has also issued a ban on transporting any bird products from the province. While most of the balut supply in Visayas is from Pampanga and nearby provinces, the bird flu outbreak also affected local businesses in Visayas and Mindanao. The DA has started to implement an Avian Influenza Protection Program in 2007 in response to further threats in the country (Philippine Institute for Development Studies 2017), yet it has been criticized for its lack of stronger implementation of policies during such outbreaks.

Politicization of the environment

The province of Iloilo is recognized as an agricultural area where majority of the livelihood is relying on the agricultural sector. As such, several policies implemented are directed to improving the agricultural sector of Iloilo. The Republic Act 10068 or the Organic Act of 2010 is focused on adopting organic agriculture in the country with the aim of increasing rice productivity, improving soil fertility, and reducing pollution in the environment (The LAW Phil Project 2010). The local government is aiming for a shift into organic farming as a part of its goal of turning it into an agribusiness economy. In rice farming, the Rice Industry Modernization Act (R.A. 11203) addresses the concern of improving the rice industry to boost the economy. The newly implemented rice tariffication bill aims to remove tariffs on imported rice to reduce its price on the local market. While its goal is to provide cheaper rice, it could potentially remove the livelihood of many Filipino farmers.

The Philippine Clean Water Act of 2004 or the Republic Act No. 9275 aims to address the protection, preservation, and revival of water resources to achieve economic growth. In the province of Iloilo, the waterworks system was initiated in 1926 (Commission on Audit 2018) resulting in the establishment of the Iloilo Metropolitan Waterworks (IMWW). The Metro Iloilo Water District (MIWD), which started in 1978, provides potable water to Iloilo City and its surrounding municipalities, including Maasin, Sta. Barbara, Pavia, San Miguel, Oton, and Leganes. The MIWD primarily acquires its supply from the Metro Iloilo Bulk Water Supply Corporation (MIB) (Metro Pacific Water 2017). At present, several private companies are responsible for delivering water supply to several municipalities. In the municipality of Sinuagan, the Sinuagan Water System regulates its water supply. An irrigation plan, called Barotac Viejo Small Reservoir Irrigation Project (SRIP), has been implemented to address the need for better water systems for local farmers. Water supply is primarily collected from nearby dams and rivers such as the Tigum River. However, two primary concerns in water access includes: (i) diversion of supply and (ii) unaffordability of water (Rola et al. 2015). The insufficient amount of water and inefficiency of the water delivery system has been both recognized as problems in Iloilo.

Issues and adaptations

The Iloilo duck and duck egg industries are highly embedded in environmental conditions such as climate and water supply as well as the harvesting season. In an agricultural area such as Iloilo, the harvesting season primarily determines the availability of feeds and space for the rearing of ducks. Ducks can feed on natural food sources such as rice and corn when there is harvest. Meanwhile, the ducks are being displaced from the rice fields during the planting season; thus, affecting the egg production of ducks.

The province is one of the high-risk areas for disasters, particularly in flooding in the Philippines (ABS-CBN News 2013). It also experiences long periods of dry season annually. As such, it will pose some difficulties in the production, incubation, and transportation of duck eggs. The condition of the ducks is highly determined by the seasonal fluctuations and the availability and quality of water. Harsh weather conditions will result in ducks getting sick, which may sometimes also lead to death. Selected duck raisers also believe that the temperature of water may also contribute to the vulnerability to diseases. Instances of typhoons often also affect the transportation of duck eggs. For Iloilo, which hugely relies on the supply coming from Luzon, the transportation process will be crucial.

To address the issues in the duck industry, duck farmers and balut dealers utilize several coping strategies. During the planting season, the farmers place their ducks in small enclosures in their respective backyards. When there is no rice or corn, the duck farmers are unable to feed their ducks since commercial duck feeds are not available. In periods of typhoon, it will be difficult to transport the eggs through cargo ships from Luzon. In that case, some balut dealers opt to have their supply delivered through air cargo. While this is considerably safer and faster option, it is known to be more expensive. According to Ferdinand, it requires an additional Php1 for each egg that will be delivered.

SOCIAL ORGANIZATION AND THEIR ROLE IN SUSTAINABILITY

Existence of formal and informal groups

In the Iloilo local duck and duck egg industries, the existence of formal or informal groups among local duck farmers could be considered minimal. The practice of duck farming in the province has been established for many years, yet it is still lacking in terms of organizational structure. From the selected informants, one has affirmed the existence of a formal organization. Lito is a duck farmer who started his business in 2012. It was after five years that a local cooperative for duck farmers and balut makers was established, known as San Lucas Balut and Salted Egg Makers. It was a government-initiated program that provides seminars for local duck farmers and balut makers with 35 members at present. As Lito recalled, "*Eh yung asawakonakapagsa training ba. Eh naka SLP. Tapos yung tray namindiyan…binibigyannaman kami ng kapital para pambili ng itlog at tsaka incubator*" (My wife was able to receive training from San Lucas group. Then we were given capital to buy eggs and an incubator). The program also aids in financial expenses by providing capital to start up their own balutan businesses. Currently, the wife of Lito serves as the president of the cooperative.

Role in duck farming and duck egg production

The existence of formal and informal groups is a determining factor in achieving the sustainability of each local business and the overall industry. Cooperatives are being recognized as 'catalysts of change' (The Manila Times Online 2017) for many local livelihoods and industries. Formal groups, such as the San Lucas group, provide assistance for their members through the selling and distribution of their products. It gives certainty that each member will be able to sell off the balut and salted eggs and that they will gain income on a regular basis. Then during off-season and calamities, an organization provides business owners with the necessary assistance they require. The San Lucas group conducts regular meeting sessions monthly to discuss and address issues affecting the duck industry. As Lito explained, "*Para* *makwanangproblema, masolusyonan... sapinansiyalamon na kwarta. Tapos among nakalubongitlog...nakakwansa incubator"* (It helps in resolving our problems… especially in finances). Meetings enable each member to monitor the status of their own businesses and the situation within their local community. Cooperation and interactions taking place within groups are necessary for their survival (Asçı et al. 2015; Bruni et al. 2008).

Intersections between producers, suppliers, and vendors

The local duck industry in the province of Iloilo is primarily comprised of duck farmers, balut suppliers, balut retailers, and balut vendors. The duck farmers serve as the producers that supply small-scale balut and salted egg businesses or directly sell fresh duck eggs in the local market. Moreover, the balut suppliers are usually from the Luzon particularly in the provinces of Pampanga and Bulacan. They process the fresh eggs into balut, penoy, and salted egg; the products will then be delivered to Iloilo through a cargo shipment. The balut retailers will collect the duck products and then sell them to vendors for a higher price. A balut retailer, such as Roselyn, employs her own vendor. They start selling at around one in the afternoon and finish at about nine in the evening. Other vendors will buy about a hundred balut on a normal basis and sell it during nighttime along sidewalks and other establishments. To maintain such business, owners must secure a consistent supply of products daily. This is where the producers, suppliers, and vendors enter a 'suki' arrangement. This localized Filipino term emphasizes the agreement between two individuals to become regular buyers and suppliers (Dolan 1991). An informal agreement will be established to ensure that they would constantly acquire supplies from them. The informal nature of the suki arrangement poses an uncertainty on how long they will remain in such agreement. In the case of Roselyn, they sign some form of 'consignment' as a formality binding them with their balut supplier.

Intersections with government agencies

Government interventions in the agricultural sector are recognized as a determining factor in sustainability. In Thailand, the government implements a rice price policy to regulate pricing—where farmers are provided with a fixed minimum price for the rice (Forssell 2008). Meanwhile, the Cambodian Government established the "Paddy Rice Production and Promotion of Milled Rice Export" in 2010 (Socheth 2012) with the aim of achieving more rice production through investment in irrigation facilities, private sector investment in exportation, and improving exportation processes. Vietnam also implemented the Agricultural Restructuring Plan (ARP) in 2014 (World Bank 2016) with the goal of increasing economic value and farmer and consumer welfare by using less human capital and less harmful inputs.

In the Philippines, government initiatives have also been implemented to support local industries such as duck farming and balut-making. The Philippine Council for Agriculture, Aquatic and Natural Resources Research Development under the Department of Science and Technology (DOST-PCAARRD) is in the municipality of Los Baños. In 2017, this government agency, in partnership with the National Swine and Poultry Research and Development Center of the Bureau of Animal Industry (BAI-NSPRDC), initiated the project called 'ItikPinas' which aims to address issues of inconsistent duck egg production and low product quality by introducing a genetically superior breeder 'itikpinas' (IP)(DOST-PCAARRD 2017). Meanwhile, the selected informants in the province of Iloilo have not yet been part of this project. Only the SLP in the municipality of Barotac Viejo has been able to seek assistance from the government sector.

Issues and adaptations

The local duck and duck egg industries of the province of Iloilo have been characterized by informal forms of negotiation and minimal support from government agencies. The province is recognized as the top duck-producing region for small-scale and backyard producers. However, it is still considered lacking in terms of organizational structure. The San Lucas cooperative has the only government-initiated program that has been accounted for in the interviews among the selected informants. However, it is mainly limited to the local duck farmers in the barangay of San Luis. As such, the absence of strong formal organizations and government initiatives for all stakeholders in the industry poses a threat to the stability of the industry.

The lack of formal organizations to support and regulate egg production among local duck farms have resulted in a network of suki arrangement among producers, suppliers, and retailers. The local duck farmers and balut makers then primarily depend on each other for the survival of their respective livelihoods. The issue of selling and distribution of duck egg products has been a common concern among many local businesses. Ferdinand, who is a balut dealer in Iloilo city, commonly experiences losses in his income brought about by the difficult transportation. As he recalled:

"*F: Mayroontalagangmalalambot. Sa biyahe, maraming basag.* (There are real eggs that are soft. During the transportation, there are many cracked eggs)
T:Ano pong ginagawaniyopagganunpo? (What do you do when that happens?)
F: Wala, tapon na. tapon na. (Nothing. We just throw them into waste)
T: Maramipobanasasayangpagganun? (Is that usually many?)
F: Oo, noongnakaraanglinggo lang angnasayangsamin sampung kahon(Yes, last week about 10 boxes were wasted)"

According to Ferdinand, each box consists of about 300 baluts and penoy. In cases like this, he cannot hold the producers liable for his economic losses, as they have an informal arrangement. As such, he will increase the prices of his products to gain back some profit. Without assistance from formal groups and cooperatives, it will be difficult to sell off and transport products.

THE TRAJECTORY OF THE ILOILO INDUSTRY

Issues of Sustainability vis-à-vis partner interventions

The landscape of the duck and duck egg industry in the province of Iloilo emphasizes the lack of initiatives from non-government and government institutions. The selected producers, operators, and retailers were mainly relying on informal arrangements such as 'suki' to maintain their respective businesses and the industry. This poses a challenge for members of the industry. One of the informants, Demfred, has complained:

"D: Kung may kapital, pautangin kami (laughs) financial. (If there is capital, they could loan us some money)

T: Mgakooperatibapo? (Cooperatives?)

D: Oo, mapadami pa naming angmag-iitiknamon no. (Yes, so that we could increase our duck farms)"

For small-scale duck farmers, such as Demfred, it is difficult to improve the number of his ducks without assistance from an institution or any other formal groups. Loans and other membership benefits from an organization will provide capacity-building for each duck farmer and balut maker. There is a need to address the problems of local duck farmers in the province of Iloilo to sustain its own balut industry. Without such interventions, the local industry will still be reliant on importing supplies from provinces such as Pampanga and Bulacan in Central Luzon. Government-led initiatives such as the ItikPinas have not yet been known by the selected small-scale duck farmers. This initiative aims to increase the productivity level by introducing a new breed of duck, which could potentially improve the farming businesses, particularly small-scale producers.

Consumer projections for balut as a product

The consumption of balut as a street food mainly in Iloilo City has been strongly linked with its unique taste and nutritional value. Selected consumers have identified balut as an affordable source of protein and energy boost. Balut has been familiarized in many countries as a form of extreme challenge as exhibited by several television shows (Matejowsky 2013). However, balut as a Filipino product has not yet been properly introduced in the global food market. Seventy-six percent of the selected consumers in Iloilo have affirmed making balut and other duck egg products as export products of the country. This could potentially boost the national economy and at the same time present the rich Filipino food culture. Fourteen percent of the selected consumers answered yes with reservation, while the remaining 10% answered no. Accordingly, it is important to consider several factors such as the continuity of supply, egg quality, and the health concerns of different countries against balut consumption. Meanwhile, 16% of the consumers answered yes with reservation. While this could be advantageous, it is important to consider several factors such as the egg quality and the health concerns of different countries against balut consumption. This primarily signifies the need to address such issues in the local balut industry before starting to introduce balut as an export product. It has been discovered that street food vendors in Iloilo are implementing minimal hygienic and sanitary practices (Calopez et al. 2017).

POLICIES, IMPLEMENTING RULES, REGULATIONS AND RECOMMENDATIONS

This study has provided a brief overview of existing policies concerning the agricultural sector and water usage in the Philippines. Policies such as the Organic Act of 2010 and Rice Modernization Act were policies directed towards the modernization and transformation of the agriculture sector into an agribusiness economy to boost economic growth. Existing policies implemented on water usage were primarily limited in Iloilo City and its neighboring municipalities. There is a lack of policy and initiatives from formal institutions in addressing the needs of agriculture as well as duck farming. The current condition of the duck and duck egg industries of the province of Iloilo requires support and interventions in order to attain its sustainability. This study recommends a review of existing policies to identify the needs of local industries such as the duck and balut industry. There is an evident need to provide assistance for small-scale farmers by giving them more capital. This could be a significant move towards capacity-building for each member of the industry. Additionally, attaining higher level of capacity could potentially reduce the dependency of the Iloilo industry on balut production in Luzon provinces. Finally, this could be a significant contribution to developing capacity-building for the sustainability of each business and the industry as a whole.

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Review: Market, capital, and foreign labor access for all Thai farmers

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Abstract. *Tanielian A. 2020. Review: Market, capital, and foreign labor access for all Thai farmers. Asian J Agric 4: 52-70.* In this quantitative study of agricultural economic indicators for Thailand, its provinces, and seventeen other countries it is shown that Thailand's agriculture sector desperately needs assistance to lift farmers out of poverty and Thailand out of the middle-income trap. Data shows diminishing activity in the agricultural sector may be harming productivity and growth. Prices and yields plateau and fall as producer costs increase and farm incomes remain among the lowest. In 2006 and 2014, the military ousted two Shinawatra Prime Ministers amid corruption and misappropriation scandals relating to failed agricultural subsidy schemes that cost the government billions of dollars, while failing to substantially improve the situations of millions of smallholder farmers throughout the Kingdom. Analysis of primary data and literature suggests Thai farmers lack sufficient access to labor, capital, and markets that would give them the resources to improve farming methods, hire short-term labor, and ultimately rise in socioeconomic status along with the rest of the population. Recommendations include a series of government-sponsored and joint public-private initiatives that organize farmers into unions and connect them with human, financial, scientific, market, and educational resources via a range of mobile applications.

Keywords: Agricultural economics; commodities markets; migrant labor; quantitative methods; rural development; Southeast Asia

Abbreviations: ANOVA: Analysis of Variance, ASEAN: Association of Southeast Asian Nations, AEC: ASEAN Economic Community,BAAC: Bank for Agriculture and Agricultural Cooperatives,C: Central,FAO: Food and Agriculture Organization of the United Nations,GDP: Gross Domestic Product,GPP: Gross Provincial Product,N: North,NE: Northeast, S: South, SPSS: Statistical Package for Social Scientists

INTRODUCTION

Thailand's political history has been tumultuous since it became a constitutional monarchy in 1932. The Kingdom's military deposed the first Prime Minister in the first year after changeover from an absolute monarchy. Martial law followed and by 1935, King Rama VII abdicated, leaving his nephew Prince Ananda Mahidol the crown. Through 1937-38, the Parliament held elections, but no order lasted beyond the Japanese invasion in 1941. Crisis continued to ensue through the end of the war when the National Assembly forced the PM out of office. Five governments and PMs passed in two years leading up to the death of King Rama VIII. The military ushered in a civilian government which was ousted by coup again in 1947. Two PMs later, the military-led government repressed military rebellions from 1948 until 1951 when King Rama IX, Bhumibol Adulyadej, returned from his European collegiate education. The King appointed a military PM and restored the 1932 constitution. Subsequent governments resisted communist rebellion through 1957 when the military ousted another PM. Another coup ousted Lt. General Thanom Kittikachorn – the King's military appointment to PM – in 1958, and a new constitution was announced in 1959. In 1963 after the passing of an Assembly-elected military PM, the King appointed Kittikachorn again to the PM post. For the remainder of the 1960s, the Kingdom descended into bloody conflicts between government forces and communist insurgencies. In 1971, Kittikachorn suspended the constitution and banned all political parties. By 1973, the King appointed a civilian PM whose government drafted a new constitution, but the government was unable to solve the communist crisis, so the King dissolved the Parliament in 1976. The military quickly rebelled and seized control of the government, which was overthrown by another military rebellion in 1977. The military government drafted another new constitution in 1979. Violence continued to plague the countryside through 1981, as the government repelled another military rebellion, and finally communist insurgents surrendered in 1982. Between 1983 and 1991, Thailand saw one military and two civilian-led governments before a 1991 coup reinstalled the military under martial law. Civilians took control again in 1992 and held the PM position until 2006 when the military deposed Thaksin Shinawatra. Five governments and five years later, the nation elected Thaksin's sister Yingluck Shinawatra, who was deposed by coup in 2014 (University of Central Arkansas 2019).

Between 1981 and 2014, the government supported farmers through "rice-pledging" systems whereby farmers would borrow money from the government in an amount equal to the value of x-kilograms of rice (FAO 2018). Farmers would surrender control of the rice to the government and after three months, farmers could pay back the loan with interest or forfeit the rice. Farmers often viewed the arrangement as a purchase rather than a loan, especially because the loan value for the rice was set at future prices higher than spot prices. When prices failed to rise on the government's pseudo-futures contract, the lender could not offload its stockpiled collateral without taking a loss. By the time of the 2014 coup when the junta government stopped the pledging scheme, the nation had lost $8-18 billion dollars depending on how much rice had already spoiled, how much would spoil before sale at auction, and how much below purchase prices the government sold the rice for at auction (Biswas et al. 2015; Niyomyat and Wongcha-um 2017).

This article presents a quantitative study of statistical data from the United Nations Food & Agricultural Organization (FAO 2019), Thailand National Statistical Office (2019), Thailand Bureau of Trade and Economic Indices (2019), Thailand Office of Agricultural Economics (2019), Thailand Ministry of Commerce (2019), Bank of Thailand (2019), and the World Bank (2019). Electronic databases provided spreadsheets of historical data for hundreds of agricultural economic indicators for Thailand, its provinces, and seventeen other countries: Australia, Brunei, Cambodia, Canada, China, India, Indonesia, Korea, Laos, Malaysia, Myanmar, New Zealand, Philippines, United Kingdom, United States, and Vietnam. Microsoft Excel generated charts, tables, and maps via Bing representing Thai domestic data. SPSS calculated ANOVA means comparisons, and correlation coefficient using Pearson, Kendall, and Spearman techniques. The next section offers a brief overview of the Thai agro-economy illustrated by color-coded maps of Thailand showing provincial values for GDP per capita, population, GPP in the agro-sector, the percent of all land used for agriculture, and work permits by province. The section following the overview presents more detailed examination of GDP per capita, GPP in agriculture, work permit grants, farm holdings, and land use in each of the four main regions: North, Northeast, Central, South. After the regional focus section, a section on agricultural inputs and outputs discusses statistics, trends, and Thai farmers face relating to land, labor, and capital. A section on agriculture and food markets follows with charts representing price, production, and inflation for several commodities.

The final section introduces potential longer-term solutions for the Thai agriculture sector, with particular focus on smallholders. Conclusions urge the government to sponsor and facilitate conception of new local agro-union-collectives that could provide support directly to farmers with machines, labor, credit, education, seeds, fertilizers, pesticides, and herbicides. Recommendations also encourage the government to fund development of a mobile phone platform that provides a forum for farmers to communicate, find information, post job openings, and put raw food commodities into the market – the app would link sellers on the farm to buyers across the country. The government is also advised to amend related labor and immigration laws to create a system of licensing for recruitment and staffing agencies that would handle the entire process from finding labor in neighboring countries to permit applications, transportation, housing, and immigration compliance monitoring. Agencies would pay for access to the mobile app and community based agro-union-collectives for market and logistical support. Various revenues would be available to the government via membership payments for the app, union dues, visa and work permit fees, and agency licensing fees. All recommendations are plainly within the scope of justifiable measures provided to the government by the 2017 Constitution.

AGRICULTURE & MIGRANT WORKERS IN THAI ECONOMY

Figures 1-3 show provinces that depend less on agriculture experience higher average incomes, and provinces low agricultural activity typically have low populations and low GDP per capita. Low incomes for agricultural workers help explain labor movement out of agriculture. Non-agriculture jobs are in higher supply in urban areas, so as people born into rural provinces sought upward income and class mobility, they moved to more urban provinces. The age-dependency ratio is growing in both N and NE regions (Keeratipongpaiboon 2012) due to increased out-migration and declining births. Births in all regions are falling, but nowhere as much as the NE where fewer children are born than in the Central region whose population is only two-thirds that of the NE.

As Thailand struggles to escape the "middle-income trap," its labor force moves from agriculture to manufacturing and services, out of rural and into urban areas. When would-be farmers move to cities, they often send money back home, which offsets some of the economic drains that resulted due to their migration. Recipients of domestic remittances can replace the agricultural labor lost by hiring farmhands with remittance money. For a farmer-parent in a NE province who receives monthly payments from an adult-child living and working in Bangkok, whether the child's migration results in a net gain or loss for the parent's household depends on the size of payments and the cost of farm labor to replace the child on the farm. Absent cheap and reliable labor, outward migration of Thais seeking job opportunities in urban areas can easily pose net-negative scenarios to farming communities.

Provinces with the highest populations generally have the most robust economies. Work permits are typically issued for manufacturing, tourism, and professional services, which are more abundant in populous provinces like Chiang Mai, Bangkok, and Nakhon Ratchasima. Work permits are also issued more in major tourist destinations like Chonburi and Surat Thani, and for technical jobs like those in the petrochemical sector in Rayong. Coincidentally, those provinces with large cities, tourist destinations, and expansive industrial estates rely less on agriculture than provinces that have fewer work permits granted.

Northern Region

The North is Thailand's largest geographical region. These seventeen provinces have more forest land than all other provinces combined (Thailand Land Development Department 2012). The North ranks second to the Northeast in terms of agricultural land area. Paddies are mostly huddled to the lower elevations (20-50m) in Sukhothai, Kamphaeng Phet, Phichit, Nakhon Sawan, and Uthai Thani, with some of Phitsanulok and Phetchabun provinces under paddy. High plateaus (400m) in Chiang Rai and Phayao are also paddy lands. Mountainous regions (1000-2500m) in Maehongson, Chiang Mai, Tak, Lamphun, and Kamphaeng Phet prevent the types of expansive paddy systems that run through low plains. Various field crops and orchards dot the landscape among sprawling mountain forests that push from Tak's western border with Myanmar, all the way around the crown northward around Maehongson and Chiang Rai and down Nan's eastern border with Laos.

Maps in Figure 4 show provinces with lower dependence on agriculture and higher incomes issue more work permits. Chiang Mai and Lamphun provinces have the highest average incomes and among the lowest agricultural sector contribution to GPP. Chiang Mai is a major tourist destination, home to the largest city in the region, and a chief coordinator of the government's initiative to legalize undocumented workers from neighboring Myanmar. Map coloration may appear to suggest that Kamphaeng Phet defies the norm with lower GPP in agriculture and higher GDP per capita while suffering fewer working permits, however, the contrast is due to outlier Chiang Mai distorting the color scheme. Data showed discernible relationships between GDPs per capita, GPP in agriculture, and work permits.

Northeastern Region

The total land area of the NE region is slightly lower than in the North, but the NE has more than 40 percent of Thailand's agricultural land and 60 percent of the Kingdom's paddy land area. More than two-thirds of the NE is farmland, and two-thirds of that farmland is paddy land (Thailand National Statistical Office 2019). Rice farmers dominate the agriculture sector, especially along with the region's irrigation networks (Thailand Land Development Department 2010a). Nong Han Lake in eastern Sakon Nakhon is the region's other main supplier of irrigation waters with systems flowing along the border with Nakhon Phanom before joining the Mekong on the Laos border. The Mun Mun irrigation system flows from the Nakhon Ratchasima city to the provincial northern border with Buriram and continues along the northern borders of Surin and Si Sa Ket provinces to Ubon Ratchathani city, where it meets the Chi Chi network. The Chi Chi channels flow from the Ubonratana dam reservoir that straddles Khon Kaen and Nong Bua Lamphu. The Chi Chi forms park of Kalasin's southern border with Maha Sarakham and Roi Et, and it follows a portion of Yasothon's western border with Roi Et before joining the Mun Mun in Ubon Ratchathani on the way to the Mekong and into Cambodia through Laos. Irrigated rice farms overwhelm lowland plateaus (100-200 m asl) throughout the region outside of mountainous Loei where altitudes reach 1,300 m asl, and aside from the hilly borderlands between Sakon Nakhon and Nakhon Phanom (300-500 m asl).

The NE has the lowest GDP per capita and highest dependency on agriculture. Two provinces stand out in terms of economic output: Khon Kaen and Nakhon Ratchasima. Khon Kaen initiated a series of programs intended to double GDP per capita, to $12,000-15,000 by 2029 (Natanri and Kongrut 2018). Khon Kaen is home of the "Smart City" program, and unsurprisingly, it has the lowest dependence on agriculture in the region. Nakhon Ratchasima is Thailand's largest province in terms of area and second only to Bangkok in population. The province boasts several comparative advantages due to its location, size, and resources. Khon Kaen and Nakhon Ratchasima help illustrate the apparent connection between higher incomes, lower involvement in agriculture, and more work permits.

Central Region

Crisscrossed by the country's widest highways, connecting the country's busiest seaports and airports, the Central region is the logistical heart of the nation. The region is also the most economically diverse. The maps show Chantaburi has the highest dependence on agriculture of any province in the Kingdom, while neighboring Rayong and Chonburi rely on agriculture less than any provinces outside of Bangkok. Chonburi draws millions of tourists annually with Pattaya. Nearby Rayong hosts Map Ta Phut petrochemical industrial estate. Chonburi, outside of the Pattaya area, is mostly field crops and orchards. Farmers in Chachoengsao, Prachin Buri, and Sa Kaeo tend various vegetables. Assorted fruit, rubber, and eucalyptus trees make up agricultural lands throughout rural Rayong, Chantaburi, Trat (Thailand Land Development Department 2010b). Forests stretch across the western half of Kanchanaburi, following the mountain range (400-1300 m asl) along the border with Myanmar through Ratchaburi and Phetchaburi. Wetlands, orchards, and rubber farms abound in lowlands of Prachuap Kiri Khan and into Phetchaburi. Water is available from the Mae Khlong, Tha Chin, Chao Praya, and Bang Pakong rivers on their ways to the Gulf of Thailand at Samut Songkram, Samut Sakhon, Samut Prakan, and Chachoengsao, respectively. Rice farming flourishes in most of Suphan Buri and Ang Thong, and again in parts of Nakhon Nayok (Thailand Land Development Department 2010d). Work permits are plentiful throughout the region, except in Saraburi and Chai Nat. Chantaburi and Sa Kaeo defy the trend that agriculture's share of provincial economic output corresponds to fewer work permits. The region's central location, relative resource abundance, high-capacity logistical infrastructure, and proximity to Bangkok create some work permit anomalies, but generally, the trend holds up that GPP outside of agriculture, GDP per capita, and work permits rise and fall together.

Southern Region

The South has the smallest land area, fewest paddy fields, and only negligible field croplands when compared to other regions. Roughly half of the South is covered by rubber tree plantations. Tourist havens include Phuket, Krabi and its islands, and Surat Thani with Koh Samui, Koh Phangnan, Koh Tao, and the Chumphon archipelago.

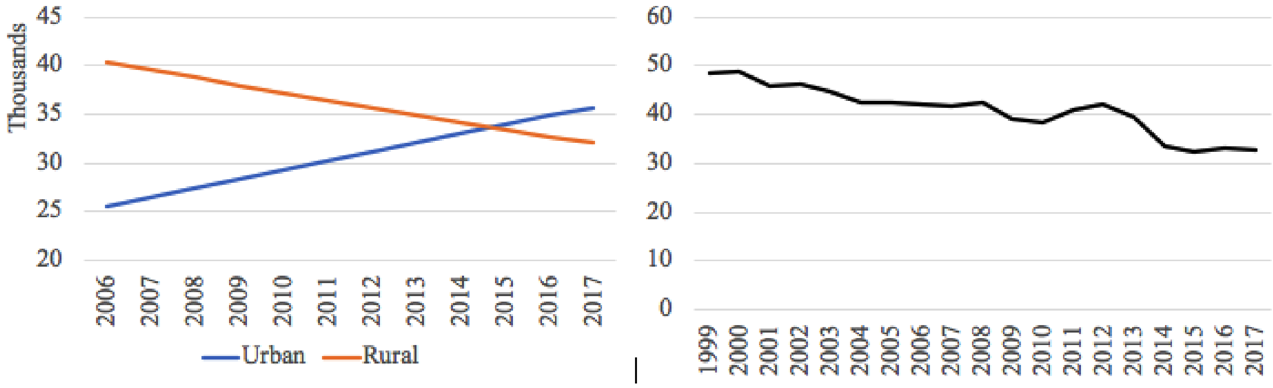

Figure 1. Thailand urban and rural populations (*left*). Thailand percent of labor force in agriculture (*right*). Data source: World Bank WDI (2019)

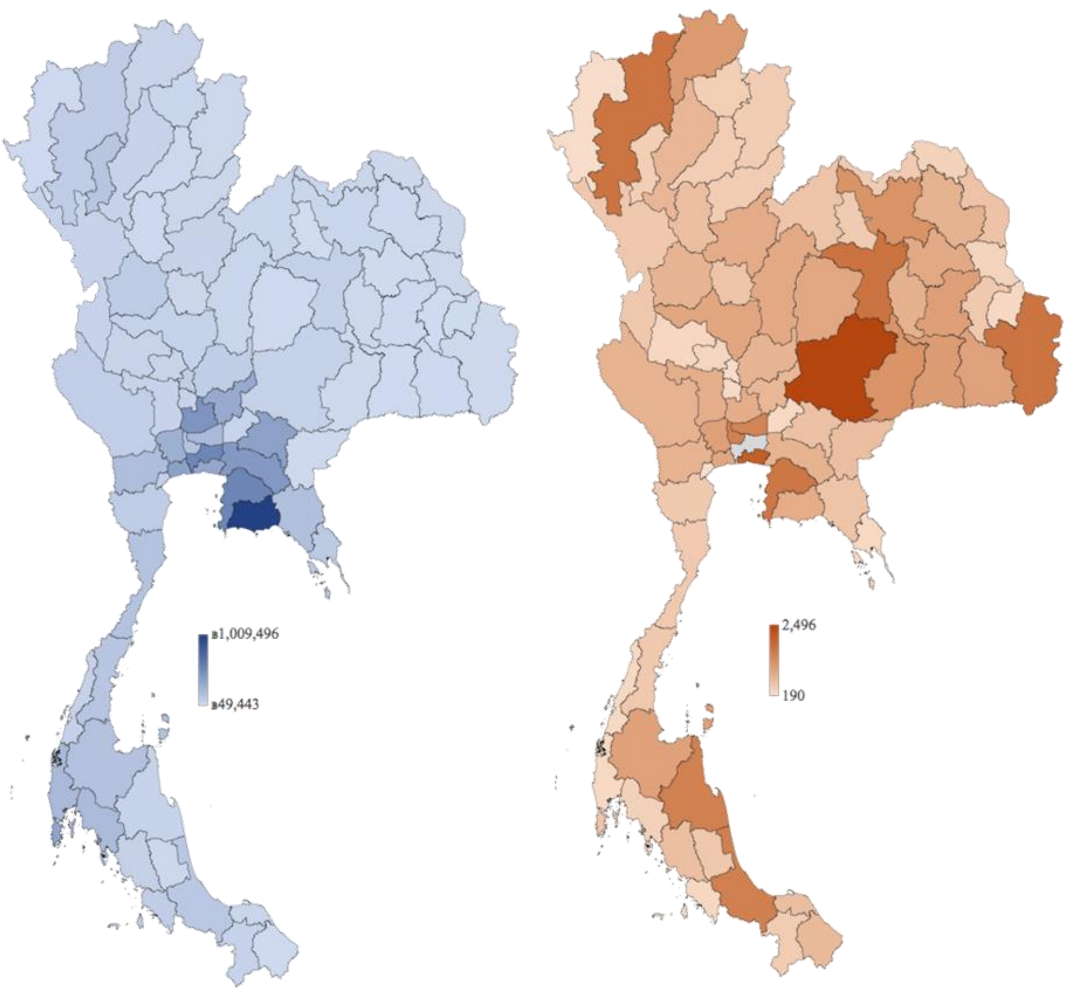

Figure 2. GDP per capita by province (*left*), population by province, in thousands of people, Bangkok excluded (*right*).

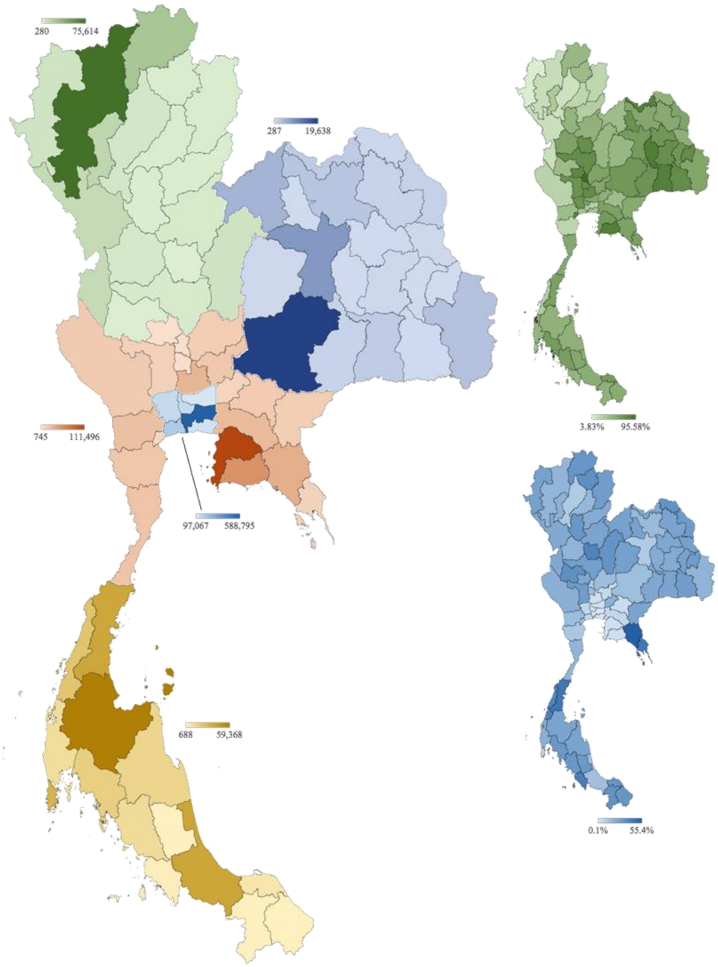

Figure 3. Work permits issued by province in each of five regions for year 2018 (*left*). Percent of land under agriculture by province (*lower right*) percent of GPP in agriculture sector (*upper right*). Darker colors indicate higher values (*lower right*). Data sources: Thailand Ministry of Labor (2018) and Thailand National Statistical Office (2019).

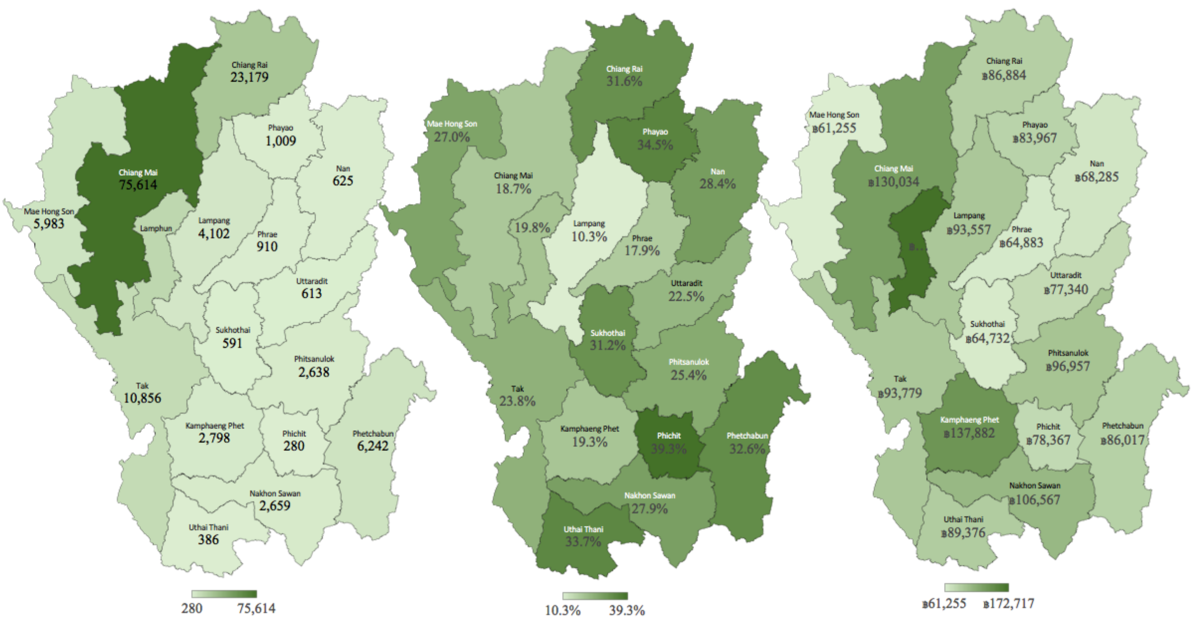

Figure 4. Northern region work permits by province (*left*), percent of GPP in agriculture sector (*center*), and GDP per capita (*right*). Data sources: Thailand Ministry of Labor (2018) and Thailand National Statistical Office (2019).

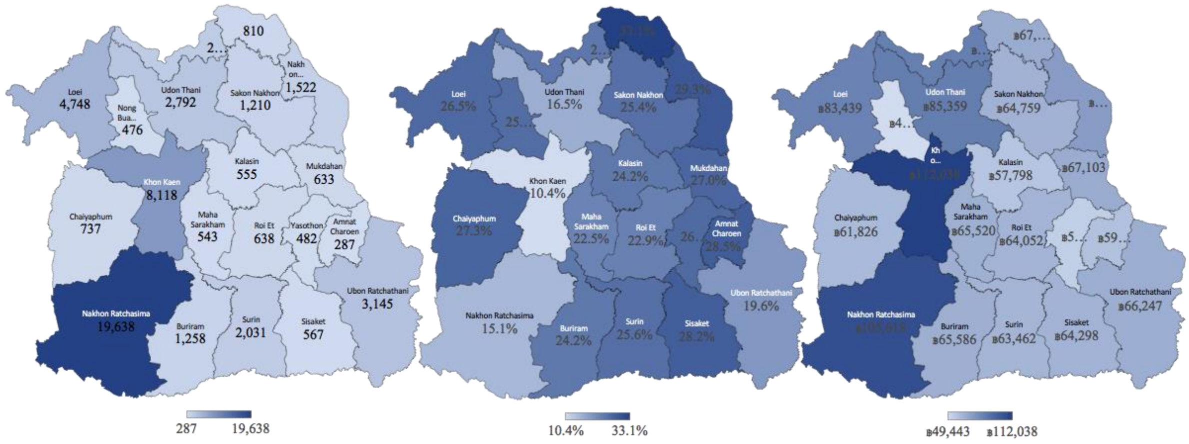

Figure 5. Northeastern region work permits by province (*left*), percent of GPP in agriculture sector (*center*), and GDP per capita (*right*). Data sources: Thailand Ministry of Labor (2018) and Thailand National Statistical Office (2019).

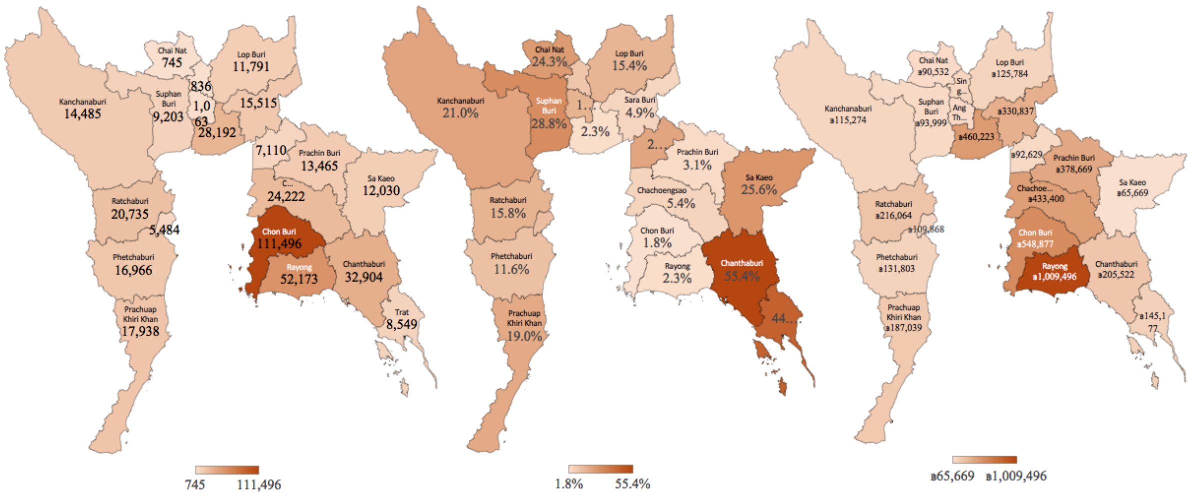

Figure 6. Central region work permits by province (*left*), percent of GPP in agriculture sector (*center*), and GDP per capita (*right*). Data sources: Thailand Ministry of Labor (2018) and Thailand National Statistical Office (2019).

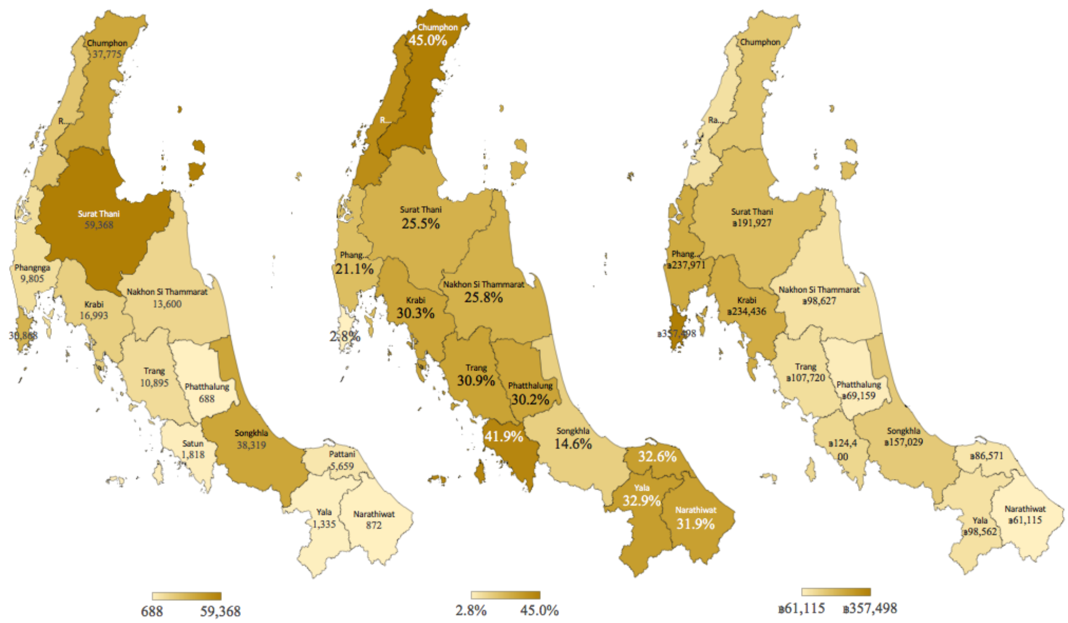

Figure 7. Southern region work permits by province (*left*), percent of GPP in agriculture sector (*center*), and GDP per capita (*right*). Data sources: Thailand Ministry of Labor (2018) and Thailand National Statistical Office (2019).

Peaks and valleys extend from Ranong's border with Myanmar south through Yala and into Malaysia on Narathiwat's west side. Rocky coastlines surround the mountainous spine of the isthmus. The Ratchaprapha Dam in Surat Thani's northwest corner provides power and some irrigation through watershed rivers that support fruit tree farming. A narrow strip of paddies follows the Gulf coast from southern Nakhon Si Thammarat through Songkhla and into Pattani, which is the only province in the region whose agricultural output is not dominated by rubber tree farming (Thailand Land Development Department 2009; Thailand National Statistical Office 2019). Satun, Phattalung, Yala, and Narathiwat are prime examples of how provincial agricultural involvement, income, and work permit grants are related.

AGRICULTURAL INPUTS & OUTPUTS

Figure 8 shows Northeastern provinces produce the most rice as they have the most land under paddy, but their yields are among the lowest in the country. Rice yield in some southern provinces is higher than in northeastern provinces despite southerners' relative lack of knowledge and experience in farming rice when compared to northeasterners. Likewise, mountainous Chiang Mai province in the north has relatively little paddy land, but still, rice yields are higher than every province in the NE region.

Several factors affect yields in the NE. Most importantly, whereas the rest of the country rarely experiences drought, most of the NE region must deal with it every 2-3 years or more frequently (Thailand Land Development Department 2010c). Anomalous rainfall and increasing temperatures in the NE (Thailand Meteorological Department 2016) pose significant challenges to farmers, but exceptionally low yields in the region cannot be explained by weather or climate alone. Farmers, especially smallholders, across the country, face issues relating to land, labor, and capital.

Farming is a tradition in Thailand. Thai people have worked in the fields for their entire collective history. Farming is as fundamental to Thai identity, along the same lines as religion or the monarchy. Thai farmers are not always particularly economical, business-minded, nor entirely organized in their approach to the trade; that is, the farm is more than numbers, margins, yields, ratios, and calculations. The average Thai farmer is also not well-educated, so his or her knowledge may not extend beyond what she or he experiences while working on a farm, and from living among and talking to other farmers. Word of mouth can generate demand for chemical fertilizers or pesticides or some methods, but common knowledge cannot solve the types of problems that can bring millions of people into a higher income group. Farmers working with only their wits, traditional knowledge, and physical vitality lack the wherewithal to switch crops. The average farmer living on $3-5 per day lacks the scientific awareness that rotating crops and leaving plots idle may reduce overall production, but it increases quality and yield which may over time increase production with less land, and that the higher-quality rice should be worth more at market. Thai farmers have improved and continue to do so to the extent possible, given their meager earnings, but there is no efficiency-driven radical transformation of the countryside on the horizon.

Unstable politicization of agriculture

World Bank (2019) provided a metric gauging political stability in various countries. An ANOVA found Thailand’s mean political stability rating for years 2006-2016 was statistically significantly lower ($p<0.0005$) than Australia, Brunei, Cambodia, Canada, China, Indonesia, Korea, Laos, Malaysia, New Zealand, Singapore, UK, USA, and Vietnam. Among the seventeen countries compared to Thailand, only Philippines was rated as less politically stable, but those results were not statistically significant ($p=0.630$). Two Shinawatra Prime Ministers have been removed from office by military coup: one in 2006. Both Shinawatras were embroiled in corruption scandals and now live in exile. The Thai Supreme Court seized more than $1.7 billion from Thaksin Shinawatra and nearly $1 billion from Yingluck Shinawatra (Hookway and Watcharasakwet 2010; Perawongmetha 2016). Shinawatras invented the agricultural subsidy schemes to embolden the farmers, especially in the NE, to vote for them and their parties. In exchange for votes, the Shinawatra parties would buy rice, rubber, and other key agricultural commodities at prices far above market averages, which created a glut of low-quality commodities and a farming population dependent on state price-fixing. Farmers borrowed money from state-sponsored financial programs based on expected earnings from sub-standard products sold back to the government at artificially inflated prices. When the futility and corrupt nature of the schemes were discovered and the military had seized power, prices fell toward what would have been their normal level and farmers were left without sufficient cash to pay debts they owed to their customer: the government. The government had a brief monopsony on extremely overpriced rice that it funded with loans that turned into bad debt, and then much of the rice was spoiled in warehouses because of the artificial boom (The Nation 2015). The government intervention failed to (i) significantly increase Thai farm incomes, (ii) improve yields or quality of crops, and most importantly, (iii) lead to a longer-term solution for ailing agricultural sectors. Thailand's public debt doubled between 2007 and 2017 due in large part to subsidies and payments to financial institutions (Thailand National Statistical Office 2019). Neither the government nor economy can withstand much more fiscal pressure.

Minimalist mechanization

From 2009 to 2016, land area under (i) paddy, (ii) fruit and other trees, and (iii) field crops remained stable in all four Thai regions. While labor is moving into cities and out of agricultural jobs, land utilization remains relatively stable. Rice is the dominant crop in the Northeast and even trial substitution in search of a higher yield crop is unlikely. Thai farmers use machines to the extent possible considering issues related to terrain and cost, the latter of which subdues more machine purchases than the former. The growth curve for new technology adoption has slowed since the 1980s for the average farmer who might make $2,000 in a year. These farmers sell their crops, but it is still subsistence living, some with support of Royal Sufficiency Economy projects (Win 2017). Most of the Thai rice, vegetable, fruit, meat, and seafood suppliers incorporate machinery into their operations, and up or down the supply chain different machines are being used in the processes. Two-wheeled tractor plows, roto-tillers, assorted water pumps, sprayers, cleaning equipment, and processing equipment make the Thai agriculture sector many times more efficient than it was forty years ago. When the tractor plow replaced the buffalo, marginal utility for machines was at an all-time high whereas now farmers might not find any benefit of purchasing a weed whacker because a machete and a hoe can do the same job. In other words, the poor farmer is not considering the implicit costs of time and physical energy spent using a simple tool like a knife to do a job a machine could do, like clean the grass and shrubs from between paddies in a terraced field; that farmer knows the machine is faster and easier, but the farmer cannot get ahead enough to afford so much as $500 for an equipment purchase. At best, the hypothetical weed-whacker would be de-prioritized to the bottom of an already long list of machines the farmer could use but cannot afford. If farmers could afford state-of-the-art machinery, another reality could exist with regards to production, yield, and profitability, but presently farmers cannot afford to adopt radically new technologies despite their better efforts to increase revenues on their croplands and borrow money from the government. Raising farm income is a problem that plagues the entire world.

Fertilizer and production

World Bank (2019) provided data on fertilizer consumption, which was significantly lower in Thailand for years 2006-2016 when compared to China ($p<0.0005$), Korea ($p<0.0005$), Malaysia ($p<0.0005$), New Zealand ($p<0.0005$), and Vietnam ($p=0.001$) as assessed by a one-way ANOVA and Tukey post-hoc test. The same tests revealed overall crop yields in Thailand were significantly lower than in China ($p<0.0005$), Indonesia ($p<0.0005$), Korea ($p<0.0005$), Laos ($p<0.0005$), Malaysia ($p=0.015$), Myanmar ($p=0.034$), UK ($p<0.0005$), USA ($p<0.0005$), Vietnam ($p<0.0005$) during the period of fertilizer application. The larger group of countries experiencing higher yields when compared to the group using more fertilizer shows there is not necessarily a direct relationship between fertilizer use and yield. FAO (2006) reported rice farming uses less fertilizer than higher-value vegetable and fruit farming. Malaysia and New Zealand use ten times as much fertilizer as Thailand, but they have different crops. Over the long term, productivity growth cannot be sustained by increasing fertilizer consumption with any crop (Tirado et al. 2008).

Thailand's yield surged in the rice-subsidy years, then it peaked and fell along with fertilizer consumption in the post-Shinawatra economy. By 2011, the government was paying 50 percent more than the market price for sub-standard rice (Kyozuka 2017). Farmers were selling more, lower-quality rice for higher prices. Figure 9 shows yield rises did not continue as production peaked and fell in 2011-2013, even amid increasing fertilizer consumption. Data represented in the graphs were for the whole Kingdom of Thailand and not by province or region.

The 2003 agricultural census showed NE farmers were earlier adopters of fertilizer with only three percent not using compared to 10.5-17.7 percent in N, C, and S regions. At that time, more farmers in the NE region had shifted to a blend of organic and non-organic fertilizers; farmers in C, S, and N regions were more likely than their NE counterparts to use exclusively organic fertilizers (Thailand National Statistical Office 2019). Waraporn (2017) compared inputs and outputs in N, C, and NE regions and found that while yields were lowest in the NE, fertilizer use was the highest, but studies suggest increasing fertilizer use is unlikely to increase yields or profits, and it comes with social risks. Nahm and Sutummakid (2015) found low marginal productivity of fertilizer in the Central region. Aditto (2010) found farmers' lack of knowledge in the Central region resulted in excessive use of chemical fertilizers in irrigated rice paddies which increased costs and polluted soils while failing to achieve optimal yields. Yields peaked and declined while fertilizer consumption was growing, suggesting the optimal level fertilizer use may have been exceeded. Furthermore, studies have shown agricultural chemical usage carries serious environmental and health risks. Doi and Pitiwut (2014) found the optimal level of fertilizer and pesticide, or herbicide use for health and safety does not produce the maximum yield. Panuwet, et al. (2012) discussed high morbidity rates in the N and NE due to agrochemical exposure.

Capital disconnect

Waraporn (2017) found Northeastern farmers faced higher prices for n-p-k fertilizers, pesticides, and human labor. The only significantly lower cost in the NE was organic fertilizer, likely due to an abundance of animal waste in the NE – the runaway leader in livestock rearing (Bank of Thailand 2019). Titapiwatanakun (2012) cited world oil price fluctuations as influencing the rise in chemical fertilizer prices and concluded that, given cost constraints, rice yields are unlikely to rise barring introduction of cultivars of higher-yielding plant strains, but such research and development also requires investment capital that is in short supply.

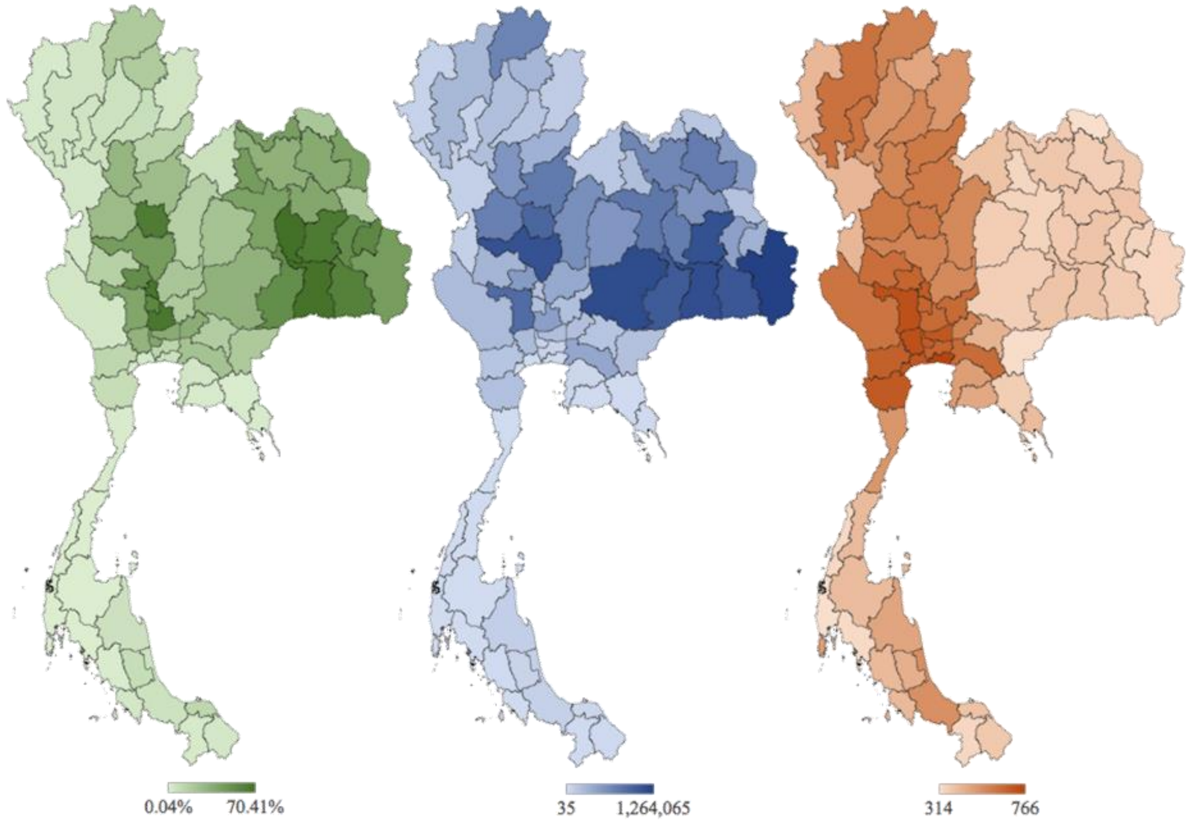

Figure 8. Percent of province under rice paddy (*left*), annual rice production by province, in tons (*center*), and rice yield by province, in kg/rai (*right*). Data sources: Thailand Ministry of Labor (2018) and Thailand National Statistical Office (2019).

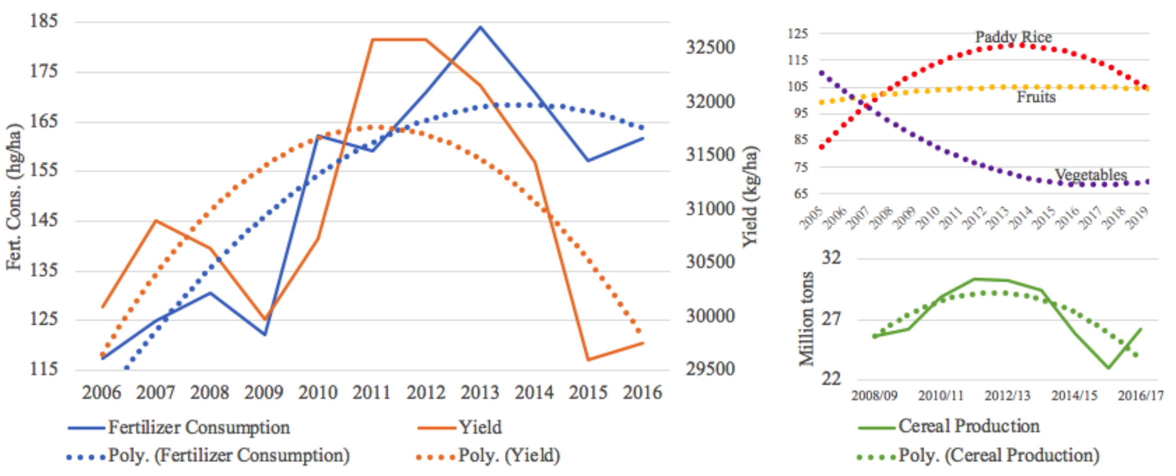

Figure 9. Thailand fertilizer consumption and yield with second-order polynomial trendlines (Left), trendlines for production indexes of Thailand paddy rice, fruits, and vegetables (*upper right*), and Thailand cereal production with second order polynomial trendline (*lower right*). Data sources: World Bank (2019), FAO (2019), and Thailand Bureau of Trade and Economic Indices (2019).

Residents in most provinces without major industrial estates or tourist attractions lack access to formal financial systems, but none as much as in the NE region where there is fewer than one bank branch per 10,000 adults (Bank of Thailand 2017). Family farms are typically excluded from commercial credit markets due to low and unpredictable income, and the NE is mainly family farms. Each successive government has offered support by way of interest payment reductions through the Bank for Agriculture and Agricultural Cooperatives (BAAC), from which more than one million rice farmers borrow between a few hundred and tens of thousands of dollars (Chiang Rai

Times 2018). Debtors use their crops or land as collateral, but debt payments frequently become unmanageable between price fluctuations, flooding, drought, and declining yields (Kyozuka 2017). Table 1 shows key balance sheet statistics at BAAC which between 2012 and 2017, saw rises in the numbers of loans, doubtful accounts, and bad debts amid simultaneous falls in return on assets, return on investment, and capital adequacy ratio (BAAC 2019). The agriculture sector faces flat and falling production indices across all crop categories, increasing costs that affect the poorest rural districts most, and neither is capital available to rapidly improve mechanization nor is increasing fertilizer use a likely solution.

Labor shortage

Migrant flows into all economic sectors increased following the 2015-2016 launch of the AEC and related bilateral and multilateral mutual-recognition agreements on labor migration. Agricultural work permits still lag those for industrial jobs, despite agriculture's greater demand for labor (World Bank 2019). Figure 10 shows flat migrant flows into agricultural sectors in the ten years prior to launch of AEC with still insufficient labor to meet job demands. Kampan (2019) surveyed 203 migrant workers from Myanmar who worked for 40 businesses. Employers complained of lengthy, complicated, and expensive work permit processes, which contributed to agricultural labor shortages for employers and resulted in wage expenses that exceeded those costs in construction, manufacturing, and services by 30 percent or more. Kampan (2019) also surveyed 147 migrants from Cambodia whose 60 employers likewise paid the highest daily wages to agricultural workers. Two-thirds of Burmese and three-fourths of Cambodians had prior work experience in Thailand – their chief complaint was high costs and complicated legal processes. Ninety-five percent of employees surveyed were referred from a friend or family member rather than recruited by an agency; such suboptimal recruiting alongside premium wages suggests serious inefficiencies in the process.

Table 1. Change in key financial data at Thailand's Bank for Agriculture and Agricultural Cooperatives. Data source: BAAC (2019).

Outstanding Loans:	57%
Doubtful Accounts:	60%
Bad Debts:	38%
Percent of Loans Non-Performing:	10%
Loans/Deposits:	2%
Return on Assets:	-29%
Return on Equity:	-25%
Capital Adequacy Ratio:	-12%

A Pearson Correlation analysis showed a province's number of work permits issued shared a high positive association with GPP ($r(32)=0.850$, $p<0.0005$), and provincial work permits shared a strong negative correlation with the proportion of land under paddy ($r(32)=-0.633$, $p<0.0005$), whereas no statistically significant relationships were found between work permits and land under field crop or fruit/food trees. One possible reason is the legal restrictions of some agricultural employment categories for foreigners under the (Thailand Ministry of Labor 2009; Thailand Board of Investment 2015). Also worthy of mention, is that data do not include employment of foreign laborers in violation of legal work permit requirements. The Thai government recognized some 3.8 million such migrant workers from Myanmar, Laos, and Cambodia whom immigration authorities seek to legalize as quickly as possible (Xin 2018). While migrant-inflow statistics show increasing legal entry and employment, there already exist millions of undocumented migrants, and the sum of all these foreign workers plus the Thai labor force still does not satisfy all labor demand. Table 2 shows sizeable increases in available jobs in primarily-agricultural northeast and multi-sectoral central regions between 2008 and 2017 whereas urban Bangkok's job vacancies decreased significantly in the same period.

Figure 10 shows that job vacancies throughout 2017 rose and fell with the crop cycle in the north, northeast, and south regions. Job vacancies in all regions peaked in the main planting season at the start of the rainy season; another relative maximum for N and NE regions is found in the winter harvest months; a third relative maximum around the dry-season planting phase is clearest in the NE where most of the country's rice is planted. The rise and fall of job openings coinciding with the plant and harvest seasons suggest these variable labor demands are in the agricultural sector, and that Thai people cannot or do not want to fill these positions. Assuming the difference between peak and valley on the 2017 jobs graph is attributable to agricultural demand, there were over 2,000 unfilled seasonal agricultural jobs in the S, more than 3,500 in the NE, and over 3,800 in the N. Thus, at least 10,000 more seasonal agricultural work permits were needed in three regions in 2017. The same method of calculating foreign agricultural labor demand (maximum minus minimum if following the crop cycle) yields an estimate of nearly 15,000 additional agricultural work permits required in the Central region, but industrial and service capacity in the region presents potential interfering variables that cannot be isolated. Figure 10 also shows that while total migrant stocks consistently increased between 2006 and 2017, migrant stocks in agriculture experienced approximately no growth overall. In the same period, ten percent of the Thai labor force exited the agricultural sector and total farmlands in the country remained flat alongside use of farm machines (FAO 2019), again indicating agriculture has been experiencing labor shortages.

Table 2. Job vacancies in Thailand by region, years 2008-2017. Data source: Thailand National Statistical Office (2019).

Location	Minimum (year)	Maximum (year)	Mean	% Change 2008-2017
Bangkok	80,236 (2017)	142,007 (2008)	104,188	-43%
Central	108,742 (2014)	194,546 (2013)	146,773	35%
North	43,837 (2011)	71,649 (2013)	58,358	-12%
Northeast	48,871 (2008)	104,143 (2013)	65,933	16%
South	46,707 (2009)	64,658 (2010)	56,150	3%

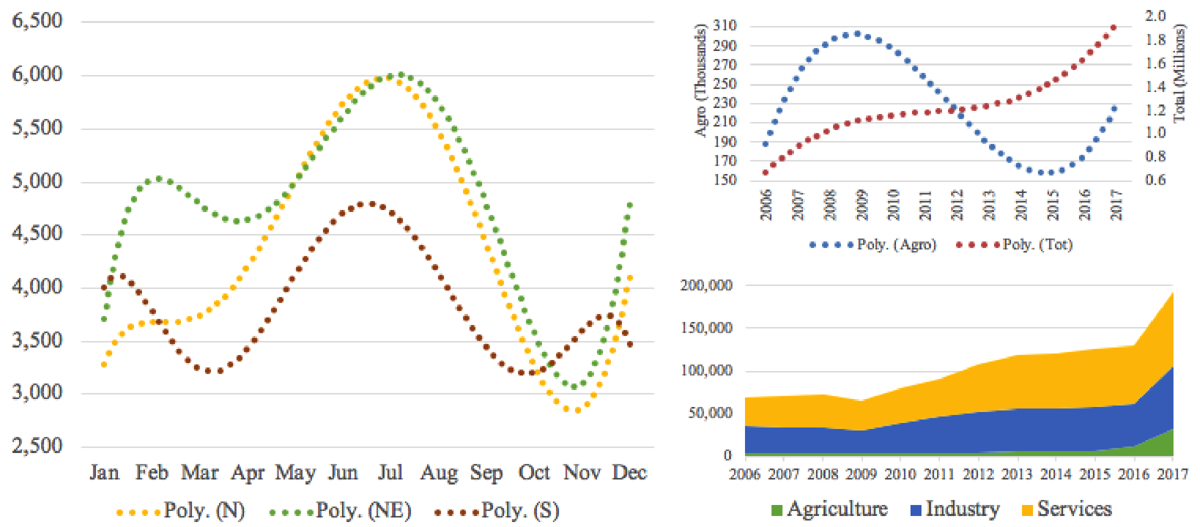

Figure 10. Trendlines for Thailand job vacancies by month and region for year 2017 (*left*), trendlines for total migrant stock versus migrant stock in agriculture (*upper right*), and migrant inflows by employment sector (*lower right*). Data sources: ILO (2018), Thailand National Statistical Office (2019), and FAO (2019).

Northeastern soil infertility

Districts throughout the Kingdom experience infertile soils, but nowhere is soil as problematic as in the NE. The map shows the Udon-Sakon Nakhon Basin in the north and Korat-Ubon Basin in the south, under which lies Maha Sara Formation of rock salts. The geological formation underlies over one-third of the NE and is the source of saline soils in the region (Mongkolsawat and Paiboonsak 2006). The map is color-coded where the darker colors indicate more problematic soils as reported by Thailand's Land Development Department (2019) in their analysis of 62 soils found throughout the Kingdom. Just under 12 percent of the nearly 169,000km^2 in the NE are plagued by saline soils. High-salinity soils cover more than 1,000km^2 more than 15,000km^2 are moderately saline; greater than 16,500km^2 have low salinity. Not all saline soils are found on agricultural lands. Coincidentally, Nakhon Ratchasima and Khon Kaen provinces both have highly problematic soil and have the lowest percent of their economies in agriculture. Farmers in those provinces, and elsewhere around the region, still struggle with soil fertility. To make matters worse, farmers may not be planting the best crops or using optimal fertilizers for their soils; their knowledge deficit precludes their independent soil analysis and mitigation strategy deployment, and their lack of capital, or access thereto, prevents them from outsourcing services. Soil fertility limits the variety of crops suitable for a farm; it contributes to production, yield, and quality which affect pricing in the market after harvest.

Agriculture and food markets

Price and production indices for agricultural commodities peaked in the years prior to the coup, after which time they consistently fell. Government subsidies artificially raised prices, and Yingluck Shinawatra's infamous rice-pledging scandal artificially increased production where demand had not increased, leaving behind warehouses full of decaying rice. Figure 12 shows cyclical production rises and falls against peaking and declining prices over more than a decade.

While production peaks maintain near-record highs, prices slump downward. Inflation in food products was significantly higher than other commodities earlier in the cycle, which benefitted farmers and others downstream in the value chain. Previously erratic prices were tamed under the Prayut government, which benefitted consumers, but without government handouts or price controls, food sellers faced deflationary pressures. Data shows food sellers experienced a growth market in the mid-00s, which attracted workers. The larger, more-profitable sector could support more laborers, but when inflation dropped below ten percent and then again into negative territory, wages were some of the first accounting entries to get cut. Figure 13 shows deflation hit all commodities in 2016, signaling trouble in the larger economy and pushing food prices further downward and into negative territory in 2017.

Volatile inflation plagued meat, eggs, and dairy for over a decade. Figure 13 shows inflation for eggs hit 13.41 percent in 2005, and then fell to negative 12.93 percent in 2006, and again rose to 13.56 percent in 2008. Inflation for eggs was highest in 2013, only one year after negative 8.83 percent movement in price. Meat inflation peaked in 2008 at 19.67 percent, one year after experiencing deflation of 6.92 percent. Fresh vegetables and to a lesser extent fresh fruits experienced similarly unpredictable inflationary swings between 2005 and 2018, during which time vegetable prices fell from over 32 percent, down to negative territory, then back up to over 20 percent, and more recently bounced between deflation and inflation higher than national averages. Agricultural commodity markets were astoundingly insecure over more than a decade. When BAAC and other banks rate farmer credit based on future crop and food sales, such volatility makes it impossible for lenders to approve larger, longer-term loans. As a result, optimal mechanization has been limited to the largest and most profitable 5-10 percent of all farms. Farmers cannot purchase more land without long-term loans, and without more land they cannot justify short-term losses associated with crop shifting. With less than 2 hectares (ha) of land, farmers cannot afford to lose one single Baht at any time, so they cannot bear the prospect of setting a fraction of that land idle even though shifting crops could make fifteen-sixteenths of the land do more work than the whole by increasing yield, quality, and therefore, price.

Whereas overall, the Thai economy has been improving, growing, and trending consistently upward, agricultural earnings peaked during the corruption years and have only trended downward to the extent that no growth is present over a decade. Agricultural workers and people involved in trade of raw foods have no higher income than they did ten years ago but their costs are higher. In fact, producers in agriculture and food sectors experienced greater cost inflation than most other sectors (Thailand Bureau of Trade and Economic Indices 2019). Agriculture and food sectors were once a source of inflationary pressure, but by 2019 their personnel was in a market where the price of virtually everything except food was rising. To make matters worse, in rural areas where agriculture provides the most jobs, inflation is generally higher than in more urbanized areas. Inflation was even higher in the poorest NE region (Thailand National Statistical Office 2019).

Value-added in agricultural sectors went into decline starting in the 2014 coup period that saw an end to the Shinawatra administration's controversial rice subsidy program. Deeper examination shows growth in agriculture was flat in 2008-09, and the growth spurt the sector experienced from 2010-14 was probably due only to the artificially-inflated prices the government paid farmers under the scheme, which cost the government as much as $16 billion (Corben 2014). Agriculture dominates the economy in the Northeastern region where adults have the lowest education on average compared to other regions. When agriculture slumps, labor cannot easily migrate into other industries due to lack of knowledge and skills. People in the Northeast were particularly susceptible to Thaksin and Yingluck Shinawatra political appeal as their governments provided income where none was otherwise present; that the subsidy programs were corrupt and put the nation in debt hardly mattered to many citizens as much as the cash in hand they enjoyed under Shinawatras. Life was easier for farmers when they could upsell low-quality crops to a government that financed and forgave debts. Those farmers developed dependency on government rescue funding because local economies have been otherwise depressed compared to more urbanized provinces where average incomes are 10-20 times higher. Farmers in a post-Shinawatra nation were left to deal with economic realities that previous policies and regimes hid from the populace.

The price of most food products has been flat over nearly two decades. Food exports fell and imports rose between 2011 and 2018 (Thailand Office of Agricultural Economics 2019), during which time Thailand lost its top ranking for rice exports. During the Yingluck years, Thailand's share of the Hong Kong rice market fell from 90 to 45 percent because the government outpriced the market trying to pander to farmers stuck in a market of stagnant prices (Janssen 2018). Understandably, Thai farmers are frustrated that they cannot push a higher price in the market, and unlike potato chip or ice cream producers, farmers cannot adjust the size to reduce costs and improve profits – a kilogram of rice or fruit or vegetable is always going to have a kilogram of that food in it. Similarly, the price of Coca-Cola was stuck at five cents for 70 years, through three wars, the Great Depression, the rise of Pepsi as a competitor, and of course, rises in producer costs. "Prices have this psychological component," explained David Kestenbaum (2015). Coke's consumers rejected attempts to raise the prices for decades, and the only way for Coca-Cola to make more money was to sell more sodas. Using data from Thailand's National Statistical Office (2019), a Pearson product-moment correlation showed that, for years 2009-2016, the Baht-value of Thailand's Agricultural GDP shared a strong, positive association with rice production in tons ($r(8)=0.899$, $p=0.002$) none with rice yield ($p=0.206$). Kendall's Tau and Spearman Rho correlations confirmed strong, statistically significant relationships between Agro-GDP and rice production ($r_s(8)=0.905$, $p=0.002$), ($\tau_b(8)=0.786$, $p=0.006$) but not rice yield ($r_s(8)=0.473$, $p=0.105$), ($\tau_b(8)=0.599$, $p=0.117$). These statistical tests are only crude measures of association, but given all other conditions and factors detailed in this report, they are not without merit. Like Coca-Cola, for Thai farmers to make more money, they may have to make and sell more food.

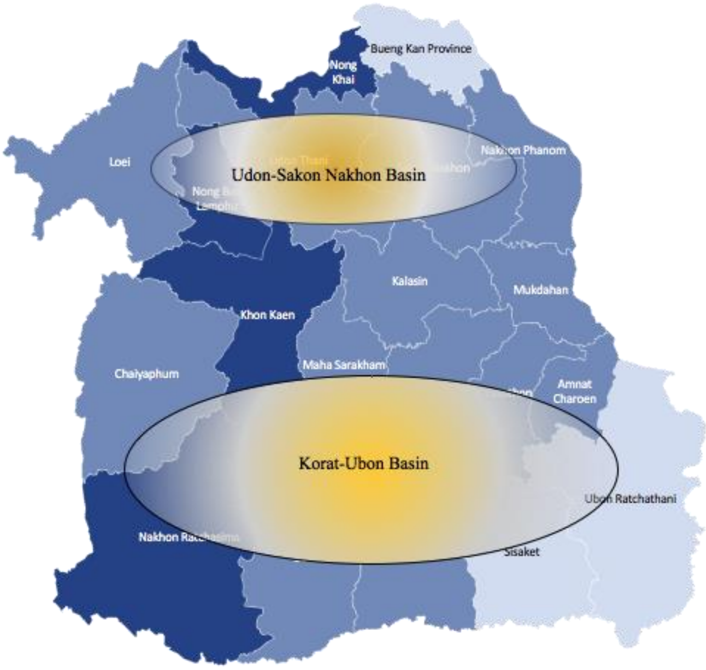

Figure 11. Northeastern region soil quality. Darker colors represent less fertile soils. Korat-Ubon and Udon-Sakon Nakhon Basins are rock salt formations that reduce soil quality. Data sources: Thailand Land Development Department (2019).

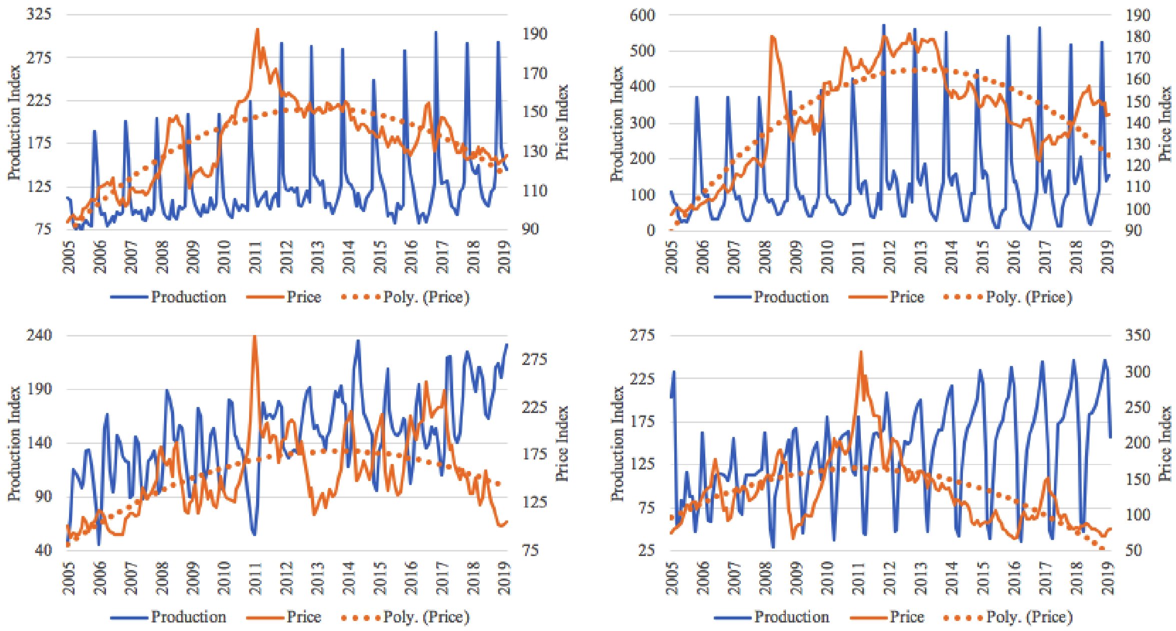

Figure 12. Price and production indices and price trendlines for all agricultural (*upper left*), grains (*upper right*), oilseeds (Lower Left), and perennial crops (*lower right*). Data sources: Thailand Office of Agricultural Economics (2019).

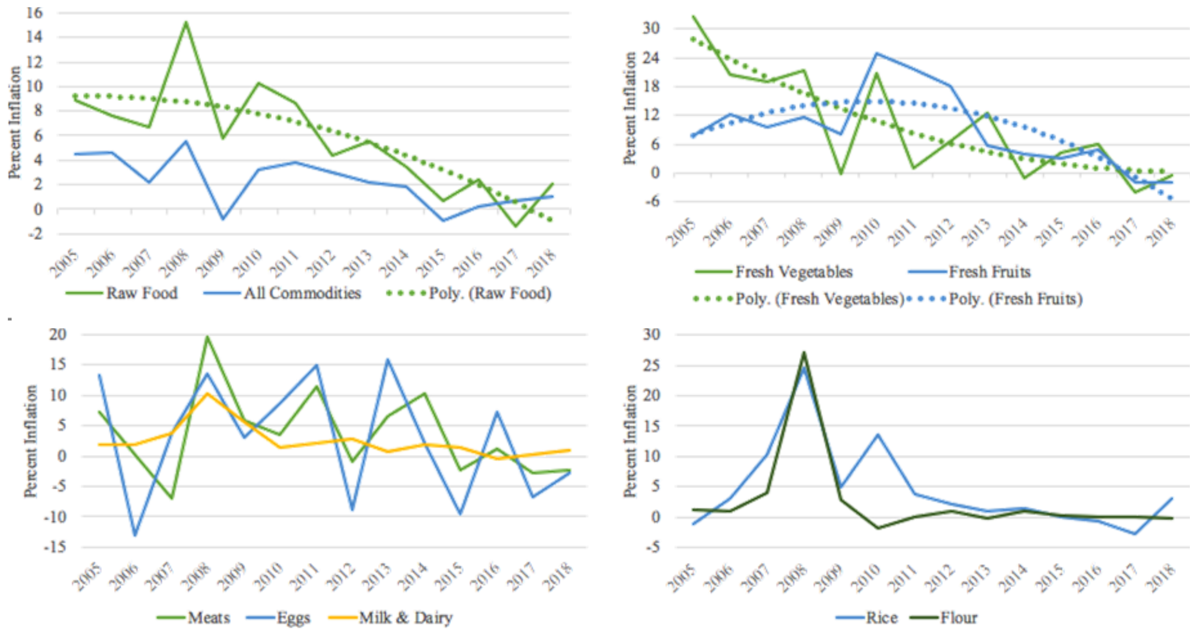

Figure 13. Consumer price index for raw foods and commodities, with trendline for raw food (*upper left*), fresh fruits and vegetables with trendlines (Upper Right), meats, eggs, milk, and dairy (*lower left*), and rice and flour (*lower right*). Data sources: Thailand Office of Agricultural Economics (2019).

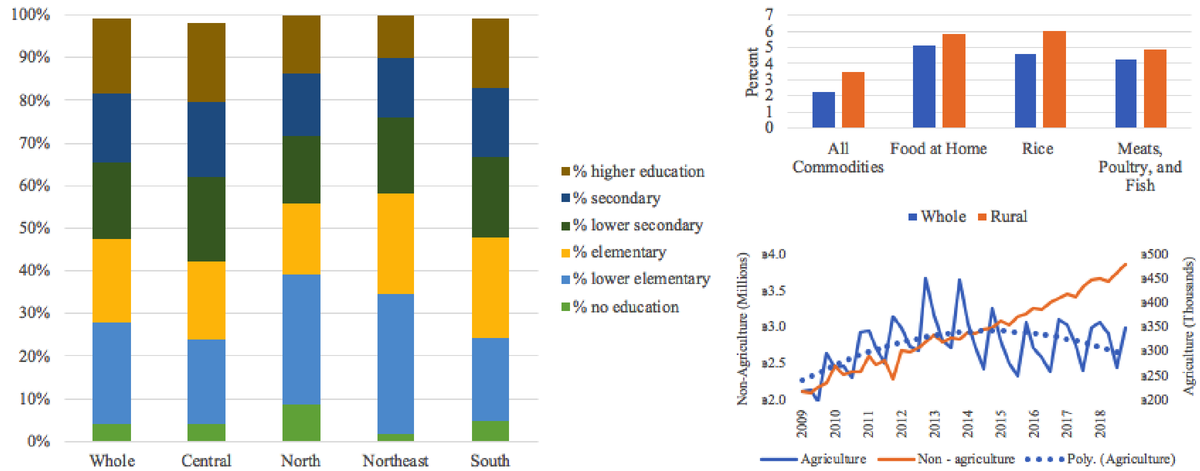

Figure 13. Percent of Thailand's adult population by highest educational attainment, separated by and region (*left*), average national and rural annual inflation for years 2005-2019, for all commodities and select foods (*upper right*), GDP for agricultural and non-agricultural sectors, with trendline for agricultural sector (*lower left*). Data sources: Thailand Bureau of Trade and Economic Indices (2019), Thailand Office of Agricultural Economics (2019).

DISCUSSION

The Thailand Constitution (2017) at §75 mandates that the State organize a fair and equitable, competitive economic system devoid of monopolistic practices, and in accordance with the Sufficiency Economy. Section 75 also recommends the State "promote, support, protect and stabilize the system of various types of cooperatives, and small and medium enterprises of the people and communities". The 2017 Constitution mentions the sufficiency economy twice and sustainability thirteen times; both can be the basis of actions under Chapter XVI on National Reform, which requires the government to work diligently and consistently toward ideals in several areas: politics, administration of State affairs, law, judicial processes, education, economics, sustainable water and waste management, fair land distribution, and appropriate health care regardless of socioeconomic status. The Constitution sets out such ambitious goals that it can easily justify virtually any bona fide project intended to relieve symptoms of poverty and help lift people into higher income classes effectively and efficiently. The Constitution at §52 provides that armed forces shall be deployed for national development; under that section, the government could employ new personnel or redirect existing military human resources to conduct in-depth social, economic and market research, then develop plans that satisfy local needs, carry out such plans until incremental and collective change occur, and follow up with the next generation of locally-tailored initiatives.

The future is mobile, connected, interactive and within reach. That future could include a $13,000 annual income for the average Thai farmer if Thailand's government can muster the resolve to pursue overarching Constitutional goals of fairness, inclusion, socioeconomic equity, and sustainable development. Achieving the government's income objectives for farmers would bring the agricultural sector back on track to perform on par with the rest of the economy and may ultimately be the key to moving Thailand out of the middle-income trap. To spur growth, increase opportunity, and organize the collective effort, the government should partner with private individuals and organizations with the aim of modernizing the agricultural sector.

Creating opportunity via licensed agencies and collectives

Once people have a taste of cash and credit subsidies, a democratically-elected government cannot easily withdraw such “entitlements” as they may be perceived on the receiving end because the duty of such a democratic government is to deliver the will of the people. Indeed, even the fiscally-conservative Prayut junta government reintroduced soft loans to village lending funds, $365 million in price subsidies for rubber farmers, and $1 billion in aid to rice farmers (Lefevre 2015). There is implicit social and moral value in any policy or program aimed to improve the quality of life for millions of people who live on $5-7 per day or less. OECD governments spent $228 billion on agricultural producer subsidies in 2016. Indonesia spent over $30 billion in 2014 and 2015, and the Philippines consistently provide more than $6 billion in annual producer support (OECD 2017). Branding itself as the “kitchen of the world,” Thailand has a compelling interest in ensuring the agricultural sector establishes and maintains a sustainable competitive advantage (Arunmas 2018).

Thailand is a good candidate for agricultural subsidies considering how integral the sector is to the Thai economy and global food security. The government provides foreign billions of dollars in tax and non-tax subsidies to private corporations (PWC 2018), mainly in non-agricultural sectors which propelled overall economic growth beyond the plateauing agricultural sector. The government, under its campaign for fairness and equity, should then have no clear reason not to provide billions of more dollars in aid to farmers who collectively comprise some 80 percent of the sector. However, the government should know by now that merely intervening in commodity pricing is not an appropriate measure; instead, the state should turn to a more holistic aid package, including education and training on farming methods, mechanization, optimal pesticide, and fertilizer utilization. Rather than distort prices of the commodities, the government should continue to subsidize interest on loans for machines and seek to erase pricing discrepancies for chemical and organic inputs across the country, so poorer farmers do not suffer higher prices. Finally, the government needs to help get farmers and collectives organized. Luckily, there are several ways the government can both aid and collect revenues from expanded work visa and permit processing. Joint public-private agricultural cooperatives can also help to streamline the recruitment, processing, transfer, and compliance assurance for seasonal migrant workers from neighboring Cambodia, Laos, and Myanmar.

Government-sponsored education and training

In 2012, integrated or diversified farms accounted for 0.01 percent of agricultural lands in the Kingdom (Thailand Land Development Department 2012). About half of those roughly 44,000 farms were in the North and slightly more were in the Northeast, with virtually none in any other region. More recently, rubber farmers have begun intercropping to offset lost income due to depressed global rubber market prices, but still, most farmers practice monoculture (Jongrungrot, Thungwa, and Snoeck 2014). Maize farmers have reduced crop diversity in response to increased demand for corn feed for animals, especially from the domestic Thai poultry industry (Nusch 2018). The National Statistical Office (2019) provided data showing maize-corn production increased by 15 percent from 2008 to 2017 without increasing overall land use, suggesting a combination of increased fertilizer use and monocropping. Panyalue, et al. (2018) found intercropping legumes with maize reduces erosion, increases soil fertility and grain yield, but farmers are either not privy to such information or do not know how to use it to their advantage. In the same vein, swine rearing in the Central, Northern, and Northeastern regions grew by 85, 60, and 51 percent, respectively, between 2008 and 2017 (Thailand National Statistical Office 2019), but the resulting organic manure fertilizer cannot be properly capitalized upon without proper animal waste management. Sub-optimal waste management is likely a contributory cause of Thailand’s higher agricultural emissions compared to Canada, Korea, Malaysia, Myanmar, Philippines, and the UK (FAO 2019).

Farmers may lack more than a few years of formal education, and they may not have an iota of knowledge on issues of agricultural economics or ecology even in cases where they attained higher levels of education. Thailand has some of the highest rates in the world for internet use, smartphone use, and mobile commerce penetration (Magnenat 2018). Thailand's twenty-first-century farms are globally connected. The government can exploit the Kingdom's mobile-mania by developing sleek, user-friendly apps to engage farmers with instructional videos, illustrations and graphics, tutorials, volumes of data and information, and real-time consultations with experts on issues affecting their livelihoods. Government-funded smartphone apps can help academicians and local farmers coordinate meetings, site visits, and practicum demonstrations. Governments can further engage the public with increased social media presence, and actively market their services directly to farmers' mobile accounts.

Government-backed financial collectives

Barnaud et al. (2006) estimated 85 percent of NE farmers are smallholders. If all agricultural land were split evenly between all 5.9 million farm holders, the average farm size would be just over 4 ha. Sources suggest as many as 90 percent of Thai farmers have less than 2 ha – not nearly enough for commercial operations (Gypmantasiri et al. 2001, Pensupar 2015; Soni 2016). Chainuvati and Athipanan (2001) found several past development initiatives failed because they did not realistically consider the limited resource base of smallholder farms. FAO (2018) reported that five million of the country's poorest seven million people live in rural Northern and Northeastern districts. In 2016, average incomes in 14 of 20 NE provinces, 4 of 17 N provinces, 2 of 14 S provinces, and 1 of 20 C provinces were below the national minimum wage of 300 Baht per day (Herbert Smith Freehills LLP 2016), and that is assuming 20 working days in the month when, for farmers, there may be 30 working days in a month, thereby decreasing the value of their labor even further. Meanwhile, the government set a goal of achieving per capita farmer income of $13,000 per year over 20 years (FAO 2018) – or 20-40 percent average annual increase through the year 2040. If farm wages are to grow even half as much as the government proposes, capital cannot remain a scarce resource for smallholders.

The government already backs BAAC and community-based lending through the Village Fund, welfare cash assistance to 5.8 million people living on 100,000 Baht or less, and other initiatives (FAO 2018), but millions of people still fall through the cracks. Saengpassa (2017) reported the Village Fund sparked the creation of 2,560 community-based financial institutions, and its non-performing loan rate is around 4 percent – equal to that at BAAC. Lewis, et al. (2013) recommended expanding Village Fund-style community micro-loans to reach the poorest of the poor. Winn (2018) reported on a mobile app called Ricult that uses GPS, weather, and satellite data to predict yields for a farmer's plot of land. Ricult has partner banks in Thailand that use the app's forecasts as an alternative or supplement to the bank's credit metrics. Unfortunately, very few farmers can afford to pay for such services, but the idea is revolutionary. The government has the know-how and funds to independently construct or commission development of a competing app that targets the poorest smartphone users in agricultural sectors. Just as social media and cellular data are collected for private monetization, the government could use personal data to target microloans and extend the reach of subsidized credit to the poorest 1 percent. Strategic distribution of medicinal marijuana production licenses under Thailand's revised Drug Abuse Act (2019) could reduce risks that financial institutions face in lending based on future crop yields as the value of marijuana crops are stable, high, and sustainable. Albeit a significantly impactful advancement in domestic legislation that stands to benefit the agricultural community immensely, these new opportunities in licit marijuana cultivation are no panacea for the Thai agriculture sector as the market cannot realistically sustain hundreds of thousands of licensed suppliers.

Extending financial services in the form of microloans to millions of people turns the flywheel another time, but it does not have the potential to raise incomes by 20-40 percent per year for 20 years as would be required to reach the government's $13,000 per capita farm income goal. In macroeconomics, participants use debt to increase growth, but banks cannot realistically offer Thai farmers as much debt as they would need to develop their farms into $13,000 per year systems; there is too much risk involved in beginning stages when farms are virtually worthless in their commercial capacities. Only government institutions can sustain the type and magnitude of risk and stress involved in shepherding the poorest people out of poverty through loans, grants, and other forms of assistance. As such, the Thai government should take steps to inaugurate and oversee agro-union-collectives that organize relief, aid, and assistance for smallholders who are largely detached from formal economies.

Local unions could manage collectively-owned machines, seed stocks, fertilizers, pesticides, and herbicides. Farmers could buy into a union on fee schedule, and their membership class would entitle them to certain rights to use machinery or take seed or other inputs. Army engineering corps could be involved in operation and maintenance of heavy equipment. A mobile phone app could simultaneously serve as a means of organizing distribution of inputs, scheduling of machine usage, and as a connection portal for farmers to share ideas, research market prices, and seek credit. As mobile phone dongles continue to improve, the app could provide real-time soil analysis. Farmers could take samples from parts of their fields as directed by the app which uses GPS coordinates and cloud-based soil reference data to provide the best possible advice to each unique farm and its many parts. All of this could occur remotely and with only limited human resources due to advances in artificial intelligence. Thailand's Land Development Department (2019) already categorizes 62 unique soil profiles, providing geographical information of each soil and potential mitigation strategies for problem soils.

Government-assisted purchasing and distribution collectives

Economic and financial data have consistently shown that the average Thai farmer lacks access to capital in amounts necessary to make big purchases like, for example, a truck to haul the harvest away from the farm and to a market where multiple buyers compete to purchase the crop. Throughout the Kingdom's rural districts, particularly in mountainous regions where there are few and unsteady roads, farmers are isolated and subject to unfair pricing by buyers who drive out to villages and pick up crops. A farmer may only have a few such potential buyers in a season and must choose to sell at a low price because there is no other way to find a buyer. Wholesalers and middlemen who troll villages looking for the lowest possible purchase price may engage in price-fixing, territorial restrictions, or other anti-competitive practices, but the Thai courts have yet to resolve this complicated problem. By connecting buyers and sellers, the Ricult (2016) mobile app provides solutions to problems of low bargaining power and exploitative commissions, but again the farmers facing the most unscrupulous treatment cannot afford more than a few dollars for an app. The government is the only possible sponsor for a comprehensive online service that could link millions of poor farmers with buyers who make competitive offers at or near market prices.

The government could provide funding and support for the launch of a mobile service that would radically change agricultural markets. Rather than the government buying rice, it could facilitate proper futures and spot contracts for all sizes of harvests, in every raw food category, and local union collectives could help with hauling in collectively-owned freight vehicles. The Stock Exchange of Thailand, Ministry of Agriculture, and National Statistical Office could use data collected via the app to forecast commodity prices, and to develop crop-science and agronomics-based responses to volatile or falling prices. Such an app could revolutionize agricultural economies throughout the Kingdom and beyond, but only the government can bear the upfront financial costs and short to medium-term risks that bringing such an app to market would entail. Local agro-unions could use the same app to make bulk purchases of chemical and organic fertilizers, pesticides, herbicides, seeds, and other agricultural commodities. Bulk purchasing arrangements would allow farmers to drastically reduce their cost per input.

Government-licensed agencies for recruitment and handling of foreign labor

Small landholdings in the less productive areas of the country make it impossible for all the individual families to get the help they need during peak seasons. Smallholders do not have the budget or human resources to recruit anybody except neighbors or whoever may be around in the village or nearby. Government-licensed staffing agencies, working in concert with local agro-unions could ease logistical burdens for smallholders who might only need a week or two of labor. Alternatively, the government could support development of a mobile app that linked farmers with labor. A team of businesspeople, software developers, and farm representatives could develop an ad hoc platform that matches farm employers and employees. In cases involving foreign labor, licensed agencies could purchase a subscription to the app service that allowed them to act as intermediaries between employers and employees who all bid on jobs of all sizes. Whether through an app or a more old-fashioned process at union offices, a foreign labor agency could organize temporary work permits for any number of people with specific skills and then manage transportation, housing, payroll, and compliance with immigration law to prevent visa overstay. Some workers could stay in one farm for the duration of their visa while others may work on a different farm every day, or every week, or intermittently as demand requires.

Ideally, the government would revise the Foreign Business Act (1999) to provide opportunities for citizens of neighboring countries to own and operate staffing agencies across the border in Thailand. The Act would have to work in tandem with an updated Alien Working Act (2008) and work permit law (Thailand Emergency Decree on Managing the Work of Aliens 2018). Beyond labor shortages and work permit processing issues, Kampan (2019) found the most common problem employers experienced with migrant workers from Cambodia and Myanmar was breach of contract by foreigners. Bearing in mind the needs of employers to have stable, predictable labor markets, the amended laws could vest most oversight and compliance responsibilities in visa service agencies who would have to submit regular reports to local immigration offices. The laws together could restrict access to this special work permit class to one channel: through licensed agencies. By law, those licensees would maintain contact with the foreigner at a determined frequency and file a report if one is missing for a specified number of days. Foreign workers could be limited to x-number of days of residence or work within the calendar year to ensure fairness in the resident-foreign labor market. Thailand can gain some perspective and guidance on building a new platform for efficient processing of temporary migrant workers by reviewing foreign legal methods. For example, the United States' H-2A visa program provides a means of authorizing and documenting seasonal, peak-load, and intermittent employment (United States Department of Labor 2016). New Zealand’s Recognized Seasonal Employer scheme “allows horticulture and viticulture industries to recruit workers from overseas for seasonal work when there are not enough [domestic] workers” (Immigration New Zealand 2019). Ultimately, Thailand’s Parliament must craft novel architecture for processing, legalizing, and following each case to ensure compliance at all levels of the hypothetical next version of Thailand’s immigration system.

Government-administered resident management app

The government has an opportunity to relieve all foreign workers of responsibilities that call them away from work and to government offices to apply and pay for simple items like re-entry permits, which could be serviced entirely online. Saudi Arabia's Absher web and mobile device applications provide both natural and juristic persons to access and update personal or company data, make requests for permits, licenses, or other services, and then track applications and pay fees remotely. The Saudi system links public safety, traffic, customs, and immigration data with the web-based system so users receive pertinent updates and notifications; it is also a single gateway for multiple government Ministries. An expansive application in Thailand would enable citizens and resident aliens alike to access their own personal data relating to Thai credit scoring data, residential address and contact info, car or motorcycle registration and insurance validity, outstanding traffic penalties, and a range of government services. The government could charge a nominal license fee to users for additional revenues which would benefit the budget alongside cost-cutting at immigration posts as fewer foreigners would need to visit physical offices. An electronic app via the internet would improve the efficiency and public relations of government offices; it would help organize and streamline communications and data sharing between government offices. Such an app could be the new face of the Thai government – a virtual frontline employee that receives, directs, and works with millions of individuals and businesses across the Kingdom.

CONCLUDING REMARK

This article showed that while agricultural sectors employ one-third of the workforce, the sector receives a disproportionate amount of work permits and thus foreign labor inputs which help keep costs low. Agricultural markets have been erratic, flat, falling, or boasting diminishing returns at best. Government assistance is imperative, but history shows solutions are scarce and each new iteration of past government price interventions, pledging schemes, or cash handouts only touches the surface of the epidemic. Smallholders across the Kingdom are cut off from labor and capital, so they cannot produce high-quality products, and they are choked out of markets by middlemen who troll villages buying bulk harvests for a fraction of the fair market value. The Shinawatra family corruption scandals are partially to blame for stagnant and declining agro-markets; the one saving grace of their legacy is that the family's business was integral in constructing one of the world's best cellular networks. Mobile phone applications and cloud-computing could literally revolutionize millions of Thai farms. The government and private sector have prime opportunities to generate interest in a joint public-private venture which (i) aims to make government interaction more convenient for Thais and foreigners alike, (ii) help smallholder farmers find labor in a timely, cost-efficient manner, (iii) gives farmers direct links to potential buyers who make competing bids for goods, (iv) provides those farmers with information and education services, (v) facilitates community-based resource management forums where members share machinery and make collective purchases of inputs to reduce costs per farm, and (vi) create hundreds of thousands of new jobs. A series of mobile phone apps operated in conjunction with research and development among government Ministries, financial institutions, scientific groups, economic faculties, and academic organizations could provide the spark that unleashes Thailand's greater potential. As the flywheel turns and cybernetic economies of scale emerge from synergies of online databases, portals, and applications, the network could later take on tax collection, voting, health care, customs processing, bank settlements, and more. A time window of 12-36 months between initiating the project and launch date for such an app would not be unrealistic given existing data cataloging and the amount of talent already within Thailand – brilliant people are just waiting to do something meaningful and impactful.

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Species distribution modeling and phenotypic diversity reveals collection gap in the *Musa balbisiana* germplasm conservation in Philippines

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Abstract. *Rabara RC, Sotto RC, Salas EAL. 2020. Species distribution modeling and phenotypic diversity reveal collection gap in the* Musa balbisiana *germplasm conservation in Philippines. Asian J Agric 4: 71-82. Musa balbisiana* is one of the progenitors of cultivated bananas. Its conservation is crucial because of its important phenotypic traits for breeding and genetic improvement of future *Musa* crops. In the Philippines, the largest ex-situ germplasm collection of *M. balbisiana* was characterized to assess their phenotypic diversity. Diversity analyses of the 97 plant samples revealed high diversity in the collection. Of the 80 quantitative traits that showed diversity, 51% showed high diversity indices (H′=0.76 to 0.99) while 20% and 29% of the traits have medium and low diversity, respectively. Nineteen percent of the scored morphological traits were invariants, which may reflect the need to increase diversity in the germplasm holdings. Species distribution analysis revealed that annual mean temperature and annual precipitation influenced the species distribution models suggesting the importance of these two environmental factors to species establishment. Overall, phenotypic diversity analyses and species distribution models revealed gaps in the collection. Further collection trips are recommended to increase diversity on traits with low diversity indices and to increase representative accessions from southern Philippines.

Keywords: Crop wild relatives, correlation, ex-situ conservation, SDM ensemble, morphological traits

INTRODUCTION

Banana ranks fourth in world's staples succeeding rice, wheat, and maize (Churchill 2011). Its cultivation is a major employment source and main staple food of over 400 million people (Hölscheret et al. 2014). In 2013, the Philippines was the second largest global banana producer, generating nearly 94% of Asia's banana export. But its production drastically declined in 2014-2015 from 3.68 to 1.85 million tons because of long drought (FAO 2014, 2017).

Ranking seventh in species diversity and endemism (Altoveros and Borromeo 2007), the Philippines is central to Musa diversity with indigenous species: *M. balbisiana*, *M. acuminata* and *M. textilis* (Lalusin and Villavicencio 2015). *M. balbisiana* or 'Butuhan' to Filipino farmers is widely utilized as food (male bud), animal feeds (pseudo-stem), and food preparation media (leaves).

Musa balbisiana is known for resistance traits against bacterial wilt (Kumakechet al. 2013) diseases. Its resistance to bunchy top and mosaic virus diseases proved useful in breeding abaca (*M. textilis*) (Bernardo and Umali 1956; Lalusin and Villavicencio 2015), Philippines' primary export fiber crop. Most significantly, hybridizations between *M. balbisiana* Colla (B genome) and *M. acuminate* Colla (A genome) produced commercial bananas (Heslop-Harrison and Schwarzacher 2007; Davey et al. 2013). Recently, *M. balbisiana* genome's association with improved vigor and tolerance to biotic and abiotic stresses improved its hold in Musa breeding programs (Davey et al. 2013).

Wild *Musa*, like other crop wild relatives (CWRs) possess useful crop improvement traits and are gene sources of disease resistance, tolerance to extreme temperatures, salinity and drought (Lane 2006; Hajjar and Hodgkin 2007; Heslop-Harrison and Schwarzacher 2007). CWRs benefits are valued at US$68 and US$120 billion for commercial and priority crops, respectively, about $196 billion when soybean and maize are included (PwC 2013; Fielder et al. 2015; Tyack and Dempewolf 2015).

Uses of CWRs in breeding increased owing to biotechnology advances like omics approaches and to geographic and ecological variation metrics to analyze gaps for improving CWRs conservation efficiency (Zhang et al. 2017), including geographic information system (GIS), species distribution modeling and other predictive tools (Hunter and Heywood 2012). GIS helped strategize conservation plans for Peruvian wild potato species (Hijmans and Spooner 2001), *Phaseolus* beans gene pool collections (Ramírez-Villegas et al. 2010) and collecting missions for Paraguay's rare wild pepper (Jarvis et al. 2005). Ecogeographic studies defined core collections and predicted gaps for optimal GenBank management (Guarino 1995; van Zonneveld et al. 2011; Parra-Quijano et al. 2012; Rabara et al. 2014).

Overall, this study focused on *M. balbisiana* characterization for future utility in banana improvement. Explicitly, this study analyzed the phenotypic diversity and geographic distribution of *M. balbisiana* conserved by a research GenBank in Laguna, Philippines that could guide breeders for specific desirable traits boosting food and fiber production and tolerances to environmental stresses of future *Musa* varieties. Results could influence future collections and conservation of *M. balbisiana* diversity and make *Musa* germplasm management efficient and cost-effective, where conserved collections remain true representations of a species' phenotypic and geographical diversities.

MATERIALS AND METHODS

Germplasm collection and phenotyping

A total of 97 *M. balbisiana* accessions were considered for this study, that were collected through field study explorations in different parts of the Philippines (Sotto and Rabara 2000). The *M. balbisiana* accessions were established at the field GenBank of the National Plant Genetic Resources Laboratory (NPGRL), Institute of Plant Breeding, University of the Philippines Los Baños as part of a national ex-situ conservation program. Phenotyping of the conserved germplasm at different stages of development were done using 99 selected morphological traits comprising both qualitative and quantitative traits (IPGRI-INIBAP/CIRAD 1996). All phenotypic traits were measured from three biological replicates, representing three mats for each accession. Multivariate data analyses were done using NTSYS software (Rohlf 2002) following the protocol described by Rabara et al. (2014). Correlation analysis was done to identify phenotypic traits that are associated with each other following methodology of Taylor (1990).

Georeferencing and species distribution modeling

Germplasm passport data were used to generate georeferenced data points for each collection using the Philippine gazetteer database downloaded from the DIVA-GIS (Hijmans et al. 2001). Locations not found in the gazetteer were data mined from online databases (http://www.geonames.org/). Figure 1summarized the processes involved in generating potential distribution of *M. balbisiana* in the Philippines following the Overview, Data, Model, Assessment and Prediction (ODMAP) protocol outlined by Zurell et al. (2020).

We utilized 19 raster-based bioclimatic variables from the WorldClim datasets (Fick and Hijmans, 2017). The set of variables was used to describe the present environmental conditions and explore the relationship between bioclimatic conditions and species distribution patterns. WorldClim provides climate models downscaled to 30 seconds, roughly 900 m at the equator (Table 1). To model the climatic habitat of *M. balbisiana*, we selected the following SDMs: Random Forest (RF) (Breiman, 2001), Boosted Regression Tree (BRT) (Elith et al. 2008), Maxent (Phillips et al. 2006), and Multivariate Adaptive Regression Splines (MARS) (Leathwick et al. 2006). These SDMs were selected based on their performance with presence-only data. We utilized a tool provided by Talbert (2012) to create a modeling workflow and develop bioclimatic-envelope models for present day conditions. The tool used source codes shared within Github (https://github.com/talbertc-usgs/sahm). Since species lacked absence data, the tool randomly generated 10,000 background points (i.e., pseudo-absences) (Phillips and Dudík, 2008). When multiple species occurrences were present within a given pixel of the climatic data, the tool consolidated them to a single occurrence per pixel. We summed up binary maps generated from probability surfaces from each statistical modeling algorithm (Liu et al. 2005). We used specificity = sensitivity as the threshold in discretizing the probability maps. This has previously been identified as the optimal threshold (Manel et al. 2001). The final map consisted of pixel values that showed the number of models in agreement that a particular pixel is suitable for the species. A pixel with a value of zero meant that none of the models identified bioclimatic suitability for the species at that location, while a value of four meant there was agreement across all four SDMs.

We removed one of each pair of highly correlated (r > 0.7) (Salas et al. 2017) environmental variables to avoid collinearity among predictors (Gama et al., 2015). We made the choices between variables based on the results of a species-specific literature search. We selected variables that were identified in one or more studies regarding the *M. balbisiana* as influencing its distribution.

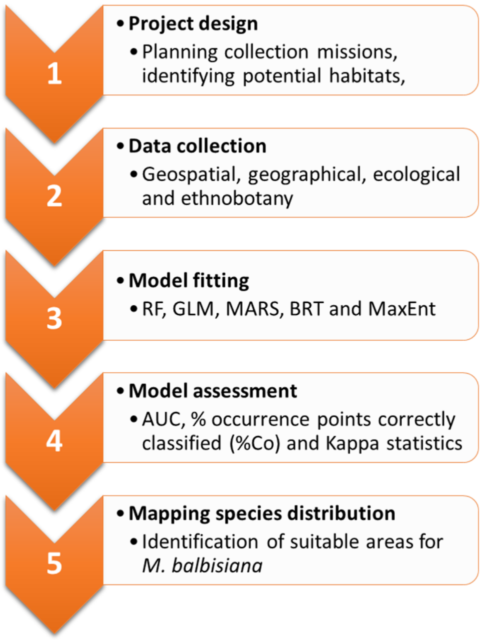

Figure 1. Generalized workflow in generation of *Musa balbisiana* distribution map following the ODMAP guidelines (Zurell et al. 2020). Model abbreviations are as follows: GLM: Generalized Linear Model, MARS: Multivariate Adaptive Regression Splines, BRT: Boosted Regression Tree, and RF: Random Forest.

Table 1. List of 19 bioclimatic variables used in bioclimatic-envelope model development. Names and descriptions are based on WorldClim. One of each pair of highly correlated (r > 0.7) variables was removed from the models to avoid collinearity among variables (Dormann, 2013). An asterisk (*) denotes final variables used for modeling the climatic habitat.

Variable	Description
Bioclim 1	Annual Mean Temperature*
Bioclim 2	Mean Diurnal Range
Bioclim 3	Isothermality*
Bioclim 4	Temperature Seasonality
Bioclim 5	Maximum Temperature of the Warmest Month
Bioclim 6	Minimum Temperature of the Coldest Month
Bioclim 7	Temperature Annual Range*
Bioclim 8	Mean Temperature of Wettest Quarter
Bioclim 9	Mean Temperature of Driest Quarter
Bioclim 10	Mean Temperature of Warmest Quarter
Bioclim 11	Mean Temperature of Coldest Quarter
Bioclim 12	Annual Precipitation
Bioclim 13	Precipitation of Wettest Month
Bioclim 14	Precipitation of Driest Month
Bioclim 15	Precipitation Seasonality*
Bioclim 16	Precipitation of Wettest Quarter*
Bioclim 17	Precipitation of Driest Quarter
Bioclim 18	Precipitation of Warmest Quarter*
Bioclim 19	Precipitation of Coldest Quarter

We assessed confidence in individual model results in terms of concordance among the different distribution models. We had higher confidence that environmental conditions were suitable for a species when three or more (at least 75% of) algorithms agreed. Information was compiled on various measures of model performance, including the Area Under the Receiver Operating Characteristic (ROC) Curve (AUC) for the test data, correct classification rate (%Co) (Warren and Seifert, 2011), and the kappa statistic (Allouche et al. 2006) for each algorithm by species combination. Swets (1988) classified values of AUC as follows: those > 0.9 indicated high accuracy, from 0.7 to 0.9 indicated good accuracy, and those < 0.7 indicated low accuracy.

RESULTS AND DISCUSSION

Phenotyping and diversity analysis of germplasm

Climate is an important factor that defines the distribution of plant species (Silva-Flores et al. 2014) and is a commonly used variable in species distribution modeling of plant species (Austin and Van Niel 2011). Philippine climate is tropical and maritime and is formally categorized into four types (Figure 2) based on the prevalence of the southwest and northwest monsoons and monthly distribution of rainfall (Altoveros and Borromeo 2007).

This study analyzed the phenotypic diversity of 97 accessions of *M. balbisiana* that are ex-situ conserved at the NPGRL field GenBank of the UPLB-Institute of Plant Breeding. Originally, the accessions were collected through field explorations from 21 provinces in the Philippines, where majority of the areas have 506 m elevation (Figure 2).

General appearance of the germplasm collections showed similar green pseudo-stem except for accession 5942 (Pisang KlutukWulung) which has distinct black pseudo-stem. Detailed phenotyping of this germplasm showed diversity in various morphological characters. Calculated Shannon-Weaver diversity indices (H′) showed that 51% of the characters measured have high diversity (H′≥ 0.76 to 0.99) while moderate (H′ ≥ 0.46 to 0.75) and low (H′ ≤ 0.45) diversity comprised 20% and 29%, respectively (Figure3). The fading color of bract base (BRBFC) had the highest diversity index (0.999) which reflected that all states under this descriptor were observed in the evaluated germplasm collections. Figure 3 summarizes the diversity indices calculated for all the 80 morphological characters scored. More than half (51%) of the scored characters have high diversity indices, while 30% of the scored characters showed low diversity. Nearly two-thirds (61%) of the characters showing low diversity were inflorescence characters. These include characters like bract imbrication, style shape and rachis position that showed the lowest diversity (H′=0.087). Only one state was observed for each of these characters which resulted in their having low diversity. This may indicate that there is no diversity in these characters or further collection and characterization are needed to capture diversity in these characters. Also, invariant traits in 19 characters were observed while phenotyping the evaluated germplasm (Table 2). Close to half (42%) of these invariant characters are description of plant habits.

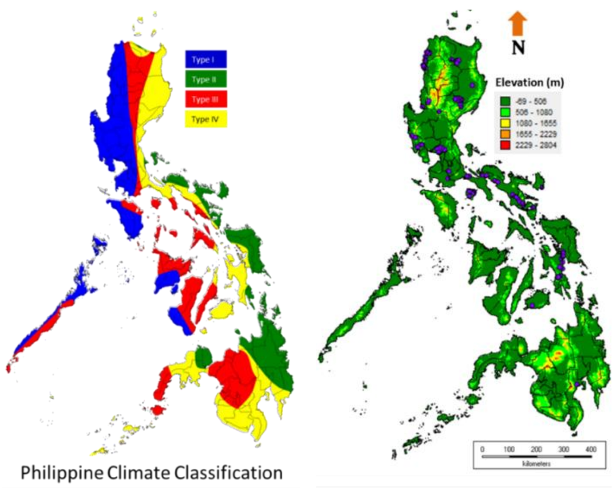

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Figure 2. Map of the Philippines: (A) Climate classification based on Coronas system(Altoveros and Borromeo 2007): Type I-two pronounced seasons: dry from November to April, wet the rest of the year; Type II- No dry season with a very pronounced rainfall from November to April and wet the rest of the year; Type III-Seasons are not very pronounced, relatively dry from November to April and wet the rest of the year; Type IV-Rainfall is more or less evenly distributed throughout the year. (B) Geographical locations of *Musa balbisiana* germplasm (purpledots) collected from different areas in the Philippines.

Table 2. Invariant characters observed in the *Musa balbisiana* collections.

Trait	Descriptor state	
	Observed	Observable states
Plant habit		
Sap color	Watery	1. Watery 2. Milky 3. Red-purple 4. Other
Petiole margins	Winged and clasping the pseudo-stem	1. Winged and undulating 2. Winged and not clasping the pseudo-stem 3. Winged and clasping the pseudo-stem 4. Not winged and clasping the pseudo-stem 5. Not winged and not clasping the pseudo-stem
Wing type	Dry	1. Dry 2. Not dry
Petiole margin color	Green	1. Green 2. Pink-purple to red 3. Purple to blue 4. Other
Edge of petiole margin	Without color line along the petiole	1. Colorless 2. With a color line along
Shape of leaf blade base	Both sides rounded	1. Both sides rounded 2. One side rounded, one-pointed 3. Both sides pointed
Color of cigar leaf dorsal surface	Green	1. Green 2. Red-purple 3. Other
Peduncle hairiness	Hairless	1. Hairless 2. Slightly hairy 3. Very hairy, short hairs 4. Very hairy, long hairs
Male bud		
Rachis type	Present	1. Truncated 2. Present
Male bud type	Normal	1. Normal (present) 2. Degenerating before maturity (like false-horn 'Plantain') 3. Like true-horn ‘Plantain’ (absent)
Color on the bract apex	Tinted with yellow	1. With yellow tint 2. No yellow tint
Bract behavior before falling	Not revolute	1. Revolute (rolling) 2. Not revolute (not rolling)
Filament color	Yellow	1. White 2. Cream 3. Yellow
Anther color	Yellow	1. White 2. Cream 3. Yellow 4. Grey 5. Brown/rusty brown 6. Pink/pink-purple 7. Black (anthers aborted) 8. Other
Pigmentation on style	Without pigmentation	1. Without pigmentation 2. Purple
Bunch/fruits		
Pedicel surface	Hairless	1. Hairless 2. Hairy
Fusion of pedicels	No sign of fusion	1. Very partially or no visible sign of fusion 2. Partially fused 3. Totally fused
Pulp in fruit	With pulp	1. Without pulp 2. With pulp
Pulp color at maturity	White	1. White 2. Cream 3. Ivory 4. Yellow 5. Orange 6. Beige-pink 7. Other

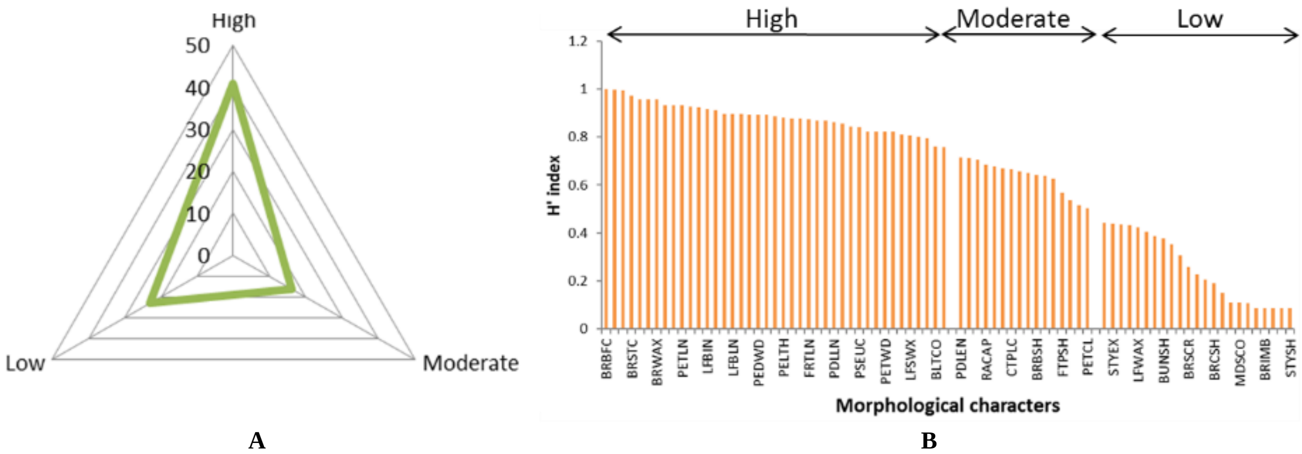

Figure 3. Calculated diversity indices (H′) of each measured and scored morphological characters of *Musa* germplasm collection at NPRGL. **(A)** Frequency distribution of diversity indices classified into high, moderate, and low (Rabara et al. 2014). **(B)** Diversity indices of each character measured.

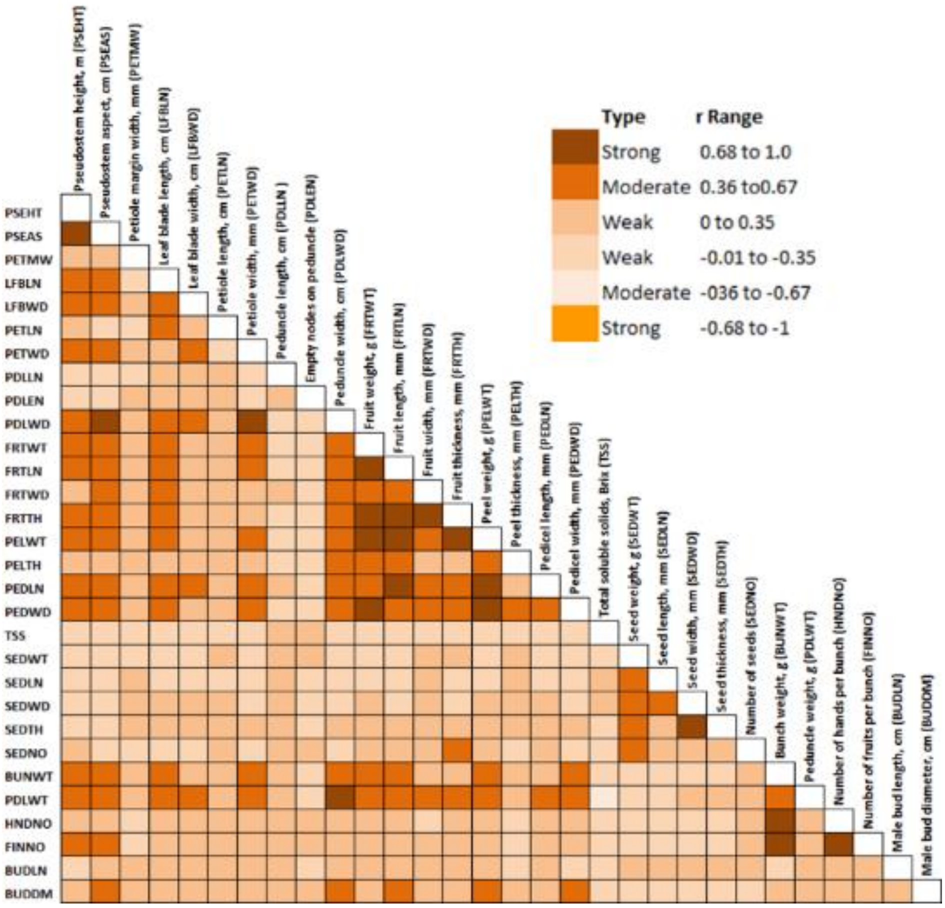

Figure 4. Heat map representing calculated Pearson's product-moment correlation coefficients among morphological traits measured in 97 *Musa* germplasm characterized. Taylor (1990) classified correlation coefficients as weak ($r \leq 0.35$), moderate ($r \geq 0.36$) and strong ($r > 0.68$).

To assess the relationship among quantitative characters measured, correlation analysis was conducted on 30 morphological characters (Figure 4). Correlation analysis can be a valuable tool in germplasm conservation and management, as highly correlated characters can be prioritized during collections. Correlation analysis showed that approximately 4.4% of the calculated correlation values have strong positive correlations. These were mostly fruit characters like fruit number, weight, length, and peel weight. Correlation between the number of hands and number of fingers present in a bunch showed the highest correlation (r=0.93). A high correlation between plant diameter and plant height (r=0.87) was also observed. Positive moderate and weak correlations constituted 21.8% and 44.1%, respectively. Negative correlation among the characters was also observed which constituted 29.4% of the total values observed.

Cluster analysis was done to assess the relationship among the evaluated germplasm based on their morphological characteristics. Generated dendrogram showed three distinct clusters with Cluster I having the greatest number of members (Figure 5). This group is composed of tall accessions with an average height of 4.2 m and pseudo-stem circumference of 67 cm. The group also produced the heaviest fruit (finger) with an average of 129 g which could be attributed to thick peel (2.32 mm) and long pedicel (26 mm). Moreover, Cluster I had the greatest number of fingers per bunch (99 fingers) but had similar number of hands per bunch (seven hands) with the accessions in Cluster II.

In comparison to Cluster I, members in Cluster II had relatively shorter height averaging 4.1 m with pseudo-stem circumference of 65 cm. Although Cluster I had lighter fruit weight (115 g) on the average compared to Cluster II, it had the greatest number of seeds (258 seeds per finger) that could have led to having the heaviest fruit bunch (15.4 kg). On the other hand, members of Cluster III had the shortest height averaging 3.6 m and smallest pseudo-stem diameter (57 cm). The group only averaging six hands per bunch, had the least number of fingers per bunch (67 fruits) and the lightest fruit weight (103 g).

Fruit weight was one of the fruit traits with high diversity index (H′=0.893). To classify the accessions based on their fruit and quantify their diversity, color-coded geogrids of the germplasm collections based on their fruit weight class were generated and their variations were measured (Figure 6). Accessions having heavy fruit weight (167-209 g) were mostly collected from the northern parts of the country. Lightest fruit weight (≤ 42 g) was measured from accessions collected in the central part of the country. However, both the northern and central regions of the country showed high diversity in fruit weight as shown by the calculated coefficient of variation (CV) values ranging between 61 and 76.

Aside from phenotypic diversity analyses, clustering in terms of geolocations was examined. Figure 4 shows the locations of members of each cluster and the type of climate of the original locations where the banana germplasm accessions were collected. Cluster I have the largest number of accessions were mostly collected from the northern parts of the country which have a Type I climate (pronounced wet and dry season); Type III (wet and dry seasons not clearly defined) or Type IV climate (rainfall evenly distributed year-round). Members of Cluster II were mostly from regions with Type I and IV climatic conditions. On the other hand, Cluster III have similar profile with Cluster I where accessions collected grew in Types I, III and IV climatic conditions. No plant samples were collected in areas having Type II climate.

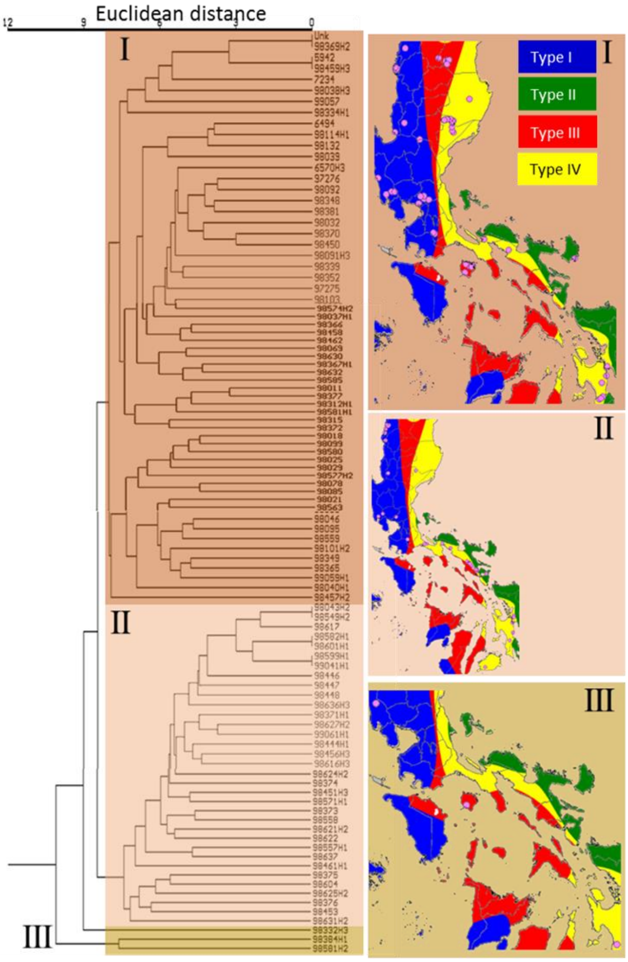

Figure 5. Cluster analysis of the phenotypic data of *Musa balbisiana* collection showing the geolocation or collection sites of accessions for each cluster. Different colors denote regional climate classifications: Type I (Blue), Type II (Green), Type III (Red) and Type IV (Yellow).

Species distribution modeling of germplasm

Using five common species distribution models, we generated climatic suitability maps derived from current climatic conditions for *M. balbisiana* in the country based on presence data (Figure 7). The models showed excellent levels of predictive performance as indicated by the area under the receiver operating characteristic (ROC) curve value (AUC) of test data and the percentages of occurrence points correctly classified (%Co) for the five different models (Table 3). Among the five models, BRT, RF and Maxent showed high AUC and %Co with BRT showing the highest computed AUC and %Co with 0.96 and 94%, respectively. The K values varied across models but follows the trend observed in AUC and %Co. Like the results for AUC, the BRT, RF, and Maxent models performed well in terms of K.BRT scored the highest (K = 0.89) while GLM scored the lowest among five models with K = 0.72. Overall, GLM had the lowest accuracy based on both the %Co and K relative to the other four SDMs.

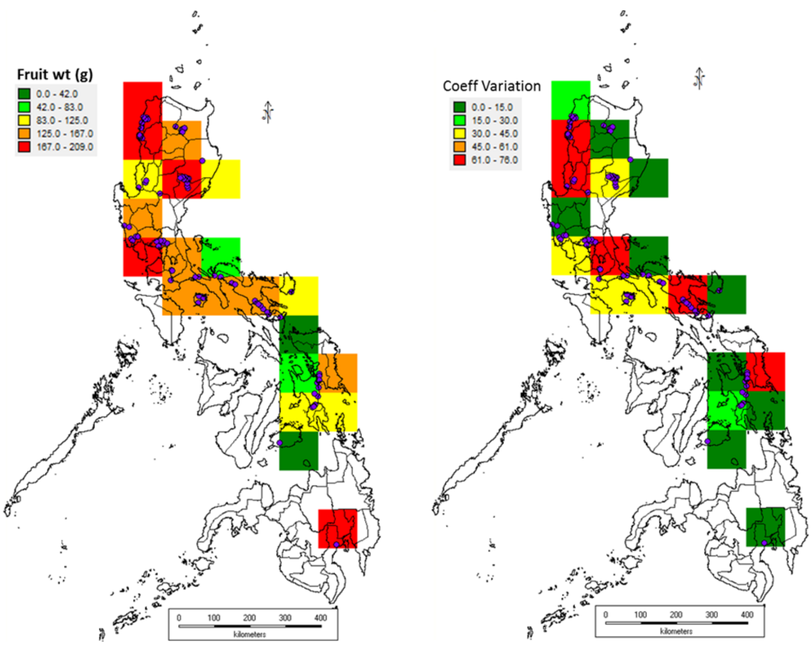

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Figure 6. Using DIVA-GIS ver.7.5.0 (Hijman et al. 2001), generated maps show diversity in fruit weight among the evaluated 97 *Musa balbisiana* collection: (A) fruit weight measured and (B) coefficient of variation in fruit weight. Colored grids on the maps denote different values in fruit weight (A) and coefficient of variation (B).

Among the climatic variables, annual mean temperature (Bioclim 1)and precipitation of warmest quarter(Bioclim 18) were the top two most important predictors for all five SDMs (Table 4). BRT, RF, and Maxent models ranked precipitation seasonality (Bioclim 15) third. Isothermality (Bioclim 3) was the least important among six variables for four of the five SDMs.

The models predicted high probability of presence in areas close to where the *M. balbisiana* germplasm used in this study have been collected as shown in Figure 7. Interestingly, the GLM model (Figure 6.b) showed many areas of the country to have high probability of presence for *M. balbisiana*. These include the islands of Panay, Negros and Cebu in the Central Visayas region of the country which has no representative germplasm collected in these regions. Panay and Negros islands have Types I and III climate while Cebu has Types III and IV. The island of Bohol has high probability of presence of the species in all five models. The island of Mindanao which has one representative germplasm showed to have high probability of *M. balbisiana* presence in areas with Types II and IV climates shown in four models (Figures 7.a-d). Both these climate types have pronounced precipitation throughout the year. In RF (Figure 7.e), the whole island of Mindanao was predicted to be suitable for *M. balbisiana* at varying degree of probability. Combining models for probability of presence improved the potential suitable areas for *M. balbisiana* in the country (Figure 8). The improved suitable maps showed that at least 60% of the algorithms agree that the bioclimatic conditions of the area are suitable for the species. This analysis identified suitable areas where no presence data was observed such as the island of Palawan (western part of the country) and the islands in the southern tip of the country such as Basilan, Jolo and Tawitawi.

Discussion

Germplasm characterization is a core activity in germplasm conservation to enhance efficient management and utilization of available germplasm in breeding programs (Rabara et al. 2014; Rabara et al. 2015). However, the management of GenBank is usually based on intuition rather than reason because of inadequate characterization data of germplasm collections (McCouchet al. 2012). This is one of the main reasons this study on extensive phenotyping of *M. balbisiana* germplasm collection conserved at NPGRL GenBank was conducted. The existing collections' phenotypic and genetic diversity need assessment to develop conservation and management strategies for current and future use in *Musa* varietal improvement. De Vicente et al. (2005) emphasized the importance of germplasm characterization in decision-making for germplasm conservation and utilization.

Based on calculated diversity indices, results clearly showed that the current collection is highly diverse on some of traits that were measured and scored. Also, results of genetic diversity assessment indicated high diversity in the collection. Some 19 traits were found to be invariants and should be considered as target traits in future collection trips to enhance diversity of these traits in the ex-situ conserved *Musa* germplasm.

Table 3. The Areas under the Curve (AUC) and the kappa statistics (K)associated with the test data and the percentages of occurrence points were correctly classified (%Co) for the five different models. Model abbreviations are as follows: GLM: Generalized Linear Model, MARS: Multivariate Adaptive Regression Splines, BRT: Boosted Regression Tree, and RF: Random Forest.

Species	GLM			MARS			BRT			RF			Maxent		
Musa	AUC	%Co	K	AUC	%Co	K	AUC	%Co	K	AUC	%Co	K	AUC	%Co	K
	0.79	76.2	0.72	0.85	82.7	0.77	0.96	93.8	0.89	0.94	92.3	0.87	0.95	91.2	0.87

Table 4. Ranking of the important climatic predictors for each statistical algorithm for *Musa balbisiana*. The two most important variables are annual mean temperature and precipitation of warmest quarter. Model abbreviations are as follows: BRT: Boosted Regression Tree, GLM: Generalized Linear Model, MARS: Multivariate Adaptive Regression Splines, Maxent, and RF: Random Forest.

Rank	GLM	MARS	BRT	RF	Maxent
1	Annual Mean Temperature	Annual Mean Temperature	Annual Mean Temperature	Annual Mean Temperature	Annual Mean Temperature
2	Precipitation of Warmest Quarter	Precipitation of Warmest Quarter	Precipitation of Warmest Quarter	Precipitation of Warmest Quarter	Precipitation of Warmest Quarter
3	Precipitation of Wettest Quarter	Precipitation of Wettest Quarter	Precipitation Seasonality	Precipitation Seasonality	Precipitation Seasonality
4	Precipitation Seasonality	Temperature Annual Range	Temperature Annual Range	Temperature Annual Range	Precipitation of Wettest Quarter
5	Temperature Annual Range	Precipitation Seasonality	Precipitation of Wettest Quarter	Isothermality	Temperature Annual Range
6	Isothermality	Isothermality	Isothermality	Precipitation of Wettest Quarter	Isothermality

The species distribution analyses showed that annual mean temperature and precipitation of warmest quarter greatly influenced results of diversity indices, ranking first and second, respectively, in all five statistical algorithms. Such attests that environmental factors play an important role in species diversification. In dryland habitats, seasonal pattern of rainfall is one of the driving forces in bio-diversification (Bonkoungou 2001). Similarly, rainfall pattern significantly influences floristic differentiation among Atlantic rainforests in Southeastern Brazil (Oliveira-Filho and Fontes 2000). A survey conducted by Zhao et al. (2018) of 2700 plants species in China has shown that mean annual precipitation and mean annual temperature predictive contribution to woody fleshy-fruited species distributions and herbaceous fleshy-fruited species distributions, respectively. Species distribution of *M. balbisiana*, an herbaceous fleshy-fruited species, was highly influenced by annual precipitation while the minimum temperature of the coldest month contributed 24% to the model. Ramirez et al. (2011) reported that decrease in rainfall can affect rates of photosynthesis and leaf emergence in bananas since they have rapid physiological response water deficit in the soil.

The strength of the models depended on both the selected predictors as well as the methodology in building them. The spatial resolution of the environmental variables used in the modeling in our study fit the spatial resolution of our species records which address one of the common mistakes pointed out by Sillero and Barbosa (2020). The bioclimatic variables that were highly correlated (r > 0.7) were removed from the models to avoid collinearity among variables, to avoid over-fitting of these variables to the model (Pradhan, 2016). The models we ran were based on the climatic data alone and excluded non-climatic variables. We believe that the distribution of suitable conditions for *M. balbisiana* would be driven by the climatic variables that we focused on. Apart from the lack of datasets projected according to the climatic dataset, scale is also an issue as non-climatic variables such as soil properties, for instance, are available at finer resolutions than the climatic dataset. Since our results for important climatic variables were based on concordance of five models, they are likely to have high transferability.

Knowledge of species distribution is an important component in biodiversity conservation programs. SDMs provide tools for GenBank curators and conservationists to identify areas for *in-situ* conservation of CWRs (Vincent et al. 2019) as well as to prioritize collecting for ex-situ conservation (Ramirez-Villegas et al. 2020). Vincent et al. (2019) proposed 150 global sites for *in-situ* conservation of CWR that will conserve 66% of major crop CWRgenepools. Ramirez-Villegas et al. (2020) used SDM to prioritize collecting of Andean and Mesoamerican bean gene pools to fill up the gap in ex-situ collection of common bean landraces. Our goal for this study was to identify potential gaps in our ex-situ germplasm collection by combining phenotypic diversity and species distribution data. In our study, we observed that *M. Balbisiana* accessions with bigger fruits were mostly found in the northern area of the country, in provinces with pronounced drier seasons like the province of Quirino. However, this observation may not hold true if compared to *M. balbisiana* accession growing in the southern parts of the country since there is only one germplasm collected in the area among the 97 accessions evaluated. Having only a single collection in the Mindanao area is partly due to inaccessibility of the region owing to conflicts and safety issues during exploration trips. This by itself requires the need for collection activities in Mindanao to increase germplasm collection and to ensure representative accessions are conserved. Increasing the number of germplasms collected from this region might improve the distribution model in the area as previous studies reported that distribution of *M. balbisiana* is influenced by precipitation. For example, *M. balbisiana* is commonly found farther north of India where dry seasons are prominent (Subbaraya et al. 2006).

One setback encountered during field exploration and collection of *M. balbisiana* germplasm was the accessibility of the natural habitat of this wild species. Due to difficulty of accessing far-flung areas in most of the provinces, majority of the germplasm collected was close to road networks (Figure 9). The geographic locations of the 97-germplasm evaluated in this study showed collection bias, one of the most commonly cited problems in field exploration(Hermann 1988; von Bothmer and Seberg 1995; Hijmans et al. 2000).

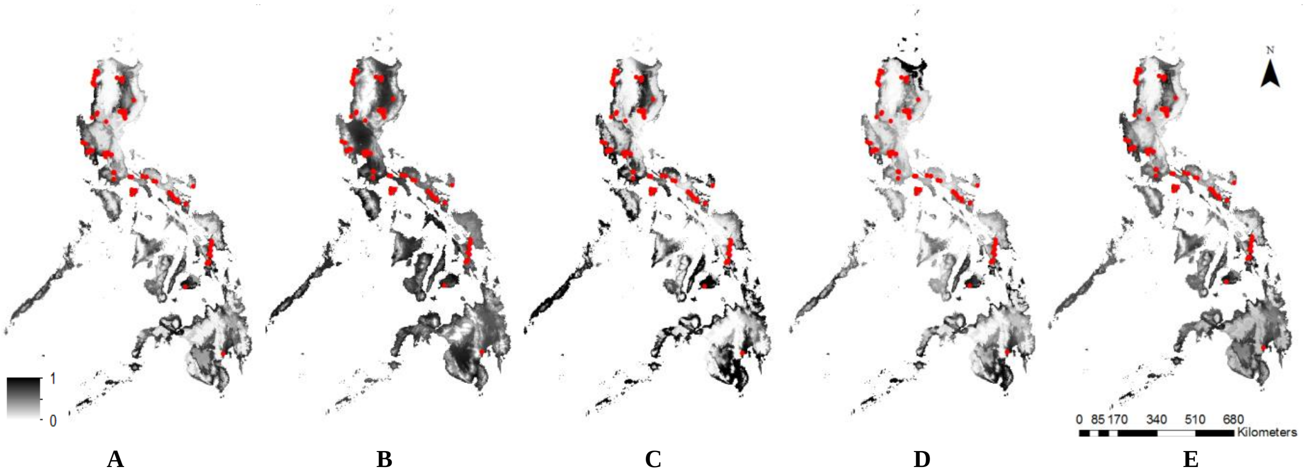

Figure 7. Climatic probability maps derived from current climatic suitable conditions for Musa (*Musa balbisiana*) using five common species distribution models: A. BRT: Boosted Regression Tree, B. GLM: Generalized Linear Model, C. MARS: Multivariate Adaptive Regression Splines, D. Maxent, and E. RF: Random Forest. Species occurrence points are shown in red dots. The map values range between 0 (white, low probability) to 1 (black, high probability).

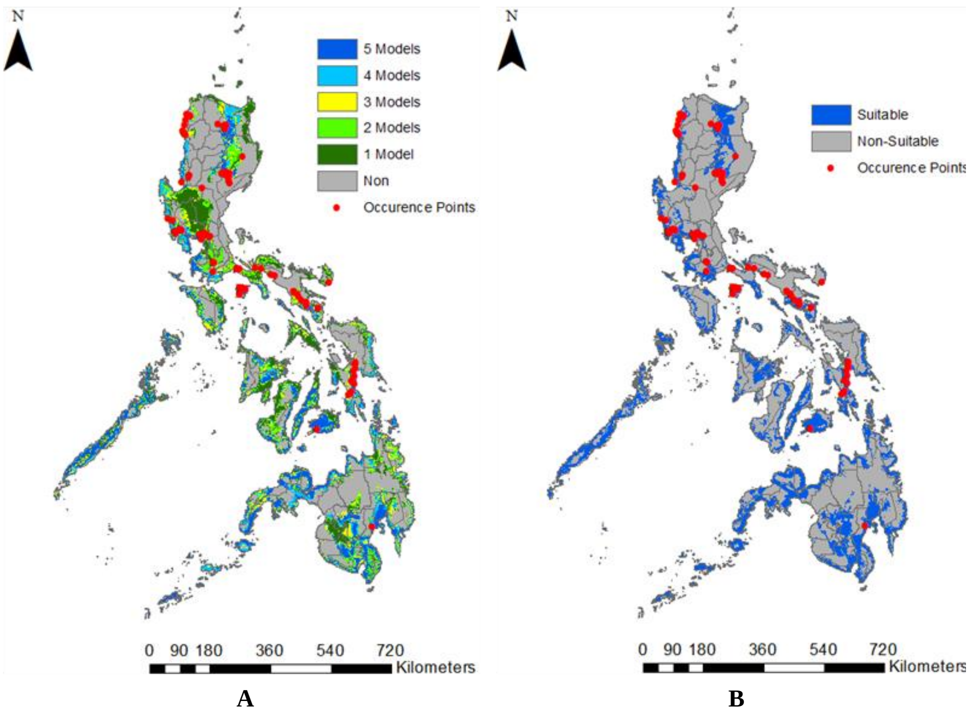

Figure 8. Combined present-day climatic models for Musa (*Musa balbisiana*): A. A score of 5 means that all species distribution models agreed and identified that pixel as containing suitable bioclimatic conditions for the species, B. With three or more (at least 60% of) algorithms agree that the pixel contains suitable bioclimatic conditions for the species. Red dots represent the species occurrence data.

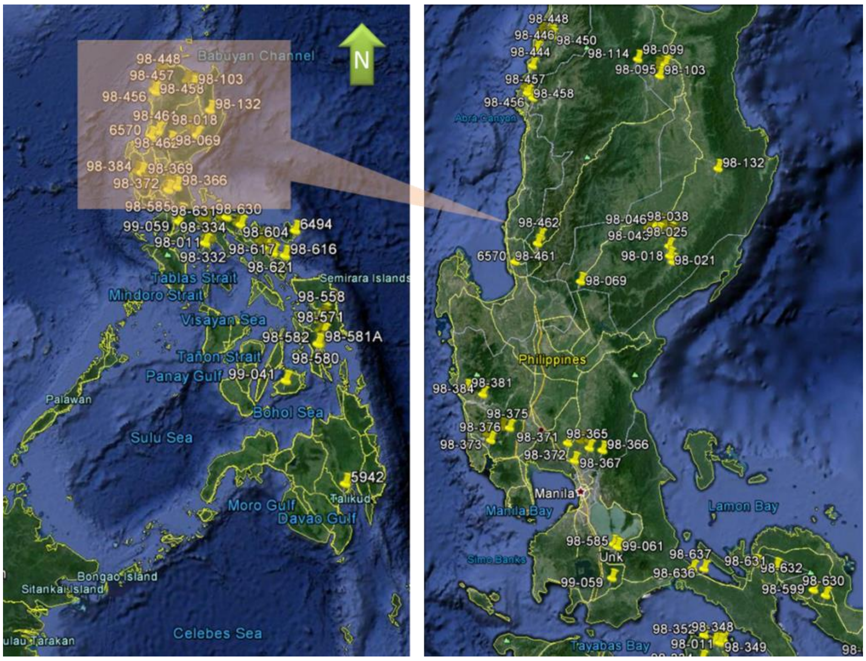

Figure 9. Map of *Musa balbisiana* germplasm collections showing accessions collected close to road networks. Maps were generated using Google Earth software

Collection bias due to infrastructure is common in collection missions because collectors tend to follow roads connected to main towns for reasons of efficiency, logistics and convenience (Hijmans et al. 2000) as well as safety and security. This bias was observed in many previously reported germplasm collections and studies (Hermann 1988; von Bothmer and Seberg 1995; Hijmans et al. 2000). For example, the Andean tuber crop collection sites were located largely in Pan-American Highway and other major roads in Ecuador (Hermann 1988) and collection sites in the distribution map of *Elymus cordilleranus* were mostly around major cities like La Paz (Bolivia), Lima (Peru) and the Pan-American Highway in Ecuador (von Bothmer and Seberg 1995). Similarly, 68% of the total germplasm holdings of Bolivian wild potatoes collection were collected within 2 km from the nearest roads (Hijmans et al. 2000). In this study, partnering with local officials made collections trips efficient and productive owing to their knowledge of local dialects and potential locations where *Musa* germplasm materials thrive.

In conclusion, following the extensive analyses of *M. balbisiana* germplasm, totaling 97 accessions, study results indicate the need for more implementation of conservation efforts to enhance the diversity of conserved germplasm for posterity as well as improve the germplasm's utility for current and future breeding activities on *Musa* species through related studies described below : (i) Exploration and collection trips with focus on invariant traits found in the *M. balbisiana* germplasm collections. (ii) Conduct collection trips in the southern region of the country, particularly Mindanao and neighboring islands to further conserve and assess the diversity of *Musa* species in the Philippines. (iii) Assessment of phenotypic responses of *Musa* germplasm to various biotic and abiotic stresses with the objective of identifying potential donor parental lines for breeding programs. Accordingly, *M. balbisiana* a wild species of *Musa*, is known to have traits that make it resistant to devastating banana diseases. Its high diversity in terms of phenotypic traits, as revealed in this study, could be source of desired characteristics in future plant types. Evaluation of this germplasm to biotic and abiotic stresses would further provide wealth of information for plant breeders for the utilization of this germplasm to abaca improvement. Results of further studies into *M. balbisiana* species' genome structure, regulatory networks and allelic diversity would elucidate the development of improved banana cultivars having desirable quality traits and resistance to biotic and abiotic stresses.

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Short Communication: Growth performance, and blood profile of kampong chicken fed diets containing *Moringa oleifera* powder and liquid

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Abstract. *Adli DN. 2020. Short Communication: Growth performance, and blood profile of kampong chicken fed diets containing* Moringa oleifera *powder and liquid. Asian J Agric 4: 83-86.* The research purpose is to carry out the possible effect of *Moringa oleifera* on Growth performance, and intestinal properties of Lohmann broiler. 80 one-day-old kampongs were randomly allocated to 4 dietary treatments and 4 replicates of 5 birds per cage. Four treatments used for research were dietary with control (T0), basal diet + *M. oleifera* 80 g (T1), Drinking water + 2 mL/L *M. oleifera* (T2), and basal feed + *M. oleifera* 80 g+ drinking water 2 mL/L *M. oleifera* (T3). The results showed that using *M. oleifera* presented no significant difference ($P < 0.05$) on body weight gain at 1-35 days and intestinal properties. The microstructure didn't affect negatively to its structure. In conclusion, addition of *M. oleifera* does not impact growth performance, and but can reduce amount of glucose in kampong chicken.

Keywords: Blood biochemistry, Kampong chicken, performance

INTRODUCTION

Intensive poultry production systems demand a supply of high protein- and easily available in developing countries. However, during the last decade, dietary protein sources for livestock have become tremendously expensive and difficult to access, challenging researchers and farmers globally to seek alternative protein sources and increase the quality and availability of alternative livestock feeds (Adli et al. 2018).

Consequently, various forage trees and shrubs have been explored as potential protein sources, and special attention has been paid to the tree *Moringa oleifera*. *M. oleifera* were substances that provide a source of antioxidant for animals. The source of antioxidant was later called natural growth promoters (Adli et al. 2017).

Originating from the Indian sub-continent. *M. oleifera* is reputed for its adaptability to grow in all types of soils and to tolerate hot and dry conditions d (Jet et al. 2014). The antibiotics are provided as a growth promoter; however, they cause bacterial resistance and residue in the carcass. Alternative feed additives, such as *M. oleifera,* have been the focus of many studies during the past five years due to their beneficial effect on feed efficiency. *M. oleifera* replaces the use of antibiotics because they are safer and act as a natural growth promoter (NGPs) in kampong chicken (Adli et al. 2018).

Moringa oleifera was a potential for natural growth promoters. The moringa can be used as feed additive in terms of non-nutritional value of poultry additive. (Jet et al. 2014). It contains negligible amounts of antinutritional factors, has a high crude protein (CP) content, significant amounts of vitamins A, B, and C in the foliage, and high amounts of polyphenols, resulting in significant anti-oxidative activity. *M. oleifera* is also called a miracle tree, since it provides a lot of chemical properties on its leaf. *M. oleifera* are economical trees that grow in tropical areas (Su and Chen 2020). *M. oleifera* acts as anti-bacterial, anti-oxidant, and anti-inflammatory (Auriem et al. 2019).

MATERIALS AND METHODS

Animals, housing, and experimental design

A total of 80 kampong chickens with initial body weight (BW) of 22.13±2.13 kg were used in an 8-weeks trial. Treatments were as follows with control (T0), basal diet + *M. oleifera* 80 g (T1), Drinking water + 2 mL/L *M. oleifera* (T2), and basal feed + *M. oleifera* 80 g+ drinking water 2 mL/L *M. oleifera* (T3). The house is set with temperature of 29ºC and 65% humidity. Furthermore, it was set to 23 hours of light and 2 hours of darkness. Feed nutrients can be seen in Table 1.

Growth performance

The kampong chickens were individually weighed at the beginning of the experiment, and every week thereafter until the end of the experiment. The gain in body weight (BWG) of birds per week was calculated as the difference between the initial and end weight at a given week (7 days, 14 days, 21 days, 28 days, and 35days). Feed intake was calculated basis of feed offered and remain. As basis mortalities set calculated during experimental.

Table 1. Experimental diet

Feed nutrient	Starter (1-28 days)	Finisher (29-56 days)
Maize	57.11	69.66
Dehulled soybean meal	36.53	26.65
L-Lysine	0.1	0.1
DL-methionine	0.55	0.55
Dicalcium phosphate	1.67	1.55
Limestone	1.13	1.02
Salt	0.3	0.3
Soy oil	2.81	0.06
Vitamin premix*	0.05	0.05
Mineral premix**	0.05	0.05
Choline	0.1	0.1
	100.4	**100. 09**
Dry matter (%)	87.00	87.00
ME (Kcal/kg)	3050	3150
Ash (%)	9.00	9.00
Crude protein (%)	22.00	18.00
Fat (%)	6.00	6.00
Crude fiber (%)	3.00	2.50
Ca	1.00%	0.95%
P	0.70%	0.75%
Copper (ppm)	30	50
Zinc (ppm)	120	120

Blood biochemistry

Blood data was taken at 21, 28, and 56 days of age. The blood non-EDTA tubes and allowed to clot for one hour, at room temperature, Blood samples were immediately centrifuged using the cryogenic centrifuge (Hettich Universal 320R, Germany) for 15min at 3000 rpm to obtain serum and further: glutamic oxaloacetic transaminase; GPT: glutamic pyruvic transaminase; TP: total protein, ALB: Albumin; GLB: globulin; A/G: albumin/ globulin ratio; TGL: triglyceride; TCHOL: total cholesterol; BUN: blood urea nitrogen; GLC: glucose (Adli, et al. 2019).

Data analyses

Data were statistically analyzed using GLM procedure of *SAS University version 4.0 red hat* (64-bit) with code encryption algorithm http://localhost:10080/SASStudio/38/index license owned by Danung Adli and the difference among treatment means ($p<0.05$) were determined using Duncan's multiple range tests. Code algorithm in SAS as follows:

Data Q1;
Set pre.Q1;
Run;
Proc ANOVA data=Q1;
Title 'one-way anova with a *Moringa oleifera* on one factor';
Class calib;
Mode shape_1shape_2 shape_3 shape 4= calib/nouni; (Widiyawati 2020).

RESULTS AND DISCUSSION

Growth performance

Data on comparation *M. oleifera* leaf and liquid in feed is shown in Table 2. Giving Red *M. oleifera* leaves and liquid doesn't improve ($p > 0.05$) on FI, FCR, and BWG. The feed intake increase may be due to correlating with body weight and body weight gain when both of these variable growth increase the feed intake will also increase. Compared with Adli and Sjofjan (2020) who stated that the use of MRF gave significant difference ($P < 0.05$) on body weight gain at 21 d and 35 d compared than control (877 g (MRF 400 g/tonne (21 d); 50 g/tonne (35d)) vs 819 g control). The result is due to the rearing condition, the kampong chicken will increase the body weight gain when the environment bedding is clean (Adli and Sjofjan 2020). Additionally, the bodyweight of poultry would be determined by the consumption of feed with a balanced energy and protein content. In the past, the use of plants in monogastric diets was restricted because of some negative aspects of feed intake and nutrient utilization attributed to phytochemical composition that varies greatly due to variety, location, and climate. The mortality result in Table 2 showed the use of MRF combination with probiotic liquid acidifier on treatment (T2 and T3) gives no significant differences ($P > 0.05$) reduces to 1.31% compared to control 3.94%. In earnest, the effect on growth performance may not be consistent, for instance, in several cases where plant extracts have been used, FI and FCR were not changed, although a positive effect on BW, BWG, organ weight, and/or energy utilization was reported (Sjofjan et al. 2019).

Statistical analysis of the meat quality is presented in Table 3. Shows *M. oleifera* leave and liquid in feed on the on-serum blood biochemistry were not significantly different ($P > 0.05$) but the results on Glutamic oxaloacetic transaminase (GOT) at 21 days began to reduce. The treatment was better compared to control (219.20 (T1), 200.10 (T2), and 215.30 (T3) vs. 243.30 U/L). Melesse et al., (2017) stated the criteria GOT were at the number less than 40 U/L. The result of the GOT may be due to *M. oleifera* content. Ogbe and Affiku (2020) stated *M. oleifera* may reduce content of anti-stress substances. The dietary treatment of feed additives depends on dose, frequency, and time rearing in vivo (Adli and Sjofjan 2020).

Based on Table 3, the use of *M. oleifera* was not significantly different ($p > 0.05$) on total protein. In the beginning, it is hard to reduce but more stable compared to control. Moreki and Gabanakgosi (2014) stated *M. oleifera* can't help to reduce total protein in a short amount of time in animals, but it will help with longer amounts of time.

The result may be due to the treatment that cannot help to reduce the amount of blood content on the heart. The serum of blood biochemistry was indicator of positive or negative results of treatment. (Sjofjan et al. 2019). Factors that affect heart weight are broiler body weight, age, broiler activity, and gender. Banjo (2012) stated the high fiber of *M. oleifera* made the additive stay more in intestinal of chicken. To reduce crude fiber, it needs to be reduced in the fiber with liquid content of substances (Sjofjan et al. 2019).

Table 2. Effect of *Moringa oleifera* on the body weight, body weight gain, feed intake, feed/gain, and mortality of kampong chicken

Day	Treatments[1]				
	T0	T1	T2	T3	SEM
Bodyweight, g/bird					
1	33.12	33.15	33.15	33.08	0.11
28	421.33	412.13	404.39	405.12	17.40
48	888.11	825.11	720.2	713.102	17.40
56	889.12	883.12	812.11	715.15	10.40
Bodyweight gain, g/bird					
1-21	674.64	670.05	671.98	668.98	42.55
1-28	1001.12[b]	1138.73[a]	1128.63[a]	1192.09[a]	47.70
28-48	1525.10	1537.10	1574.70	1486.90	65.20
1-56	1856.90	1842.70	1878.40	1786.60	167.20
Feed intake, g/bird					
1-21	909.80	979.10	855.40	807.30	21.06
1-28	1874.60	2018.40	1822.90	1727.80	53.70
28-48	2264.70	2414.40	2273.40	2102.00	70.00
1-56	2668.60	2810.80	2690.10	2499.00	76.80
Feed/gain, g/bird					
1-21	1.33	1.49	1.22	1.22	0.09
1-28	1.73	1.72	1.54	1.44	0.23
28-48	1.52	1.58	1.54	1.49	0.37
1-56	1.48	1.54	1.50	1.44	0.14
Mortality, (%)					
1-56	5.94	2.26	2.26	2.26	2.26

Note: Mean values not sharing the same superscripts in a row differ significantly ($P < 0.05$)

Table 3. Effect of *Moringa oleifera* on the serum blood biochemistry kampong chicken at 56 days of age

Item	Treatments[1]				
	T0	T1	T2	T3	SEM
GOT (U/L)	219.20	200.10	215.30	243.30	121.1
GPT (U/L)	3.00	1.75	2.00	2.75	0.97
TP (g/dL)	2.97	2.97	2.92	2.95	0.29
ALB (g/dL)	1.27	1.27	1.17	1.22	0.16
GLB (g/dL)	1.70	1.70	1.77	1.70	0.18
(A/G)	0.77	0.77	0.67	0.72	0.11
TGL (mg/dL)	32.25	30.25	30.50	29.00	5.66
TCHOL (mg/dL)	128.50	128.75	114.50	123.50	12.38
BUN (mg/dL)	0.97	0.47	0.62	0.47	0.32
GLC (mg/dL)	251.00	205.00	213.75	227.00	29.10

Note: Mean values not sharing the same superscripts in a row differ significantly ($P < 0.05$)

Based on Table 4, the use of *M. oleifera* was not significantly different ($p > 0.05$) on total cholesterol, blood urea nitrogen, and glucose. Compared to control, TCHOL was at 114.50 (T2) and 123.50 (T3) with SEM 12.38. The total cholesterol was at the same time lower with glucose due to surface area of *M. oleifera*. The key absorption was spread to blood area of body (Sjofjan et al. 2020). Additionally, to Abdulsalam et al. (2015), *M. oleifera* is much better to provide antioxidant compared to other leaves.

In conclusion, addition of *Moringa oleifera* does not impact growth performance, and but can reduce amount the amount of glucose in kampong chicken.

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Plants with modified anatomical structures capable of oxygenating the rhizosphere are threats to sulfidic soils under varying soil moisture regimes

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Abstract. *Michael PS. 2020. Plants with modified anatomical structures capable of oxygenating the rhizosphere are threats to sulfidic soils under varying soil moisture regimes. Asian J Agric 4: 87-94.* Acid sulfate soils (ASS) are naturally occurring soils, sediments or substrates formed under waterlogged, reducing conditions. These soils either contain sulfuric acid or have the potential to form it, in an amount that can have detrimental impacts on the environment. In general, ASS with sulfuric materials and that have acidified through oxidation of pyrite are referred to as sulfuric soils. ASS with sulfidic materials that contain pyrite and have the potential to acidify when exposed to air are referred to as sulfidic soils. In an undisturbed state below the water table, the sulfidic soils are benign, unless exposed due to various natural processes or anthropogenic activities. This study examined the importance of organic matter addition, plant macrophytes and turnover of organic matter from the plant macrophytes co-existing on pH, redox and sulfate content of sulfidic soil under flooded conditions. In almost all cases, organic matter without plants induced ameliorative effects. Presence of plants led to higher Eh values, low pH and higher sulfate contents, and acidified the sulfidic soil.

Keywords: Eh, live plants, organic matter, pH, sulfate content, sulfidic soil

INTRODUCTION

Acid sulfate soils with sulfuric (pH<4) and sulfidic (pH>4) materials are widely distributed globally and commonly associated with lakes, rivers and wetlands (Fitzpatrick et al. 2009; Baldwin and Fraser 2009). The global distribution of ASS is shown in Figure 1. When submerged, these soils pose no problem because sulfides are retained in the reduced state (Michael et al. 2015). The sulfidic soil formation process is shown in (1) (Michael 2013). However, when exposed to falling water levels, e.g. during a drought event (Hanhart et al. 1997), the sulfides are oxidized and lead to generation of sulfuric acid. This process is shown in (2) (e.g. Ahern et al. 2004; Buschmann et al. 2008; Fitzpatrick et al. 2010; Michael et al. 2012).

In aerobic soils, cellular respiration of plant roots is supported by oxygen that reaches the rhizosphere through porous soils or via channels created by roots (e.g. Michael et al. 2017). Under anaerobic soil conditions (e.g. flooded), adapted plants use specialized aerenchymatous structures to transport oxygen from the shoots to support root respiration (Armstrong et al. 1996). The presence of an adequate amount of oxygen in the rhizosphere of plants, through whatever mechanism, offers various advantages in almost all soil types except ASS. In ASS, oxygen causes the oxidation of sulfidic soil materials (pH>4), which leads to the production of sulfuric acid (pH<4) (Pons 1973). Under reducing soil conditions, transportation of oxygen into the rhizosphere of plants in sulfidic soil by aerenchymatous structures would lead to oxidation of sulfidic sediments and sulfide-bearing minerals, generating sulfuric acidity (Reid and Butcher 2011).

We have reported in several recent studies that incorporation of various forms of dry organic matter such as dry leaves of common reed (*Phragmites australis*) (Michael et al. 2015), lucerne (*Medicago sativa*) hay and pea (*Pisum sativum*) straw (Michael et al. 2016) generates reducing soil conditions that favor reduction of sulfate and increase the pH. The magnitude of the changes in pH was also dependent on the nitrogen content of organic matter (Michael et al. 2016; Michael 2020a). Under natural conditions, plant turnover adds decaying organic matter so that both live and dead plant material co-exist in or on the soil, in varying proportions (Michael et al. 2017), influence microbial activity in the rhizosphere and alter the chemistry (Jayalath et al. 2016; Michael and Reid 2018).

In a similar study, Reid and Butcher (2011) investigated the effects of several plants with shallow rooting systems on ASS pH and found that the effects varied depending on the plant types and the depth of root penetration. However, two other important aspects of soil chemistry (redox potential and sulfate content) that are strongly associated with pH changes and influenced by plant roots were not investigated. One of these plants, *Phragmites* (common reed) is able to grow in highly acid soils (pH optimum 2–8) and thrive in highly reduced soil conditions. In addition to the extensive rooting systems, *Phragmites* has self-mulching effects due to rapid turnover of organic matter either by the leaves on the surface or by root decay.

$$Fe_2O_{3(s)} + 4SO^{2-}_{(aq)} + 8CH_2O + ½O_{2\,(g)} \rightarrow 2FeS_{2(s)} + 8CHO_3^-{}_{(aq)} + 4H_2O_{(aq)} \quad (1)$$

$$FeS_{2(s)} + 3½O_{2\,(g,\,aq)} + H_2O \rightarrow Fe^{2+}{}_{(aq)} + 2H^+{}_{(aq)} + 2SO_4^{2-}{}_{(aq)} \quad (2)$$

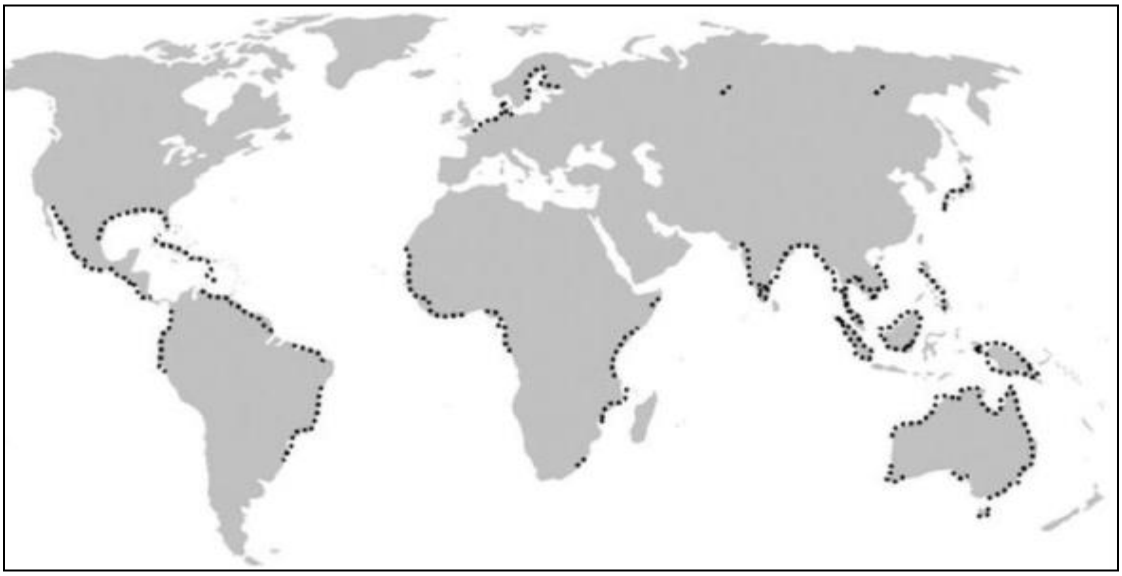

Figure 1. The global distribution of ASS. Of the estimated 17-24 million ha of ASS (Ljung et al. 2009; Poch et al. 2009), 6.5 million occur in Asia, 4.5 million in Africa, 3 million in Australia, 3 million in Latin America, 235 000 in Finland and 100 000 in North America, respectively (Simpson and Pedini 1985).

In addition, the plant possess modified anatomical structures capable of transporting oxygen into the rhizosphere (Marks et al. 1994), oxidizing sulfidic minerals present in sulfidic soil and generating sulfuric acidity, making it an ideal plant to assess the effects on ASS chemistry.

This study investigated the importance of organic matter addition, plant macrophytes and turnover of organic matter from the plants co-existing on pH, redox and sulfate content of sulfidic soil under flooded conditions.

MATERIALS AND METHODS

Soil

The ‘sulfidic soil’ was collected from a ‘sulfuric subaqueous clayey soil’ (Fitzpatrick 2013) at a depth of approximately 1 m in the Finniss River in South Australia at Wally’s Landing (35°24028.28″S; 138°49054.37″E). Details on soil classification using the Australian ASS Identification Key (Fitzpatrick et al. 2008) and Soil Taxonomy (Soil Survey Staff 2014) is given in Michael et al. (2016). In addition, comprehensive lists of references containing further information on the soil morphology and geochemistry prior to rewetting (i.e. sites AA26.3 and FIN26) in Fitzpatrick et al. (2009) and after reflooding are given in Table 1 of Michael et al. (2015; 2016; 2017). The ‘sulfidic material’ (Soil Survey Staff 2014) used in this study is representative of typical global inland and coastal wetlands, in terms of sulfidic and organic matter content.

The pH of the freshly collected sulfidic material measured in water 1:5 (pH_w) was 6.7. The water holding capacity based on wet and dry weight was estimated to be 49%. The estimation was made by setting soil samples at 100% field capacity after soaking in water and draining through a filter overnight. These soils were weighed to obtain the wet weight, and oven-dried for 3 hours, then microwaved for 30 seconds to ensure removal of any residual moisture and reweighed to obtain a final dry weight. The residual organic matter content estimated using the weight loss-on-ignition method (Schulte and Hopkins 1996) was 10.6%. The presence of sulfidic materials (minerals) capable of producing sulfuric acidity was measured by treating 1 g of sulfidic soil with 5 ml of peroxide (1:5 w/w) as per Ahern et al. (2004). The pH following peroxide treatment (pH_{ox}) was 1.4, a strong indication of high amounts of oxidizable sulfides (Sullivan et al. 2009).

Organic matter

To use as organic matter, the first three younger and fully open leaves of *P. australis* were collected and prepared as previously described in various studies (Michael et al. 2016). All the leaves were chopped into pieces, air-dried overnight under room temperature and then oven dried at 60 ºC for three days. The dry pieces were finely chopped using an electric blender to pass through a ≈0.5 mm sieve. The nitrogen content of the organic matter analyzed by ICP-OES using 0.5 g samples (*n*=3) was estimated to be 3.7%. The carbon content can be approximated to be similar to grass (leaf) clippings from the data in Kamp et al. (1992).

Plant establishment

The *Phragmites* plants were initially raised as shoots (plantlets) by rooting rock stocks in a rooting medium (compost: sandy loam 2:1 w/w). The well-rooted plantlets used in setting the experiments were approximately 8–12 weeks old. In each treatment, two plantlets each was transplanted which produced multiple shoots throughout the experiment. A dibble was used to make small holes, shoots, or seedlings transplanted and the soil gently pressed to ensure the roots were in contact with the soil as would have been the case under any soil use condition. In all the experiments, the control treatments were not planted.

Experiments and treatments

The experiments described below were conducted in 50 cm tall (9 cm in diameter) stormwater tubes whose bottom ends were tightly capped. In all the tubes, the bottom 22 cm was filled with sand and the top 22 cm with 1300 g of sulfidic soil by weighing to add the exact amount in each tube. The treatments were replicated four times and set out in a complete randomized design under glasshouse conditions in polythene crates. The anoxia was created by keeping all the treatments under flooded conditions with adequate amount of water ponding on the surfaces by regular addition of water (once in the morning and in the evening) (Michael et al. 2016) for 6 months.

Experiment 1: This experiment was conducted with *P. australis* plants established with organic matter incorporated in the soil (80:1, soil: organic matter w/w) by bulk mixing. Bulk mixing was done by weighing out the amount of soil or organic matter needed using a portable scale at 80:1 (w/w), and thoroughly mixed in 20 L mixing troughs using a spade. The control treatment contained the same amount of organic matter but not plants.

Experiment 2: In this experiment, *P. australis* plants were established in the sulfidic soil under the same soil conditions but without added organic matter to compare the results of Experiment 1. The control treatments were set without plants.

Measurements and root biomass quantification

In all the treatments, measurements were made only from the top 22 cm of the sulfidic soil. Changes in redox potential (redox/Eh), pH and sulfate content were measured from the surface (0-20 mm), middle (50-100 mm) and deep (150–200 mm) soil profiles as previously described (Michael et al. 2015; 2016; 2017). Redox was measured using a single Ag/AgCl reference and platinum (Pt) electrode combination using an automated data logger (Michael et al. 2012; 2014). To measure the Eh, a handheld electric drill, with a drill bit head the size of the Pt electrode, was used to make holes through the tubes with care taken to avoid disturbing the soil. The Pt electrode was inserted in the holes and reference electrode was inserted into the soil from the surface. This was allowed to equilibrate for 10 minutes and then Eh measured at 1 minute intervals for the next 10 minutes and averaged (Rabenhorst et al. 2009). These values were corrected for the reference offset to be relative to the potential of a standard hydrogen electrode by adding 200 mV (Fiedler et al. 2007). The stability and accuracy of the electrodes were maintained according to Fiedler et al. (2007). The pH was measured using 2 g soil (1:5 water) with a pre-calibrated Orion pH meter (720SA model).

Sulfate was extracted according to the method of Hoeft et al. (1973) for soluble soil sulfate. Replicate samples (0.5 g each) were placed in tubes with 1.5 ml of an extraction solution (0.2 g CaH_2PO_4, 12 g glacial acidic acid and 88.5 g deionized water). After 30 minutes, soil was sedimented by centrifugation for 5 minutes, and duplicate aliquots from the three replicates were transferred into 4 ml cuvettes and diluted with 1.5 ml of the extraction solution. The samples were mixed with 0.7 ml of 0.5 M HCl, and 0.7 ml of 0.1 M barium chloride-polyethylene glycol reagent was added and mixed again. After 10 minutes, the samples were mixed again and the absorbance read at 600 nm using a spectrophotometer. The readings were compared with a standard solution of 0–2 mM Na_2SO_4. The initial sulfate content of the sulfidic soil ranged between 12–16 µlmol g^{-1} soil. The detection limit based on an absorbance reading of 0.1 of this method is 0.6 µlmol g^{-1} soil.

The root biomass was quantified as described by Michael et al. (2017) from the soil profiles from which the changes in Eh, pH and sulfate content were measured. Soil from these sections was placed in a sieve (0.05 mm) and held under gentle running tap water and the soil is carefully broken up to free the roots using the aid of forceps. The loose soil particles were allowed to drain through but roots that were trapped by the sieve and those that floated during washing were collected. These roots were taken, gently washed again to remove soil material, placed in weighing boats and oven dried for two days. The dry weights were taken by weighing, and weights of the replicates were pooled, averaged, and kept as the final data.

Statistical analyses

The Eh values obtained over a 10 minutes period were averaged and a treatment average obtained by taking the mean of the three replicates (Michael et al. 2012; 2014). Similarly, treatment average pH and sulfate content were obtained by taking the mean of the three replicates (Michael 2015). To compare the treatment means, significant differences ($p \leq 0.05$) between treatment means of each profile were determined by two-way ANOVA using statistical software JMPIN, AS Institute Inc., SAS Campus Drive, Cary, NC, USA. If an interaction between the treatments and profile depths was found, one-way ANOVA with all combinations was performed using Tukey’s HSD (honest significant difference) and pairwise comparisons. The values shown in all the figures are mean ± s.e. of three replicate measurements. The dotted line is the initial pH. An asterisk indicates significant difference ($p \leq 0.05$) between the treatments and the controls at same depths.

RESULTS AND DISCUSSION

Combined effects of organic matter and plants on pH

The main aim of the experiments was to assess the importance of organic matter addition and the effects of live plants as well as the organic matter turnover on sulfidic soil chemistry (pH, Eh and sulfate content) under falling water regimes, such as during a drought event. The expectation is that under reduced soil conditions as a result of flooding, the sulfidic soil will remain reduced. However, in the planted soils, parenchyma is expected to pump oxygen into the rhizosphere, resulting in oxidation of the oxidizable sulfides, lowering the soil pH. The second aim associated with the live plants was the distribution of the biomass (root) and the effects on sulfidic soil chemistry and whether organic matter addition had influenced the biomass distribution and whether that had an effect on the sulfidic soil chemistry.

The biomass was equally distributed throughout the soil profiles except in the middle, near 5 g, in the soil organic matter was added (Figure 2). Interestingly, presence of plants lowered the alkaline pH to 6 from an initial pH of 6.7, compared to the changes measured in the control soil where no organic matter addition was made. The decrease in soil pH measured showed that the plant with modified anatomical structures capable of pumping oxygen into the rhizosphere did exactly that and the amount was sufficient to oxidize the sulfidic soil, lowering the pH. There was no clear relationship between the biomass distribution and the changes in pH measured. Under the flooded soil condition with organic matter addition, pH was expected to remain higher than the starting pH, however, that was not the case on the surface (Figure 3). A decrease in pH of the surface soil occurred as a result of fluctuation in the amount of water that was ponding on the surface that allowed oxygen to penetrate the surface soil as would be expected due to loss from evaporation (Michael and Reid 2018).

Combined effects of organic matter and plants on redox potential

Under the flooded soil conditions, biomass distribution and soil redox had no clear relationship (Figure 4). In the 20 mm profile of the control, Eh was 168 mV when the lower depths were at -11 and -28 mV, respectively. In the organic matter amended, the soil was moderately reduced, Eh ranged from -18 mV within the surface to -100 mV at depth. These results showed presence of the plant led to oxidation because the soil was expected to remain reduced as a result of anoxia created by flooding as seen in the control soil. The unplanted soil was reduced as deep as expected because of flooding and reduction reactions of the organic matter. Generally, the changes in Eh measured correlated to the changes in pH, indicating that redox influences soil pH. For example, in profiles where changes in pH were the lowest, the Eh values were high and positive, compared to high pH and low and negative Eh values. In profiles where Eh values low and negative, more biomass tended to accumulate. This phenomenon could be an adaptive mechanism for the plant used to deliver more oxygen and oxygenate the rhizosphere so as to keep the roots alive under anoxic conditions. This assertion is true in many plants adapted to living in specific soil and water conditions that use such modifications to survive, e.g. modified parenchymatous tissues in plants adapted to marshlands (hydrophytes) to meet oxygen demand, extensive root systems of plants adapted to deserts (xerophytes) in search of moisture or as a survival mechanism under harsh conditions, such as in acidic soil (tolerant) or high salinity (halophytes).

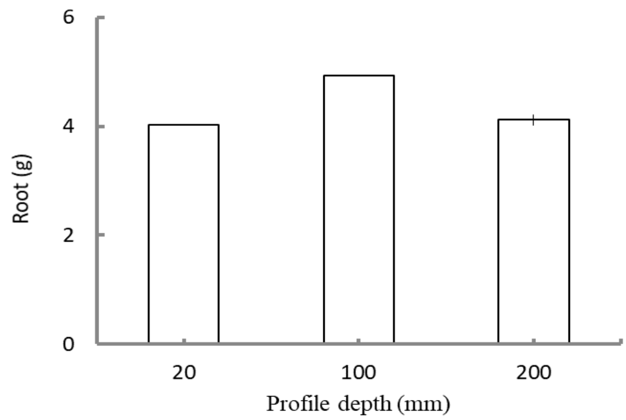

Figure 2. Root biomass distribution in soil amended with organic matter

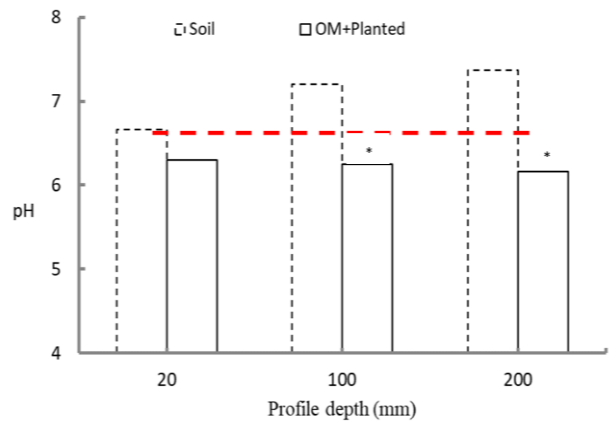

Figure 3. Effects of organic matter with or without live roots on pH

Combined effects of organic matter and plants on sulfate content

In the organic matter amended soils without plants, the sulfate content was significantly reduced to near 3 µmol g^{-1} soil throughout the profiles (Figure 5), compared to the initial sulfate contents, ranging from between 12-16 µmol g^{-1} soil. In the soils organic matter and plants were co-existing, the sulfate content was smaller within the surface and higher at deep soils, ranging from 5.7 to 13.6 µmol g^{-1} soil. As in pH and Eh, no clear relationship between biomass and sulfate content was observed. These results have strongly indicated that in the presence of plants capable of oxygenating the rhizosphere, sulfate reduction is minimal even if labile organic matter is available to soil microbes. The significant reduction in sulfate contents by 9 to 14 µmol g^{-1} soil showed organic matter is an important resource needed by facultative or anaerobic microbes. In most soils, sulfur-reducing bacteria (SRB) operate when the soil redox was reduced to values lower than or closer to -100 mV (e.g. Michael et al. 2015; 2016; 2017). The results shown in Figure 4 shows that the redox, especially in the deep profiles, was reduced to -80 to -100 mV, conducive for SRB to operate. This is a strong point that SRB was responsible for the reduction in sulfate measured. We have reported similar findings in a number of studies (e.g. Michael et al. 2015) and pointed out SRB was responsible, even under aerobic soil conditions with organic matter addition. The results further pointed out how important the slightest change in redox is to sulfate reduction. For instance, in the deep soil, Eh was -28 mV (Figure 4) and the sulfate content remained nearly unchanged at 14 µmol g^{-1} soil from a range of 12-16 µmol g^{-1} soil, regardless of organic matter availability.

Effects of common reed alone on soil pH

The results of study conducted without organic matter addition is shown in Figures 6, 7 and 8. Under the flooded soil conditions, the distribution of biomass was irregular with more roots being found in the middle profile (Figure 6). The biomass distribution was well below 3 g (Figure 6) compared to the biomass data given in Figure 2. These results indicate that organic matter is important for root biomass, or maybe just general plant growth. In both studies, however, more roots were found in the middle soil than the surface or the deep. The main probable reason for this observation is that the plants as much as possible accumulated roots near to the surface where there was sufficient oxygen than at depth where anoxia was quite pronounced. This phenomenon, again, is an adaptive mechanism (aided by the modified anatomical structures) to avoid drowning of the roots and enhance continued respiration to survive under soil condition of limited oxygen. The opposite is true for plants that are used to aerobic soil conditions. Most terrestrial plants do not possess the modified anatomical structures as such as parencymatous tissues; therefore, do not survive long under flooded soil conditions. Roots of plants used to well aerated soils immediately suffocate as soil get flooded, and as anoxia sets in, cellular respiration stops and the root tips slowly die out, resulting in starvation and ultimate death of the whole plant.

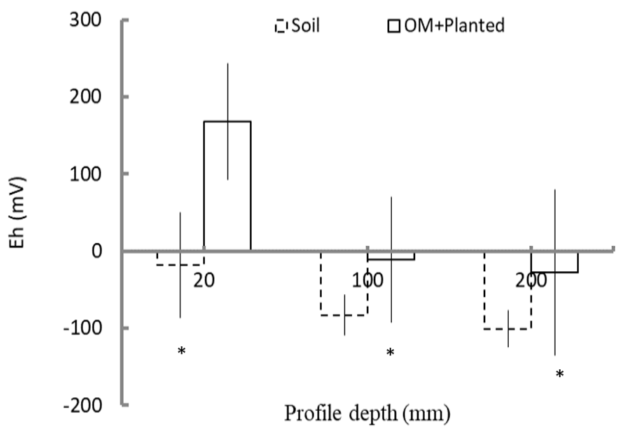

Figure 4. Effects of organic matter with or without live roots on redox potential

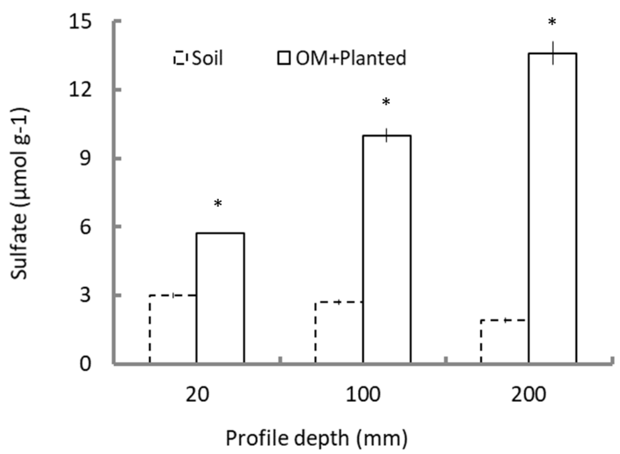

Figure 5. Effects of organic matter with or without live roots on sulfate content

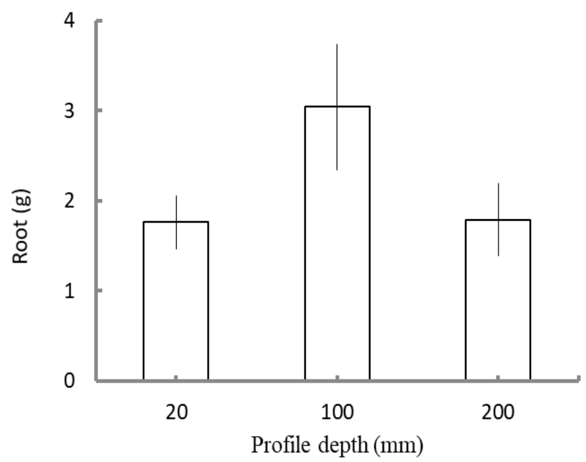

Figure 6. Root biomass distribution without organic matter addition

In the unplanted, the pH remained nearly unchanged with a small decrease within the surface soil as shown in Figure 3. The similarity in the changes in pH in both experiments meant the mechanisms involved in inducing the changes in soil chemistry measured were the same. In the planted soil, the pH significantly decreased to near 5 units, with the highest decrease in the profile of bigger biomass. Unlike the previous experiment (data in Figure 3), in the absence of organic matter higher biomass resulted in significant reduction in pH (Figure 7). For example, 3 g of roots resulted in 1.3 unit decrease in pH. The opposite was true in the surface soil of 1.8 g biomass which resulted in pH decrease by 1.1 unit only. These results strongly demonstrated that in the absence of organic matter, oxygen penetration into the soil through modified anatomical structures results in severe acidification, lowering the pH. Under the continuously flooded soil conditions, the influence of plants on pH was less pronounced in the soil with organic matter, which most likely reflects the dominant role of certain microbes depleting the oxygen transported via parenchyma using the organic matter as energy source. In the absence of added organic matter, the opposite happened. The mechanism underlying the adverse effects of live plants can be related to the processes occurring when dead plant material is either incorporated (Charoenchamratcheep et al. 1987) or distributed as surface mulch (Michael et al. 2017).

Effects of plants alone on redox potential

Plants adapted to growing in water have developed anatomical modifications that provide channels for the exchange of oxygen and carbon dioxide between roots and shoots (Michael 2018a). This study demonstrated that *Phragmites* have the capacity to transport large amounts of oxygen into the rhizosphere and leak some of this oxygen, as evidenced by the high redox values (Michael 2018b). The oxidation phenomenon was more pronounced in the soil without added organic matter (Figure 8). Explanation for this is that the oxygen delivered via the parenchyma to the rhizosphere oxidized the soil, even under flooded soil conditions. In the unplanted soils, redox was highly reduced in the absence of added organic matter, as a result of the anoxia created by the flooding and the reduction reactions that ensured. In our previous studies, organic matter addition in sulfidic soil under various moisture regimes without live plants had similar changes in pH, Eh and sulfate concentrations (e.g. Michael et al. 2015; 2016), confirming that organic matter ameliorates sulfidic soil chemistry even under falling soil moisture regimes (Michael 2018c; 2020c).

Organic matter, especially that with large nitrogen content induces the proliferation of aerobic microbes which consume available oxygen (Michael 2015) and cause the Eh to fall into the range in which SRB can convert sulfate into sulfides (Michael et al. 2015). This phenomenon explains the changes in soil chemistry of the unplanted soils with added organic matter, in addition to a moderate level of residual organic matter (10.6%) already in the soil. The most obvious difference between the control soils and the planted soils was the large difference in Eh. The planted soils with organic matter resulted in high Eh values (168 mV) within the 20 mm profile (Figure 4) compared to the planted soil without organic matter (Figure 8) of 400 mV.

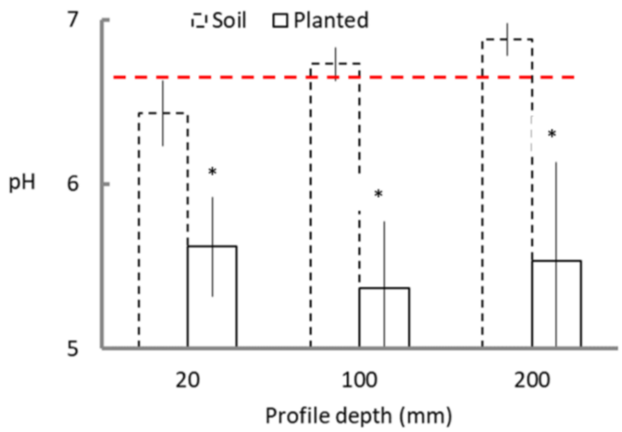

Figure 7. Effects of live roots on pH without added organic matter

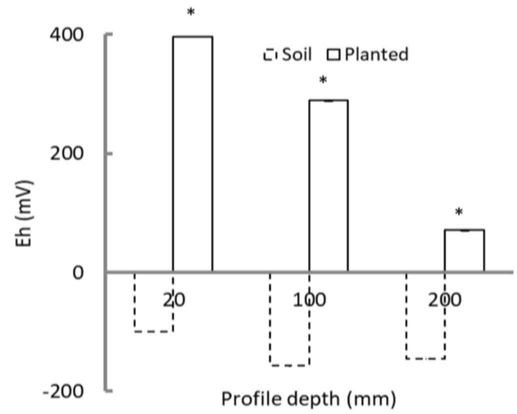

Figure 8. Effects of live roots on redox without added organic matter addition

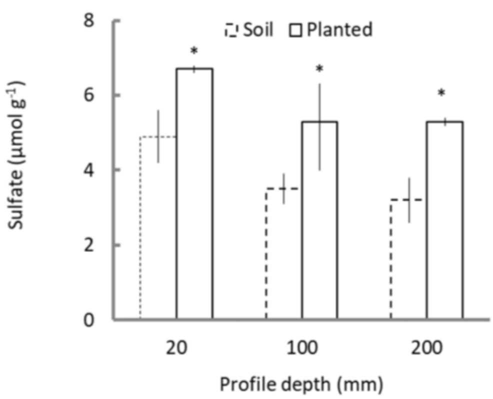

Figure 9. Effects of live roots on sulfate content without added organic matter

Effects of plants alone on sulfate content

The *Phragmites* plants were young with very few senescing leaves and therefore little dead organic matter turnover to the soil. In the planted soils with added organic matter, a high concentration of sulfate was measured at deep (Figure 5), compared to the planted soil without added organic matter (Figure 9). This is a strong indication that soil microbes used the added organic matter to reduce the sulfate to sulfide (Michael 2018c; 2020e). In the control soil of study shown in Figure 9, an estimated 10.6% residual organic matter was present but this was not sufficient to help microbes to reduce the sulfate content compared to the reduction shown in Figure 5 where addition was made. In mature stands of this plant, there is constant turnover of live and dead tissues (Michael 2020a; b; c); hence, the acidifying effects of live plants would be partly offset. These studies however demonstrated this plant even co-existing with organic matter causes oxidation even under flooded soil (Michael 2020d; e). The opposite is true; existence of organic matter alone would sustain sulfidic soil alkalinity (Michael 2020d; e).

The management implications revolve around the balance between live and dead plant material turnover under falling soil moisture regimes (Aipa and Michael 2019; Michael and Reid 2018). For example, growing of live *P. australis* plants in or on the edge of water bodies can be problematic, especially if the surface and groundwater levels of such wetland areas decrease during drought conditions (an anticipated event of a change in climate), which will accelerate pyrite oxidation and the formation of deep sulfuric soils (Simpson et al. 2010). If the acidified areas are adjacent to major river systems and are reflooded, metal and metalloid contaminants can be released from the sulfuric soils and can pose risks to the public and environment (Michael 2013; Reid and Butcher 2011).

Under normal soil use and management conditions, organic matter addition as mulch or as turnover from leaf litter and organic compound secretion (even under falling moisture regimes) would enable soil microbes to act on these different substrates and consume acidity generated via Eqn. 2, generating alkalinity (e.g. Michael et al. 2015; 2016; 2017). This will create microenvironments conducive to lower Eh, sulfate content and increase the pH, important for management of sulfidic soil alkalinity (pH>4), during extreme climatic events (Michael 2019a). Presence of plants will accelerate the fall in soil moisture because of water use in photosynthetic reactions (Michael 2019b), therefore, under such conditions, the plants need to be mowed to the ground and the shoot systems (aboveground biomass) removed. In the absence of the shoot systems, the remaining root systems (underground biomass) will use the culm to draw atmospheric oxygen into the soil and continue to oxidize the sulfidic materials. This management issue will most likely be addressed by reworking the land, e.g. plowing, and getting the exposed ends of the culms covered by soil to prevent oxygen penetration (Michael and Reid 2016).

In contrast to the positive effects on sulfidic soil of organic mulches derived from dead plant material, turnover of organic matter as leaf litter or secretion of organic compounds from live plants, the growth of live plants with roots capable of transporting oxygen downwards via aerenchymatous tissue induces acidity. Organic matter addition gave rise to more biomass, resulting in more oxygen in the rhizosphere. Under excess moisture regime, in other words, flooded soil condition, an important management option would be to slash but would lead to deoxygenation. The culms would continue to transport oxygen into the soil if the slashed ends remain open and were not covered. Under falling moisture regimes, decomposition of the slashed plant matter on the surface would lead to offsetting of oxidation and generation of sulfuric acidity.

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