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Closing yield gap of maize in Southeast Asia by intercropping systems: A review

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Abstract

Maize (*Zea may* L.) is a cereal crop grown extensively throughout Southeast Asia, particularly in Thailand, Indonesia, Vietnam, and the Philippines. However, maize yield in this region varies yearly due to several factors such as soil infertility, poor management practices, unpredictable weather conditions, and geography. This review aims (i) to demonstrate constraints and mitigation strategies for closing yield gaps and optimizing land use efficiency through the integration of companion crops into maize cropping, based on existing research in Southeast Asia between 1980 and 2021, and (ii) to discuss the benefits and drawbacks of growing maize alongside with other companion crops in Southeast Asia. Based on existing 50 articles of maize-based intercropping conducted in Southeast Asia founded from Google Scholar, Scopus and Web of science, cassava, legumes, potato, rice, grasses, and perennial crops such as rubber and coconut are the most frequently grown as companion crops in this region. Much emphasis of maize-based intercropping is paid to erosion control. Intercropping maize with other crops can successfully minimize soil erosion, runoff, and maintain the topsoil fertility. Therefore, less fertilizer input is required in intercropping system, which can also have a positive influence on the off-site environment. In addition, we discovered that maize-based intercropping improves the Land Equivalent Ratio (LER) (LER > 1) when planting time, crop spacing, and management practices are appropriately implemented. On the other hand, there are just a few studies that indicate the restrictions associated with maize-based intercropping (LER < 1). While it is theoretically beneficial to grow maize alongside with legumes due to biological nitrogen fixation, research undertaken in this region has not confirmed this statement when maize is intercropped with rice bean. Although, maize-based intercropping in Southeast Asia had been more thoroughly investigated in a variety of ways, further research is still needed to determine how maize-based intercropping mitigates the impact of climate change.

Keywords: Crop diversity, soil erosion, soil fertility, upland maize.
Abbreviation: LER_Land Equivalent Ratio.

Introduction

Maize is a major grain crop grown in Southeast Asia, particularly in Thailand, Indonesia, Vietnam, and the Philippines (Fig. 1). Maize has historically been farmed largely as a food crop in Southeast Asia. Recently, maize usage as a food crop has decreased while demand for feed crops has soared. The high demand for protein and the quick expansion in meat and poultry consumption have led in a rapid increase in the demand for maize as a livestock feedstuff (Dong et al., 2015). It is anticipated that maize demand in East and Southeast Asia will be increase to 291 million tons in a 10-year time (Rosegrant et al., 2001). To increase food security and to reduce competition for land with other food crops, additional maize production should largely come from the sustainable intensification of existing farmlands to improve yield per unit area and minimize negative impacts on the environment (Pretty, 2008; Tilman et al., 2011). Much attention has been given recently to intensification prospects from closing yield gaps (Lobell et al., 2010; Grassini and Cassman, 2012). Since the past decade, the maize yield has been improving over time in this region due to improvement of hybrid maize technology that allows maize to be grown in a wide range of environment and utilize resources more efficiently. Nevertheless, a large yield gap also was found between Thailand, Indonesia, Vietnam, and the Philippines. The average yield of maize in Southeast Asia reported by FAOSTAT (2019) indicated that maize production in this region is still having a big yield gap, where yield of maize in these majors four countries ranged from 3 to 5.5 Mg per ha in 2017 (Fig. 2). Therefore, numerous aspects should be considered to understand the reason of variation in maize yield, including biotic and abiotic stresses.

Diverse maize agro-ecologies may indicate more favorable environmental conditions such as soil, topography, irrigation, drainage, rainfall, and other climatic variables (Gerpacio and Pingali, 2007). Proper farmer management practices would be the most beneficial strategy to boost maize yield productivity. Altering cropping dates and patterns may be an alternative for mitigating the influence of climate variance, namely rainfall (Gerpacio and Pingali, 2007; Khongdee et al., 2021, 2022). Another option is integration of companion crops to maize cropping as intercropping systems. Intercropping is an old age practice of mixed cropping and defined the agricultural practice of cultivating two or more crops in the same farmland at the same time (Seran and Brintha, 2010; Yin et al., 2020). Intercropping has been a regular practice by the farmers of India, Africa, Sri Lanka, China, and Malaysia. Intercropping is mainly practiced to reduce the risk of failure of one of the components crops due to variability of weather or pest and disease incidence. The yield advantages of intercropping systems are mostly due to the varied usage of growing resources by crops. When the growth patterns of component crops diverge in time, complementarity occurs (Searle et al., 1981; Yin et al., 2020). In most of intercropping system in tropical regions, maize is considered as one of the best component (John and Mini, 2005).

To better understand the mechanisms by which maize, companion crops, soil, environment, climatic conditions, and management all work together to produce a sustainable maize crop, researchers have investigated a variety of components of maize-based intercropping systems. This review paper aims to (i) demonstrate constraints of sole maize cropping and mitigation options in closing yield gaps and efficient use of land by the integration of companion crops into maize cropping based on research carried out in Southeast Asia and (ii) to discuss benefits and limitations of growing maize together with other companion crops and find out the most suitable practice to increase sustainability of maize growing in Southeast Asia.

Maize situation in Southeast Asia

Maize is one of the most versatile emerging crops having wider adaptability under large agro-climatic conditions. Maize normally grows at latitudes ranging from the equator to slightly above 50^{o} North and 50^{o} South under temperate and tropical climates. Southeast Asia is located between 25^{o}N and 10^{o}S, where close to the equator and is defined as a tropical region. In Southeast Asia, maize can be grown on the flatlands and plains of Indonesia and Vietnam, as well as in the upland and hillside (up to 2,500 meters above mean sea level (m.m.s.l)) in the Philippines, and Thailand. Maize is being grown in a wide range of environments, from extreme semi-arid to sub-humid and humid regions, as well as in the low and mid-hills of the western and northeastern regions (Gerpacio and Pingali, 2007). In most tropical environments, maize requires 600 – 700 mm of rainfall with well distribution over growing periods (Du Plessis, 2003). As shown in Fig. 3, farmers in Southeast Asia who are partially or completely dependent on rainfall must adjust their cropping calendars for each growing season to capitalize on moisture when precipitation is sufficient to meet crop water requirements. In the tropical rainfed areas of Indonesia, the Philippines, and Thailand, rice is typically planted on flatland during the rainy season, followed by maize. However, maize is often cultivated during the rainy season in rainfed highland areas. If extreme weather occurs, maize can be harmed by dry periods and high temperatures during critical growth phases (Khongdee et al., 2022). In tropical maize environments, high mean air temperature is about 28^{o}C with maximum and minimum temperature about 32^{o}C and 22^{o}C, respectively. Generally, temperature variation during the maize cropping season does not critically affect the maize crop compared to rainfall variation (Gerpacio and Pingali, 2007).

Since breeding technology has been developed continuously, hybrid varieties of maize provide more yield than local/traditional varieties, with both of those rainfed lowlands and rainfed upland maize productions. Across production environments, hybrid maize yields have been increasing continuously from 1990 to 2017 (Fig. 2a). Thailand maize yield ranged from 1.7 Mg ha^{-1} to 4.8 Mg ha^{-1} while maize yield in Indonesia and Vietnam have been increasing in a similar trend and have been maximized below 5 Mg ha^{-1}. Nevertheless, hybrid maize yield of the Philippines per unit area always had received lower than those with a maximum yield of about 3 Mg ha^{-1} from 1990 to 2017. In contrast, yields of local/traditional maize varieties ranged from a low of 0.9 Mg ha^{-1} to 3 Mg ha^{-1} in rainfed lowland in Southeast Asia (Gerpacio and Pingali, 2007). Fig. 2(a) shows that maize yield in Thailand seemed to achieve higher than those countries in the beginning. However, the yield improvement was lower than those countries. Yield index of maize in Fig. 2(b) also indicated that maize yield of four major maize producing countries in Southeast Asia have been increased continuously from 1991 to 2017. Maize yield in the Philippines has steeply improved approximately up to 200 %, while maize yield in Thailand has slightly been improved only about 50% over 17 years. At the same time, maize yield in Indonesia and Vietnam have been increased similarly up to 150 %.

In all surveyed reported by Gerpacio and Pingali (2007), several reasons for increasing yield gap by farmers are reported. The first and most popular problems are weather conditions with erratic and unpredictable condition that affects negatively to maize growth and yield in all maize producing areas. For example, the Philippines is in the tropics and consists of many islands. Tropical storms often occur in the area and can easily damage THE maize crops. Moreover, weather extremes i.e. heavy rain (flood), drought, and extreme low and high temperature during a sensitive period of maize adversely affect maize productivity (Mi et al., 2018). One of the big issues that broaden yield gaps in upland maize producing countries is soil degradation, affecting 1966 million hectares worldwide (Lal, 2007). Lal (1998) estimated average soil erosion in tropical countries at 200 – 1000 Mg km^{-2} year^{-1} depending on slope gradient and rainfall characteristics. Erosion adversely declines soil fertility and the continued loss of fertile topsoil i.e. hillside maize production of Thailand and Vietnam (Pansak et al., 2008;

Tuan et al., 2014) as probable causes of maize yield gaps in Asia. Other causes are pest incidence and poor management practices (Gerpacio and Pingali, 2007; Khan et al., 2020).

Is maize-based intercropping a strategy for closing maize yield gap in Southeast Asia?

Maize – based intercropping systems have been widely practiced for smallholder farmers in many developing countries (Tsubo et al., 2003). Benefits of this practice seem to be outweighed constraints as proved by several studies around the world. Table 1 demonstrates benefits and constraints of maize – based intercropping systems.

Yield advantage of intercropping systems could be indicated by various methods. LER is the most common method used to evaluate the efficiency of intercropping and yield per unit area as compared to monocropping system. LER greater than 1 indicates a beneficial effect of intercropping in the same unit area compared to monocropping, while LER less than 1 indicates that intercropping has less beneficial effect than monocropping systems. In Southeast Asia, maize intercropping occurs with many companion crops e.g. leguminous crops, potato, rice, and cassava (Table 2).

In Thailand, Polthanee and Trelo-ges (2004) carried out a research on maize intercropping systems with various leguminous crops including peanut, soybeans, and mungbeans. They reported that LER of maize intercropped with peanut, soybean, and mungbeans was 1.66, 1.60, and 1.48, respectively. Moreover, Devkotat and Rerkasem (2000) reported LER rane of 1.2 to 1.6 in maize intercropped with lablab beans in different spacings. Therefore, the beneficial effects of maize intercropping were better than growing maize monoculture.

In Indonesia, several studies have been working on maize-based intercropping systems. Hamdani and Suradinata (2015) found that maize-potato intercropping was more profitable than maize monoculture, in which LER was about 1.2 – 1.6. Wargiono et al. (2000) studied various maize intercropping systems with varieties of companion crops including cassava, rice, and peanut. This research indicated that LER of intercropping treatment ranged from 1.6 and up to 2.1. Similarly, Islami et al. (2011) researched maize-cassava intercropping. The result showed that LER of maize intercropped with cassava was above 1 (1.28-1.59). Another study about maize – soybean intercropping system conducted by Syafruddin (2017) and LER of maize intercropped with soybean was also higher than 1 (1.35-1.70).

Only a few studies on the LER of maize-based intercropping have been undertaken in the Philippines. A study was conducted on the benefits of maize intercropping with potato. The results indicated that LER values ranged between 0.99 and 1.25. Intercropping systems provided benefits comparable to monocropping or slightly greater than monocropping (Batugal et al., 1990).

There are few effective studies of maize-based intercropping in Vietnam for increasing LER. Maize intercropping with grass had an LER value less than 1, indicating that maize intercropping had no benefit in terms of enhancing yield productivity (Tuan et al., 2014). Furthermore, maize intercropped with rice beans and maize intercropped with cassava both has an LER value of one. Intercropping can effectively reduce soil erosion (Tuan et al., 2014; Boll et al., 2008).

Mechanisms and effects of maize-based intercropping in Southeast Asia

Intercropping has been regularly used by farmers in many parts of the world for the last century. Numerous studies have been undertaken on intercropping systems of various commercial crops to determine their benefits and drawbacks, particularly in Asian countries such as India, Pakistan, and China, but less so in Southeast Asia. Numerous studies on intercropping systems in various areas have also been undertaken in Southeast Asia. The primary focus of this review is on maize-based intercropping in four key maize-producing countries in Southeast Asia, namely Indonesia, Thailand, Vietnam, and the Philippines.

Maize–based intercropping in Indonesia

Indonesia is located between the latitudes of 11°S and 6°N, and the majority of the country is made up of islands. Indonesia has a tropical climate with year-round high temperatures and humidity, a rainy and dry season. Due to the diversity in topography and size of these islands, regional climate fluctuation occurs. Due to its proximity to the equator, Indonesia experiences little seasonal change in temperature. The wet season is only around 1°C higher than the dry season. As a tropical country, rainfall is expected throughout the year. However, the wet season typically sees a significant increase in rainfall. As a result, maize is a significant crop to cultivate in this country at any time of the year due to the year-round availability of water. However, while maize does not require a lot of water during the growth season, it must adapt to receive a lot of water in order to increase yield and land productivity.

Numerous researches have been conducted in this region using maize intercropping systems. Several crops, including cassava, potato, rice, peanut, soybean, cowpea, coconut, and grasses, were considered for co-culture with maize. Hamdani and Suradinata (2015) investigated the influence of maize and potato row intercropping systems on growth and yield. The results indicate that potatoes grown in a 1:1 arrangement (one row of maize) have a greater height and leaf area than those grown in a 1:2 arrangement (two rows of maize), but their dry mass output and chlorophyll content are lower. The 50 cm row spacing method within maize plants boosted the dry mass and production of potatoes, but not the LER value. Syafruddin (2017) investigated intercropping maize and soybeans with double row plant spacing. Intercropping maize and soybeans with double rows of plants resulted in a greater grain production and LER than monoculture. On the other hand, there was no significant difference in height, leaf area index, or leaf chlorophyll between maize monoculture and maize intercropping with soybean ($P>0.05$). Maize – soybean intercropping performed best with double rows of plants spacing 40-110 x 20 cm and 50-100 × 20 cm intercropping two rows of soybean. Both of these spacing strategies resulted in the highest levels of productivity and profitability. Moreover, there is a research working on maize intercropped with tree species. Braconnier (1998) examined intercropping systems of maize and coconut. The research established that shade and root competition had an influence on maize growth and yield. Shade has a negative effect on maize growth and production. Intercropping maize with coconut trees had no influence on maize yield when maize was planted at a light transmission ratio of greater than 70%.

Table 1. Benefits and uncertainties of intercropping systems.

Benefits	References
Allows more than one harvest per year (e.g. with relay intercropping)	Amanullah et al. (2016)
Diversification of crops for market supply	Gebru (2015); Seran and Brintha, (2010)
Reducing risks of crop failure	Gebru, (2015); Khongdee et al., (2021); Seran and Brintha (2010)
Higher yield, improved resource efficiency, maximized land use	Seran and Brintha (2010); Knörzer et al. (2009)
Boosting the soil nitrogen content in medium to long term especially when legumes are involved	Regehr et al. (2015)
Soil structure may improve if plants with various root structures are grown	Seran and Brintha (2010)
Improving soil erosion control	Pansak et al. (2010); Tuan et al. (2014)
Weed, pest and disease control	Hamdollah Eskandari (2012)
Uncertainties	References
Limited possibilities for production mechanization	Knörzer et al. (2009)
Harvesting produce more difficult	Knörzer et al. (2009)
Higher management demand	Knörzer et al. (2009)
No extensive production of stable or cash crops	Knörzer et al. (2009)
A poorly chosen intercrop competes with main crop	Knörzer et al. (2009)
Intercropping may not significantly improve the soil nitrogen levels	Knörzer et al. (2009)
Herbicide use may be constrained	Knörzer et al. (2009)

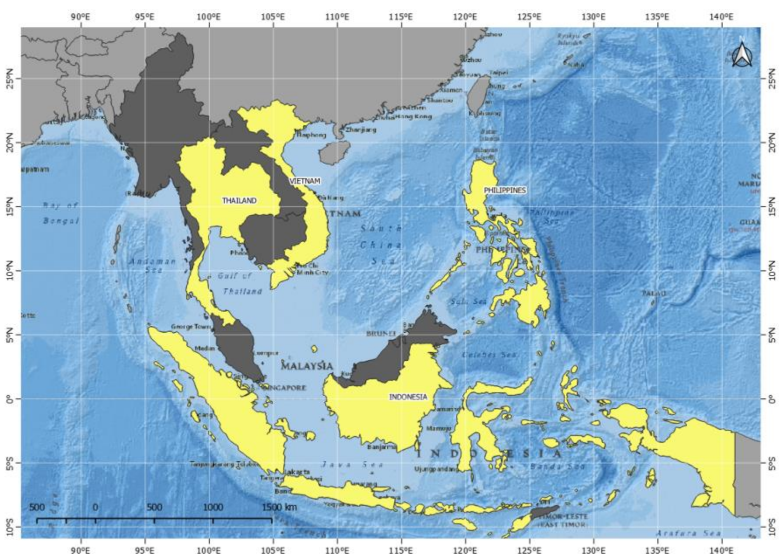

Figure 1 Map of major maize production countries of Southeast Asia.

Table 2. Overview over experiments and main researches dealing with maize-based intercropping in Southeast Asia.

Systems	Regions	LER	References
Maize-peanut	Thailand	1.66	Polthanee and Trelo-ges (2004)
Maize-soybean	Thailand	1.60	Polthanee and Trelo-ges (2004)
Maize-mungbeans	Thailand	1.48	Polthanee and Trelo-ges (2004)
Maize-lablab bean	Thailand	1.2-1.6	Devkotat and Rerkasem (2000)
Maize-potato	Indonesia	1.2-1.6	Hamdani and Suradinata (2015)
Maize-cassava-rice-peanut	Indonesia	1.6-2.1	Wargiono et al. (2000)
Maize-soybean	Indonesia	1.35-1.70	Syafruddin (2017)
Maize-cassava	Indonesia	1.28-1.59	Islami et al. (2011)
Maize-potato	Philippines	0.99-1.25	Batugal et al. (1990)
Maize-grass	Vietnam	<1	Tuan et al. (2014)
Maize-rice bean	Vietnam	1	Tuan et al. (2014)
Maize-cassava	Vietnam	1	Boll et al. (2008)

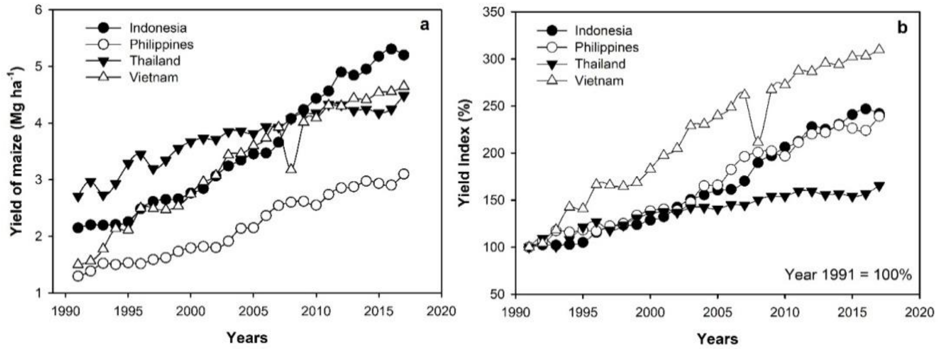

Figure 2. Yield and yield index of maize (1991–2017) of selected countries in Southeast Asia.

Table 3. Yield evaluation by unit area**:** Land Equivalent Ratio of maize intercropping.

Systems	Regions	Main research	References
Maize-Potato	Indonesia	Effect of row intercropping system of maize and potato on growth and yield	Hamdani and Suradinata (2015)
Maize-cassava-rice-peanut	Indonesia	Effect of rainfall distribution on yield of cassava clones	Wargiono (1991)
Maize-soybean	Indonesia	Maize-soybean intercropping in double row plant spacing	Syafruddin (2017)
Maize-cassava-rice/soybean/cowpea	Indonesia	Cassava-based intercropping systems on Sumatra island in Indonesia: productivity, soil erosion, and rooting zone	Iijima et al. (2004)
Maize-coconut	Indonesia	Maize-coconut intercropping: effects of shade and root competition on maize growth and yield	Braconnier (1998)
Maize-cassava	Indonesia	Maize yield and associated soil quality changes in cassava + maize intercropping system after 3 years of biochar application	Islami et al. (2011)
Maize-cowpea/peanut	Indonesia	Weed communities on monoculture and intercropping cultivation techniques	Widaryanto (2017)
Maize-grasses	Indonesia	Different tillage and maize grass intercropping on root systems, growth and yield of rainfed maize	Ahadiyat and Ranamukhaarachchi (2011)
Maize-cassava	Thailand	Reducing soil erosion in cassava production systems	Vongkasem et al. (2001)
Maize-lablab bean	Thailand	Effects of cutting on the nitrogen economy and dry matter yield of lablab grown under monoculture and intercropped with maize	Devkotat and Rerkasem (2000)
Maize-peanut/soybean/mungbean	Thailand	Growth, yield and land use efficiency of corn and legumes grown under intercropping systems	Polthanee and Trelo-ges (2004)
Maize-lablab bean/Rice bean/Cowpea/Mungbean	Thailand	Intercropping maize with legumes for sustainable highland maize production	Punyalue et al. (2018)
Maize-lablab bean/Rice bean/Cowpea/Mungbean	Thailand	Legume intercropping to reduce erosion, increase soil fertility and grain yield, and stop burning in highland maize production in northern Thailand	Punyalue et al. (2018)
Maize-rice bean	Thailand	Measurement of N_2 fixation in maize – rice bean intercrops	Rerkasem et al. (1988)
Maize-rice bean	Thailand	Yields and nitrogen nutrition of intercropped maize and rice bean	Rerkasem and Rerkasem (1988)
Maize-Jack bean/Vetiver grass/Ruzi grass	Thailand	Changes in the relationship between soil erosion and N loss pathways after establishing soil conservation systems in uplands of Northeast Thailand	Pansak et al. (2008)
Maize-Para rubber	Thailand	Effect of rubber intercropping on plant nutrients and soil moisture on slop land of northern Thailand	Khongdee and Pansak (2015)
Maize-cassava	Vietnam	Spatial Variability in Maize Productivity in Uplands of Northwest Vietnam	Boll et al. (2008)
Maize-rice bean	Vietnam	Mitigation potential of soil conservation in maize cropping on steep slopes	Tuan et al. (2014)
Maize-potato	Philippines	Intercropping potato with maize in lowland Philippines	Batugal et al. (1990)
Maize-trees	Philippines	Maize production under an intercropping system with fast-growing tree species	Sato and Dalmacio, (1991)
Maize-legumes	Philippines	A cost-benefit analysis of hedgerow intercropping in the Philippine uplands using the SCUAF model	Nelson et al. (1996)
Maize-grass	Philippines	Cost-benefit analysis of alternative forms of hedgerow intercropping in the Philippine uplands.	Nelson et al. (1998)
Maize-timber tree	Philippines	Growth and yield of maize and timber trees in smallholder agroforestry systems in Claveria, northern Mindanao, Philippines	Bertomeu (2012)

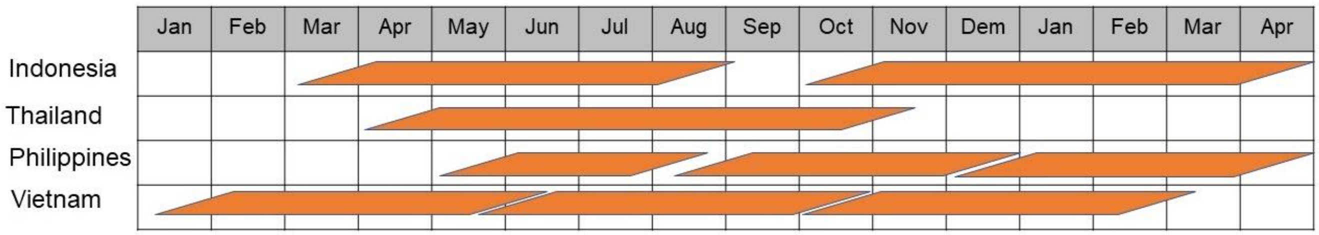

Figure 3. Major cropping calendars of maize in major maize production countries (Indonesia, Thailand, Philippines, and Vietnam) in Southeast Asia.

Another objective of maize-based intercropping research in Indonesia is to mitigate soil erosion. Iijima et al. (2004) investigated the productivity, soil erosion, and rooting zone of cassava-maize-rice-cowpea intercropping systems. These findings suggested that intercropping maize and cassava would be the most helpful in terms of economics (yield) and soil erosion control. Islami et al. (2011) also assessed the maize and cassava intercropping system in relation to maize yield and soil quality three years after applying biochar. Biochar increased soil quality, maize and cassava yields, and land use efficiency. Maize intercropped with cassava and treated with biochar had the highest LER. Ahadiyat and Ranamukhaarachchi (2011) conducted research on intercropping systems of maize and grasses. The study examined the impacts of tillage and intercropping with grass during the rainy seasons, as well as their effect on the root systems, plant growth, and yield of rainfed maize during the dry seasons. The following season's root depth and total root length were found to be unaffected by preceding intercropping. Prior to deep tillage, root dry weight and dry biomass were larger in intercropped maize lemon grass and maize elephant grass than in monocrop. The prior tillage methods and intercropping had no discernible influence on yield. This study concluded that intercropping maize with lemon grasses may be done without impairing following maize yields during the dry season. Furthermore, as Widaryanto (2017) observed, maize-based intercropping has a positive effect on weed control. The study examined weed communities on maize monocultures and maize intercropping strategies incorporating cowpea and peanut farming. The benefits of maize intercropping were discovered to be that weed control may be accomplished ecologically by intercropping maize and cowpea, which indirectly inhibited weed growth, broadleaf weeds, riddle weeds, and narrow leaf weeds, as well as decreased total dry weight of weeds.

Maize – based intercropping in Thailand

Thailand is located between latitudes 6^{o}N and 21^{o}N. Both the summer and winter monsoons have their own effects on the country. Thailand's climate is divided into six months of rain during the rainy season, including three months of dry and cool weather during the cool season, and three months of heat during the hot season. Temperature fluctuates between 18°C and 38°C. Temperatures have risen and rainfall has gotten more variable year after year. These variable weather conditions have a negative impact on the rainfed maize crop.

Numerous studies have been conducted in Thailand to address the issue of maize-based intercropping systems. As the majority of Thailand's maize production area is upland or hillside, soil and water conservation are the primary concerns. Pansak et al. (2008) investigated the association between maize intercropping and soil and nitrogen losses in upland maize of Northeast Thailand. They used maize-jack bean hedgerows or a ruzi grass barrier with vetiver grass to prevent soil erosion and nitrogen loss. Using jack bean as a contour hedgerows had a positive impact in reducing runoff (~25%) and soil loss (~50%), particularly during the initial stages of maize cropping. When contour hedgerows are used together with soil conservation strategies such as low tillage and mulching, hedgerows play a less significant role in reducing soil loss. Due to resources competition, maize yield in intercropping systems were lower than maize sole cropping. Punyalue et al. (2018) conducted a research in highland of Northern Thailand on maize-legume intercropping to reduce erosion, boost soil fertility and grain output, and eliminate burning in highland maize farming. This study revealed how soil and nitrogen loss due to erosion can be efficiently decreased in highland maize cultivation in Northern Thailand by intercropping maize with lablab bean. In the highlands of Northern Thailand, intercropping maize with legumes enhanced maize grain output over time and reduced soil erosion, while avoiding the need to burn crop residue and its associated adverse smog effects. Additionally, the increased harvest of legume grain may offer farmers with an immediate economic benefit. Khamkajorn et al. (2014) also conducted research on conservation agriculture using para rubber – maize intercropping to mitigate erosion in the upland of lower north of Thailand. Intercropped para rubber and maize can help prevent soil erosion and runoff. However, the farmer may plant maize alongside para rubber until the para rubber is around 5 years old. Additionally, Khongdee and Pansak (2015) conducted a study in the lower north of Thailand on the same trial of Para rubber intercropped with maize. This research examined the effect of intercropping Para rubber on plant nutrients and soil moisture. Soil nutrient availability and soil moisture were not limited during intercrop period; therefore, growth of both crops was similarly with sole cropping. These two crops can be planted in together to boost land productivity and prevent soil erosion until para rubber reaches a maturity of 5-6 years. In Thailand, leguminous crop has mostly been intercropped with maize. Polthanee and Trelo-ges, (2004) investigated the growth, yield, and land use efficiency of maize and legumes cultivated under intercropping systems. This research involved intercropping maize with peanut, soybean, and mungbeans. Intercropping lowered grain yields by 28%, 39%, and 51% in peanut, soybean, and mungbeans, respectively, when compared to monocropping, owing primarily to the reduced number of pods per plant. The number of pods per plant was reduced by 46%, 57%, and 58%

in peanut, soybean, and mungbeans, respectively. According to land use efficiency, intercropping maize and legumes resulted in LER of between 1.48 and 1.66. According to LER, monocropping systems require approximately 48 to 66% more area to grow the same quantity of maize and legumes as intercropping systems. Additionally, the data reveal that peanuts are the most shade-tolerant crops, followed by mungbeans and soybeans. Punyalue et al. (2018) conducted study on maize intercropped with legumes for highland maize production sustainability. This study describes two experiments: (I) a field experiment evaluating maize intercropped with rice bean, cowpea, lablab, and mungbeans as an alternative to maize cultivation with residue burning, as well as the effect of intercropping on soil biodiversity; and (II) a participatory experiment comparing the performance of maize intercropped with rice bean to maize sown after residue burning grown by the same farmers. The findings indicate that maize intercropped with legumes can serve as a model for processes that contribute to the sustainability of maize production in the highlands. Intercrops of maize and legumes can boost nitrogen buildup through biological nitrogen fixation. Soil biodiversity was also increased, with a positive link between soil fauna diversity and richness and residue biomass and nitrogen concentration. Increased nitrogen supply resulted in the accumulation of crop residue, which preserved the soil surface, controlled weeds, and allowed maize to be seeded without burning the field. Rerkasem et al. (1988) conducted study on N_2 fixation in maize–rice bean intercrops. The concept that intercropping a legume with a non-legume crop increases the legume's ability to fix nitrogen was tested in rice bean and maize planting systems. Rice beans cultivated in a 75:25 maize:rice bean intercrop were capable of nitrogen fixation comparable to that of the monocrop.

For the current research on maize-based intercropping in Thailand, Khongdee et al. (2021) evaluated the effect of maize – mungbean relay cropping on mitigating climate variability. Compared to maize sole cropping, maize-mungbean relay cropping boosted maize nitrogen uptake, decreased soil temperature, and contributed to a greater yield under conditions of high temperature and drought. However, the resources competition i.e. light was found during intercropped period.

Maize – based intercropping in the Philippines

The Philippines is located in a tropical climate (5^{o}N – 18^{o}N of latitudes) that is normally hot and humid year-round. It can be roughly divided into a dry season between November and May, and a wet season between June and October. In recent years, summers have been extending into June and July due to climate changes. Average annual temperatures of 26°C are experienced across the country, with May being the hottest month of the year in the Philippines. Figure 3 reveals that farmers in the Philippines normally grow maize 2 – 3 times a year starting from May each year. The yield of maize in this region always was lower than other countries in Southeast Asia with the average maize yield of the whole country was only 3 Mg ha^{-1} in 2017 (Fig. 2). Many attempts have been done to improve maize yield productivity in the Philippines including maize – based intercropping systems.

The hedgerow intercropping with shrub legumes has been the most common form of the technology promoted to upland farmers in the Philippines. Nelson et al. (1996) and Nelson et al. (1998) studied the costs and benefit of leguminous and grass hedgerow intercropping in the Philippines upland maize cropping using SCUAF models. It is predicted that maize yield of monocrop will be higher when hedgerows are being established in first 2 years, then maize yield will be declined continuously, even lower than hedgerows maize intercropping about 40 % after 10 years. The pattern of maize yield decline can be described by the erosion rates that associated in declining soil quality. Hedgerow intercropping has potential to sustain maize yields by reducing erosion, but the costs of establishment are a major disincentive for adoption in the short term. However, natural vegetation and grass strips such as hedgerow intercropping are more attractive to farmers than shrub legumes because of reduced establishment and maintenance costs (Nelson and Cramb, 1998). Moreover, Bertomeu (2012) carried out research on growth and yield of maize and timber trees in smallholder agroforestry systems in Claveria, northern Mindanao, Philippines. In the tree hedgerow treatment after two cropping, yield of maize was significantly reduced as compared to maize monocrop. In this case, canopy width can be better indexed of tree competitiveness, light resource is more captured by tree canopy than available to maize. This research reveals that intercropping tree with maize at wider space (planted at 10 m or more) is more profitable and feasible to smallholders' farmers than maize monoculture. In lowland, Batugal et al. (1990) conducted research on intercropping maize with potato in lowland area of Philippines. Yield of maize intercropping was greatest when maize was planted two weeks after potato. However, maize planted 2 weeks before potato showed 35 % lower yield than growing after potato. Economic aspects suggest that potato is a 90 day-crop and maize is a 120 days crop. This work recommended that maize could be harvested about 90 days as fresh material for better land use efficiency and net returns.

Maize – based intercropping in Vietnam

Maize is cultivated in diverse environments being as a source of feed for the livestock industry. Vietnam is located between 8^{o}N – 23^{o}N of latitudes. Due to the differences in latitudes and the variety in topography within the country, the climate tends to vary considerably for each region. In the south of Vietnam, maize has been planted on around 0.3 million ha under rainfed conditions (Giang et al., 2015). However, the average of the national yield is only 4 Mg ha^{-1} which is pretty far below from the potential yield of commercial maize hybrids. The yield of commercial maize hybrids grown in the south of Vietnam was approximately 8 Mg ha^{-1} (Giang et al., 2015).

Since mid-1990s, maize production area of Northwest Vietnam has strongly increased mainly by expanding maize area into steep slope area. This often results in severe erosion, soil degradation, and declining crop productivity. Tuan et al. (2014) studied mitigation potential of soil conservation in maize cropping on steep slopes of Vietnam. Grass (*Panicum maximum*) barrier controlled effectively for soil loss but yield of maize decreased significantly (26% reduction) as compared to maize monoculture due to competition for cropping area. However, grass can be used as fodder for ruminant animals. The combined effect of minimum tillage with maize relay cropped with rice bean was the most effective practice that can reduce soil loss and provide the same maize yield performance with farmers' practice. Boll et al. (2008) also studied maize productivity in uplands of Northwest Vietnam. Maize intercropped with cassava was assessed for maize yield productivity and erosion control. Comparing long-term cropping history with young cropping history of maize monocrop resulted in severe declining of top soil fertile. Maize field of young cropping history has still higher potential than old cropping history for obtaining good maize yields as soil parameters are still suitable. However, integration of cassava with long-term cropping history of maize as intercropping system could mitigate soil erosion, and increase yield potential of maize in long-term cropping field.

Conclusion

Maize as feedstuff is highly demanded in Southeast Asia, due to rising demand in protein source for human consumption and highly development of poultry and meat industries. However, maize yield in this region has still not reached to the maximized yield potential for hybrid maize. Maize growing potential of each major maize production countries in this region including Indonesia, Thailand, the Philippines, and Vietnam are still having large differences due to the differences of geography, climate, agro-ecology, and farmers' practices. Closing yield gaps by maize intercropping systems for maximizing use of land and minimizing use of resources are interesting until nowadays. Many attempts have tried to demonstrate benefits and constraints of maize – based intercropping systems in this region. Most common companion crops in this region are cassava, legumes, potato, rice, grasses and perennial crops; rubber and coconut. Attentions to maize–based intercropping systems in Southeast Asia emphasizes that erosion control since maize has been widely expanded to upland area of all major maize production countries. Evidentially, maize–based intercropping can effectively control soil erosion, water runoff, and prolong top soil fertile. As consequences, less nutrients input needs in maize–based intercropping systems and this can also reduce environmental impact in down slope area. We found that almost all researches conducted in this region, have shown improvement of land equivalent to ratio of LER > 1, if planting time, crop spacing, and managements are properly considered. Growing maize together with legumes theoretically benefits both crops because of biological nitrogen fixations, but researches conducted in this region did not confirm this statement when maize intercropped with rice bean. Planting calendar and planting arrangement are very important to compromise maize – based intercropping systems to mitigate unfavorable conditions. There is still a need to study maize – based intercropping mitigating impact of climate change (drouth and heat), as this issue is a severe problem nowadays to shorten yield gaps of maize and to sustain maize production in Southeast Asia.

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