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Rice and food security amidst agricultural transformation in the highlands of northern Thailand

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Transformation of the highlands of northern Thailand holds lessons for agricultural development in other parts of the world, especially for the agroecosystems that sustain local populations while also providing critical ecological services. This article aims to highlight these lessons, by reviewing agricultural changes in the region from the final decades of the 20th century, especially for rice and food security. The traditional practices that have endured over time are also acknowledged in this review. The paper begins with a description of the highlands and local agriculture before the change, followed by an examination of changes in crop production after the abolition of opium cultivation. The economic integration of highland agriculture is then discussed. The agriculture in the highlands has largely shifted from subsistent to commercial production, in response to demand from the lowlands and facilitated by an integration of the highlands into Thailand's national economy and the global market. The roles played by financial support and subsidies have been relatively minor. Productivity growth was driven by technological innovations such as high yielding hybrid maize, rubber adapted to cooler and drier environments. These activities have been carried out along with the use of fertilizers and other purchased inputs, as well as the exploitation of cooler temperatures at higher elevations for growing temperate crops. Essential technical support, market and price stability for some crops have been provided by contract farming. However, subsistence rice production remains central to food security for many communities. Wetland rice accounts for only about 20% of the annual highland rice area and 30% of total paddy production, upland rice plays a dominant role in highland food security, despite yielding only 50–70% of what wetland rice produces. The crucial roles in forest management and conservation played by highland communities and farmers should be recognized. The problem of air pollution caused by residue burning in highland maize production urgently requires practical solutions. The transformation of highland agriculture in northern Thailand may provide important lessons for agricultural development worldwide, especially in balancing local livelihoods and ecological services.

KEYWORDS

food security, highland development, mountain agriculture, opium replacement, residue burning, rice germplasm, shifting cultivation

1 Introduction

The importance of mountain ecosystem services has gained attention with growing awareness of resource scarcity, particularly freshwater from mountain watersheds (Schild and Eklabya, 2011). Like other mountainous regions worldwide, the highlands of northern Thailand face challenges in balancing the needs of the local communities with maintaining the ecosystem services essential to the wellbeing of the lowland population. Thailand's primary watershed, located in the northern highlands, supplies water for domestic use, irrigation and industry, while also preventing seawater intrusion from the Gulf of Thailand. Other crucial ecosystem services such as biodiversity conservation and carbon sequestration are also derived from the highlands. However, the highlands of northern Thailand are also home to 1.4 million people (Figure 1), predominantly from ethnic minority groups who have only been gaining Thai citizenship relatively recently. The traditional cropping practice of slash-and-burn or shifting cultivation, is opposed by the country at large due to their generally perceived contribution to forest destruction (Komkris, 1978). Additionally, the illicit production of opium by some of the minority groups was a cause for both national and international concern. Furthermore, the air pollution that blankets the lowlands each cool season is attributed to agricultural burning in the highlands (Moran et al., 2019). Efforts to improve highland agriculture, ranging from the search for alternative crops to replace opium to eliminating the need for burning, have been hindered by the complexity of the highland agroecosystem. This article aims to highlight these lessons by reviewing agricultural changes in the region since the final decades of the 20th century, especially for rice and food security, while also acknowledging the traditional practices that have endured over time. The review begins with a brief description of highland agriculture before the end of the 20th century. Changes in crop production that accompanied social and economic development extending into the highlands, including the strictly enforced abolition of opium cultivation, are examined. These focus on the scaling up of economic integration of highland agriculture, marked by the expansion of highland maize production, movement of rubber from the south and commercialization of crops that benefit from the cooler temperatures at higher elevations. The importance of rotational shifting cultivation, which remains central to the food security of a significant portion of the highland population, is reviewed, along with an account of highland rice germplasm, a valuable genetic resource. The transformation of highland agriculture in northern Thailand may provide important lessons for agricultural development worldwide, especially in balancing local livelihoods and ecological services. An understanding of the key mechanisms and processes underlying

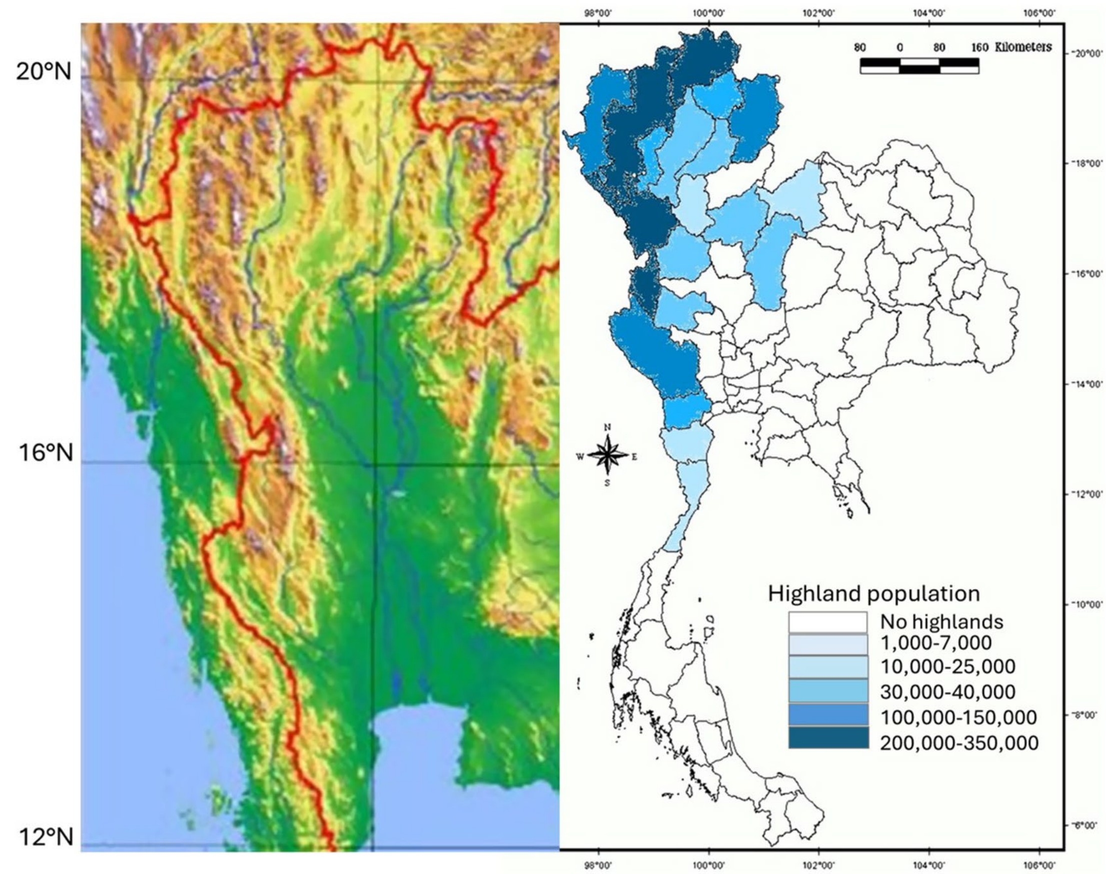

FIGURE 1
Topographic map of northern to central Thailand (left) and distribution of highland population (right). Source: Map adapted from Thongthammachat et al., (2005) (left) and highland population by province drawn from data in HHDC (2016) (right).

highland agricultural transformation, should contribute to effective and sustainable mountain development in other parts of the world, and agricultural development in general.

2 Highland agriculture before the end of the 20th century

Highland agriculture in northern Thailand has traditionally been shaped by the region's mountainous terrain, ethnic diversity, and unique environmental challenges. Theories explaining agricultural practices here often highlight the interplay between ecological adaptation, socio-cultural factors, and economic pressures. Shifting cultivation (swidden agriculture) is a key traditional method, rooted in indigenous knowledge and ecological adaptation, where farmers rotate crops with fallow periods to maintain soil fertility. This practice is theorized as sustainable when population density is low but can cause deforestation and soil degradation if cycles shorten due to land pressure. The shifting cultivation, a crop production system in which natural vegetation is allowed to regenerate after one or several years of cultivation. Land is prepared by cutting down the vegetation and burning it, a practice commonly referred to as slash-and-burn farming. The mountainous highlands of Thailand remained physically and socially isolated from the rest of the country until the final decades of the 20th century. By 2016, the highland population was estimated at 1.4 million (HHDC, 2016), consisting largely of ethnic minorities, including the Karen, Hmong, Lahu, Akha, Lua, Mien, Lisu, and Khmu, along with approximately 15% self-identified ethnic Kon Muang (northern Thais), who form the majority lowland population in the Upper North provinces. The highland minority groups were not officially recognized as Thai citizens until recent decades, and they remain little understood by broader Thai society. Their shifting cultivation practices are often blamed for deforestation and air pollution. Among these groups, the Karen, Lua, and Khmu are traditional rice growers, while the Hmong, Lahu, Akha, Mien, and Lisu formerly depended on opium as a cash crop. Rice-growing communities primarily cultivate upland rice on steep slopes, although wetland rice paddies have also been developed wherever land could be leveled and supplied with water. Additionally, some Karen groups were skilled timber workers, including elephant handlers (mahouts), who were historically involved in the forestry industry.

The basic types of shifting cultivation identified in the highlands of Thailand have been categorized as rotational or pioneer systems (Grandstaff, 1980). Rotational shifting cultivation was practiced by sedentary villages, where crop fields followed cycles of 1 year of cultivation followed by several years of forest regeneration (fallows; Figure 2). While these villages remained in place, new settlements were historically established when family groups split off to claim new land, due to population pressure or other social challenges. In contrast, pioneer shifting cultivators were migratory. Their fields were cultivated for several consecutive years before being abandoned, prompting the relocation of villages to areas where new patches of forest could be cleared. In northern Thailand, pioneer shifting cultivation was commonly found at altitudes above 1,000 meters, as these higher elevations met the climatic requirements for opium, the primary cash crop. Beyond opium cultivation, highland crop production was largely subsistence-based. Rice served as the main staple food, while maize was primarily grown to feed household pigs. Opium also had widespread medicinal functions, being used to relieve aches, pain, fever, diarrhea, coughs, and various other ailments (Suwanwela et al., 1980). Additionally, sesame, perilla seeds, dried chilies, and dry beans such as ricebean, cowpea, and lablab were sometimes cultivated, either for sale or barter in exchange for rice.

In addition to staple rice, shifting cultivation fields contributed to nutritional security and dietary diversity, as well as various other useful products. A study in a Lua village in Mae Sariang District, Mae Hong Son, identified 184 food plants (including varieties of single species), 31 plants used as animal feed, and 210 plants utilized for various other purposes in both cultivated and fallow fields (Kunstadter, 1978). Although opium was primarily cultivated as a cash crop, the opium-based cropping system was also recognized for its rich genetic diversity and high productivity, with the capacity to provide a year-round food supply (Sutthi, 1985). The dry mixed deciduous and dry Dipterocarp forests, where shifting cultivation was practiced in the highlands of northern Thailand, are highly fire-prone during the hot, dry season (Smitinand, 1980; Moran et al., 2019). Despite the use of slash-and-burn techniques, shifting cultivators played a crucial role in fire management. Their careful fallow management and controlled burning practices contributed to reducing the risk of uncontrolled wildfires (Kunstadter, 1978; Nakano, 1978; Yimyam, 2006). On the other hand, in countries like Bangladesh and India, shifting cultivation continues to contribute to soil erosion and deforestation, particularly in hilly regions like the Chittagong Hill Tracts and North-East India (Hossain, 2011; Punitha et al., 2018). The reduction in fallow periods has exacerbated these environmental issues, leading to significant ecological concerns (Mistri and von Hauff, 2025).

3 Social and economic integration and highland agricultural changes

The social and economic integration in highland agriculture explains how connecting highland societies to national and global economies transforms traditional agricultural systems. It highlights how social and economic integration connects highland farmers to wider markets and society, resulting in both developmental opportunities and significant challenges for agricultural sustainability and community resilience in northern Thailand. Transformative changes reached the highlands by the turn of the millennium (Rerkasem and Rerkasem, 1994). These included the gradual process of granting citizenship to ethnic minorities, which began with the Household Registration Law in 1974 as a condition for citizenship eligibility. An abolition of opium production was strictly enforced from 1985, opium fields in bloom were cut down by squads of soldiers and police officers, and nationwide logging ban imposed from 1989. The application of natural conservation laws, such as the National Park Act (1961) and the Wildlife Protection and Conservation Act (1992), also became increasingly stringent, even in areas that communities claimed to have cultivated for centuries. The Household Registration Law effectively halted village relocation by the 1990s. Meanwhile, expanding road construction in the 1970s and 1980s connected highland villages with lowland towns and major urban centers, opening economic and educational opportunities, especially for younger generations who migrated to the lowlands. However, these opportunities remained out of reach for those without the crucial official citizenship identification card. As of 2023, it is estimated that

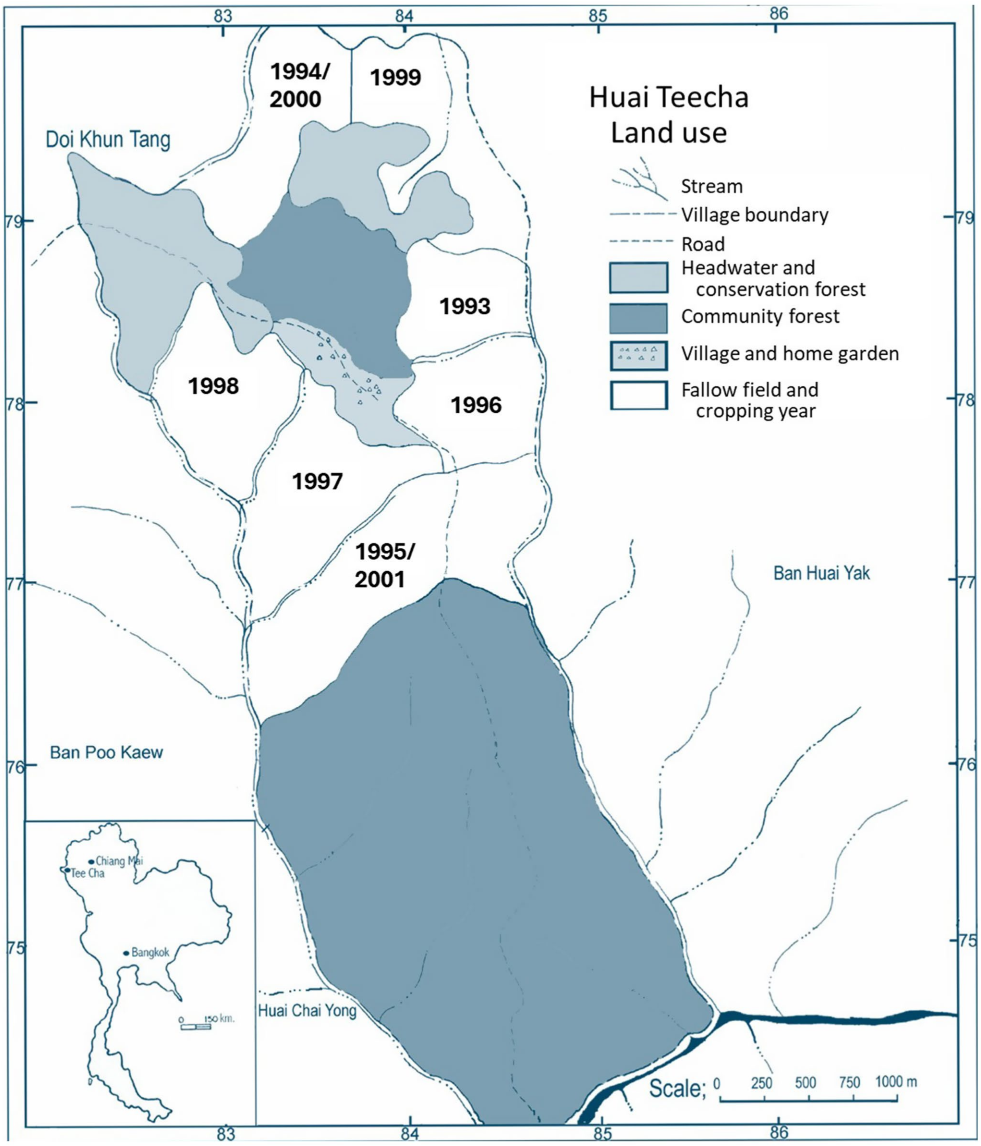

FIGURE 2
An example of rotational shifting cultivation fields at Huai Tee Cha village in northern Thailand, and the cropping cycle from 1994 to 2001, and other land use types. Source: Adapted from Yimyam (2006).

nearly 40% of the highland ethnic minority population, just under half a million people, including one-fifth who are children, still lack Thai citizenship [computed from data in BORA (2023)]. This represents an insurmountable barrier to their participation in and benefit from the country's economic development, as well as their access to public services such as education, healthcare, and financial assistance programs. The Thai government's current initiative to expedite the citizenship process for highland ethnic minorities, their children, and other stateless individuals (Thai Government, 2024) has given many renewed hopes. The abolition of opium cultivation in the late 20th century was closely linked to shifts in citizenship policy. In particular, the Household Registration Law of 1974 served as a catalyst for granting rights and legal recognition to ethnic minorities, enabling them to participate in new agricultural practices. This recognition was crucial for these communities, as it allowed them to engage in alternative crop production during their transition away from an opium-based economy. In contrast, many regions in countries like Laos and Nepal still face challenges such as limited access to infrastructure, healthcare, and education, which hinder the transition from shifting cultivation to more sustainable practices (Rerkasem et al., 1989). Population pressure and land tenure issues also play a significant role in the persistence of shifting cultivation in these regions (Boonprakob and Byrne, 2005).

3.1 Opium 'replacement'

Despite opium's status as a cash crop, its growers had minimal direct engagement with the market. The crop required few external inputs, and buyers, often claiming ties as creditors, arrived promptly in villages after harvest. Opium eradication, driven by both multilateral and unilateral international pressures, brought new technologies and market integration to the highlands. The establishment of the Royal Project by King Bhumibol Adulyadej in 1969 is widely credited with spearheading Thailand's highland agricultural research, development, and extension efforts (Jayamangkala, 2006). The country's academic institutions and public services were mobilized to find viable alternatives to opium cultivation, leading to extensive research on temperate crops. One key innovation was the introduction of refrigerated transportation, the cold (chilled) supply chain, which enabled the transport of highland-grown vegetables to Bangkok. Highland agricultural development efforts expanded significantly in the 1970s and 1980s with international support (Diskul et al., 2019). For instance, the US Department of Agriculture, through USAID, tested hundreds of crops, including beans, barley, lettuce, potato, and wheat, for their potential as 'opium replacement' options in the 1970s (Kumar et al., 1985; Rerkasem et al., 1989). As the highland climate of northern Thailand does not provide sufficiently low temperatures to meet the chilling requirements of most temperate fruits, a breeding program for no-chill stone fruits (e.g., peach, plum, apricot) was initiated (Boonprakob and Byrne, 2005).

For crops deemed economically promising, on-farm trials were accompanied by technical support, subsidized inputs, and marketing and price guarantees. However, most of these crops were not sustainable without continued financial support. The unfamiliar new crops from the highlands found little demand from the 1970s lowlands, where most of the population had little disposable income to pay for them anyway. By the 1980s, most highland development initiatives had broadened their focus beyond agriculture to include comprehensive social and economic development programs. These efforts aimed not only to reduce opium cultivation but also to improve livelihoods, infrastructure, education, and healthcare in highland communities. Recognizing that highland agriculture had historically been underserved by research and development efforts focused on the lowlands, the Highland Research and Development Institute (HRDI) was established in 2005 as a public organization dedicated to supporting agricultural advancement in highland areas (HRDI, 2005). Improvements in infrastructure, such as road construction and increased access to markets, have played an essential role in integrating highland farmers into national and global agricultural systems. Enhanced infrastructure has facilitated market access for previously isolated communities, encouraging them to adopt new cash crops beyond opium.

3.2 Crop diversification

Highland agricultural development has taken place in response to growing lowland demand, driven by national economic growth that led to Thailand achieving a lower-middle-income status in 1988 and upper-middle-income economy status in 2011 (World Bank, 2011). Cash cropping expanded naturally to meet the growing demand from rapidly urbanizing lowland centers, with the highlands' cooler temperatures proved advantageous for commercial production of vegetables, such as cabbages, tomato, ginger, green beans, and others, over the lowlands especially during the hot and humid wet season. Former opium growers adopted commercial vegetable production, integrating their traditional intensive cultivation techniques with both locally developed and modern technologies. These included gravity-fed sprinkler irrigation systems, chemical fertilizers, pesticides, and imported hybrid vegetable seeds. Some rice-growing villages also transitioned to cash cropping. For example, in the Karen village of Mae Rid Pagae (Mae Hong Son), cabbage was incorporated into both upland and wetland rice-based cropping systems, leading to a doubling or even tripling of rice yields, likely due to residual fertilizer from the cabbage cultivation (Rerkasem and Rerkasem, 1994; Yimyam et al., 2016). A detailed survey conducted in the early 2000s across 10 Karen villages and one Lahu village in Mae Hong Son, Lampang, Chiang Mai, and Chiang Rai found that four had become largely dependent on cash cropping, while five had maintained the rotational shifting cultivation to produce their subsistence rice (Cramb et al., 2009). Some Karen farmers also earned wages by working for commercial vegetable growers, much as they had previously worked in opium cultivation.

Maize, which has seen the most significant area expansion into the highlands, now covers six times the area under rice (Table 1). While maize cultivation declined by more than half its nationwide area from the peak in the 1980s, it continued to grow in the highlands throughout the 21st century (Figure 3). Maize is ecologically adaptable to a wide range of conditions (Troyer, 1996). Growing domestic demand for maize, combined with the innovation of tropical hybrid maize technology (Edmeades et al., 2017), stimulated the expansion of highland maize cultivation despite official discouragement and public objections from the lowlands (e.g., see (Talerngsri and Pongkijvorasin, 2015; Punyalue et al., 2018a; Punyalue et al., 2018b; Rungruangwong et al., 2023). Since 1990, maize yields in Thailand have increased by approximately 60 kg/ha/year [computed from FAO (2025)], driven by the widespread adoption of hybrid maize technology (Poolsawas and Napasintuwong, 2013). Highland maize production has clearly benefited from these advancements, particularly hybrid seeds and fertilizers, as evidenced by yields comparable to those in the rest of the country (Figure 3). As a result, the highland provinces (Upper North plus Tak) now contribute nearly 40% of national maize production, up from just 10% in the 1970s and 1980s. These highland provinces together account for about 30% of Thailand's annual demand, over 6 million tons, primarily for feed, livestock and other industries that supply both domestic and export markets, with another 20% imported [computed from data in FAO FAO (2001)], mainly from neighboring Myanmar, Laos and Cambodia to meet the production shortfall.

A key agronomic advantage of maize is its ability to be grown repeatedly on the same land without significant yield decline, providing that soil fertility is maintained, and weeds are effectively controlled. This contrasts sharply with upland rice, which invariably suffers declining yields and eventual crop failure under repeated cropping (Gupta and O'toole, 1986). Maize production in the highlands may, at first glance, resemble traditional shifting cultivation due to the use of fire for land preparation, but there are fundamental differences. Crop residue from the previous maize season is burned mainly to clear the soil surface for direct seeding of the next season crop, thus the crop is grown continuously on the same land without rotation. In contrast, traditional shifting cultivation relies on long fallow periods to restore soil fertility and control weeds and pests, with fallow management and slash-and-burn operations requiring substantial labor. In the case of maize, these ecological functions are replaced by purchased inputs such as fertilizers and herbicides. However, residue burning from maize cultivation is linked to the haze

TABLE 1 Crop production in Thailand's northern highland provinces in the 21st century.

Crop (year of record)	Provinces (crop area in brackets)	Reference(s)
Rice (2011)	Highlands only (70,110 ha, 78% upland, 22% wetland) in the Upper North[1]	Computed from Dumrongkiat, 2013
Maize (2024)	Upper North plus Tak (420,000 ha)	OAE, 2025
Rubber (2023)	Upper North (153,128 ha, 90% in Chiang Rai, Nan, and Payao)	OAE, 2025
Tea (2023)	Chiang Mai, Chiang Rai, Mae Hong Son, Nan, Phrae (2,243 ha, 90% Assam tea, 10% Chinese tea)	OAE, 2024
Arabica coffee (2024)	Upper North (18,312 ha, 75% in Chiang Mai, Chiang Rai)	OAE, 2025
Potato (processing)[3]	Tak, Chiang Mai (5,702 ha)	OAE, 2025
Ginger (for export)[3]	Chiang Rai, Phetchabun (limited area[2])	Rerkasem, 2010; Jijuban et al., 2020; Sawetchottanakon et al., 2022
Green soybean (for export)[3]	Chiang Mai, Chiang Rai, Lamphun, Lampang, Payao, Uthai Thani, Phetchabun (limited area)	Rerkasem, 2010; Geeratipunsirikhun et al., 2022
Hybrid maize seed[3]	Mae Hong Son (Mae Sariang and Sob Moei districts); Chiang Mai (Mae Chaem) (limited area)	Konsaeng, 2010; Arunrat and Pumijumnong, 2019
Passion fruit	Chiang Mai (limited area)	Chamnannin, 2011
Avocado	Tak (limited area)	Nuangklin, 2022

[1]Chiang Mai, Chiang Rai, Lampang, Lamphun, Mae Hong Son, Nan, Phayao and Phrae, where nearly 20 times as much rice is produced in the lowlands as the highlands.
[2]Author's estimates, area in hundreds to some thousands of hectares.
[3]Contract farming.

and air pollution that affect northern Thailand every winter (Moran et al., 2019; Paluang et al., 2024). The blame is also attributed to maize grown in neighboring countries (Marks and Miller, 2022). This has led to a cabinet decision to ban the import of maize produced through residue burning (Bangkok Post, 2024; Reuters, 2024), although it is noteworthy that no action has been taken against similarly produced maize in Thailand's own highlands. Biomass burning has indeed been shown to be closely correlated with urban air pollution in Bangkok (Fotiou and Perkins, 2021). However, the problem is likely exacerbated by atmospheric temperature inversion, in which pollutants are trapped near the ground by a layer of warm air sitting above the cold winter air (e.g., see Trinh et al., 2019; Nejad et al., 2023).

Highland crop production has diversified significantly beyond maize and vegetables, encompassing a variety of other crops (Table 1). While the list is not exhaustive, it highlights the range of crops successfully integrated into the national economy, and international markets. Crops such as rubber, arabica coffee, tea, and potatoes for processing are cultivated over large enough areas to be recorded in national agricultural databases, while others are produced commercially on a smaller scale. The reasons behind the economic success vary from crop to crop, although production has generally expanded to meet demand from the lowlands and the export market in some cases. Certain crops, such as arabica coffee, tea, and potatoes, are better suited to the cooler temperatures of the higher elevation. Rubber, in contrast, is less productive when grown at elevations higher than 600 m (RAOT, 2025a). The rubber area has spread from its previous centers of production in the humid, tropical South and Southeast Asia, into regions considered sub-optimal for rubber. It is driven by high rubber prices and an adaptation widening technology, including development of clones for cooler and drier environments (Priyadarshan et al., 2005). The migration of rubber into the highlands since the late 20th century is an apparent success, with yields approaching those in the rest of the country [computed from data in OAE (2024)], mirroring trends across Southeast Asia (Chapman, 1991; Fox and Castella, 2013; Ziegler et al., 2009).

A program to stimulate rubber production was implemented by the government of Thailand that provided substantial financial and technical support for an establishment of rubber plantations in the North and Northeast in addition to the traditional area in the South since 1991 (Weerathamrongsak and Wongsurawat, 2013). However, the expansion of rubber in the highlands appears to have been driven more by the crop's economic potential and less by government support and encouragement. The majority of the rubber plantations in the northern highland provinces was established on land without formal land rights documentation [computed from RAOT (2025b)], therefore was not eligible to government support. A system of online auctions has helped farmers to bypass traders when selling their rubber and retain more of their profits (Kruekum and Sittsak, 2017). Stimulation for rubber production in the highland provinces also comes from demand from the rubber industry in Yunnan, China, facilitated by the river trade on the Mekong (RAOT, 2025b; Saiyarod, 2023). Numerous commentaries and reports have criticized rubber plantations in mainland Southeast Asia for their negative impacts on local livelihoods and the environment (e.g., Ziegler et al., 2009; Liu et al., 2006; Li et al., 2007; Siriphon, 2013; Boonyanuphap et al., 2018). Many of these authors focus on how large-scale plantations have displaced small farmers, as documented where such plantations dominate. For instance, small-scale rubber production accounted for only 17% of the total rubber area in Cambodia, (Diepart et al., 2023), while concessions totalling 182,900 hectares were granted to 40 foreign companies for rubber production in Laos in 2007 (Luangaramsri, 2012). The situation differs markedly in the highlands of northern Thailand, where average plantation size is 2.3 hectares [computed from data in OAE (2024)]. Large-scale plantations, over 40 hectares, which are often operated by those who have migrated and brought skills in plantation management from the South, account for only 11% of the total rubber area in the North (Buakaew and Kunalasiri, 2015).

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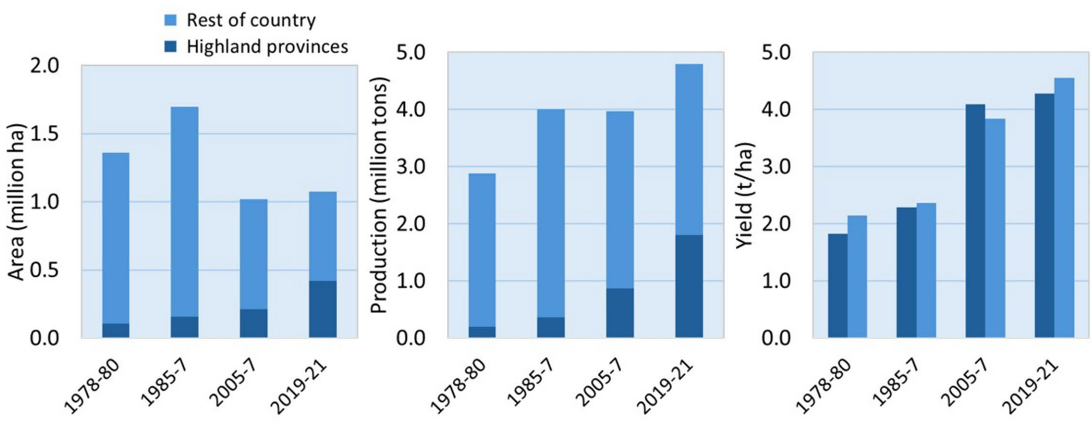

FIGURE 3
Expansion of maize production in Thailand's highland provinces (Chiang Mai, Chiang Rai, Lampang, Lamphun, Mae Hong Son, Nan, Phayao, Phrae, and Tak) from 1978–1980 to 2019–2021. Source: drawn from data in OAE (1979, 1986 2025).

Concentrated research and development of arabica coffee (*Coffea arabica*), which is better adapted to higher altitudes than the tropical robusta (*C. robusta*) common in the lowlands, began in 1982 at Chiang Mai University with a decade-long support from the Government of the Netherlands (HRTC, 2025). Two years later, the Department of Agriculture under the Ministry of Agriculture and Cooperatives joined the initiative, focusing on varietal improvement (Noppakoonwong et al., 2014). These efforts laid the foundation for the highland arabica coffee industry that would later develop. However, good quality arabica coffee can only be grown at elevations of 800 meters or higher. The five-fold expansion in arabica cultivation since 2005 has primarily occurred in Chiang Rai and Chiang Mai. The time and effort required to establish new perennial crops in the highlands are exemplified by arabica coffee, as well as locally unfamiliar crops such as avocado and macadamia. Although arabica seedlings distributed to farmers during the early years of opium replacement grew and yielded well, their economic value was not realized until the coffee bean market became established. This process took more than three decades in the Doi Chang area of Tambon Wawee, Mae Suai district, Chiang Rai, which has since become renowned for its arabica coffee with premium quality and prices (Borvonsin, 2017).

Tea is unique in that the plant (*Camellia sinensis* var. *assamica*) is indigenous to the Hill Evergreen Forests of northern Thailand (Preechapanya, 1993; Khanongnuch et al., 2017), which are situated at elevations of 1,000 meters or higher (TCHM, 2025). Traditionally, plantations were developed from natural stands of wild tea, with young leaves harvested for processing by steaming and fermenting into *miang*, a traditional chewable beverage favored by northern Thais. With the decline in miang consumption and market, the leaves are now primarily sold for processing into Assam tea (Pinta et al., 2024), which accounts for 90% of the tea produced. The remaining balance consists of the much higher-priced Chinese tea, produced from *C. sinensis var. sinensis* introduced from China and propagated through cuttings. Chinese tea can also be grafted onto Assam tea rootstock to increase yield and drought tolerance without compromising the quality of the tea leaves (Tuwei et al., 2008; Karunakaran and Ilango, 2019).

Potato for processing, green soybean and ginger for export, and hybrid maize seeds are produced under contract (Foythong, 2001; Konsaeng, 2010; Rerkasem, 2010; Geeratipunsirikhun et al., 2022). This involves a legal agreement established at the beginning of the season, specifying the quantity, quality, and price of the product to be purchased from farmers by the company after harvest. The contracting company, i.e., the business party, also provides inputs such as seeds, fertilizers, and pesticides, along with technology, quality control, and credit. However, low-cost loans for farming are generally available from the government's Bank for Agriculture and Agricultural Cooperatives to those with proof of citizenship. Strict quality control is imposed on green soybeans and ginger for export, particularly regarding pesticides banned in importing countries, which are strictly prohibited. Additionally, maximum residue limits are enforced for permitted pesticides. Specific potato varieties are mandatory for different processing methods, such as for chips or pre-cooked fries. An advantage of hybrid maize seed production in highland villages is the avoidance of genetic contamination due to their isolation. The success of hybrid maize seed production by approximately 400 farmers across seven villages in Mae Hong Son, working with several multinational and domestic seed companies, demonstrates the technical capabilities that farmers can develop (Konsaeng, 2010). Since its introduction in 1982, some farmers have become experts in hybrid maize seed production procedures and are relied upon by companies to guide newly graduated field officers in field practices. Hybrid maize seed production is a proprietary technology that is jealously guarded by the owners. Thefts of inbred paretal materials used in the production of hybrid maize seeds are known to have caused the villages' contract to be rescinded.

Cash cropping in the highlands does not inevitably lead to the loss of forests and their ecological services. Arabica coffee provides an example of a valuable cash crop that benefits, in terms of quality and long-term productivity, from being grown under forest shade (Beer et al., 1998; Bote and Struik, 2011), as has also been demonstrated in Thailand (Subchoktanakul et al., 2014). Where agriculture is part of the forest landscape, as in the highlands, the roles of forest management and conservation by communities and individual farmers are often overlooked. A detailed study of two highland villages in Mae Hong Son (Mae Rid Pagae, Skaw Karen; and Teecha, Pwo Karen) and one in Chiang Mai (Pah Poo Chom, Hmong) revealed how forest management by villagers plays a crucial role in maintaining highland forest cover alongside their agricultural practices (Yimyam et al., 2016). The study demonstrated that a significant portion of the carbon stored in all three villages was accounted for by the forests they managed and utilized. The headwater forest, which is strictly conserved due to its critical role as the village water source, had the highest carbon density. In contrast, the community forest, where firewood and timber extraction, minor forest product collection, and cattle grazing are permitted, had barely half the carbon density of the headwater forest. Land under permanent crops had less than one-fifth of the carbon density of the headwater forest, with significantly lower soil organic carbon and very little biomass carbon. Unfortunately, the majority of cash crops, including maize, can only expand at the expense of forest cover. Rubber grown on slopes, on the other hand, is less effective than natural forests in preventing soil erosion and surface water runoff (Boonyanuphap et al., 2018). On sloping land, runoff and soil detachment were found to be much greater under mature rubber than maize and young rubber, due to the much barer cover of the soil surface under old rubber (Neyret et al., 2020). The commercialization of highland agriculture increased demand for crops such as maize and rubber, creating a symbiotic relationship with ongoing infrastructure improvements. Market dynamics directly influenced farmers' crop choices and contributed to economic changes within highland communities, further reinforcing the interplay between infrastructure development and market demands.

4 Rice and food security

Rice in Thailand is grown predominantly in the lowlands, where the majority population lives and makes their living. This is also true in the highland provinces, where rice grown in the lowlands is sufficient to supply the region's entire population more than twice over. Rice now occupies only a small fraction of the highland crop area (Table 1) and contributes a minor share of the overall economic value of highland agriculture. Nevertheless, self-sufficiency in rice production remains closely linked to food security for the highland population (e.g., Cramb et al., 2009; Dumrongkiat, 2013; Erni and Nikornuaychai, 2015). Wetland rice, grown on soil submerged under a few centimeters of water, accounts for only about 20% of the annual highland rice area and 30% of total paddy production. Meanwhile, upland rice, grown without soil flooding, plays a dominant role in highland food security, despite yielding only 50–70% of what wetland rice produces and half the yield of maize [computed from Dumrongkiat (2013) and OAE (2025)]. This section of the review first examines the role of rotational shifting cultivation in upland rice production and its contribution to food and nutritional security, followed by a brief discussion of wetland rice in the highlands. Finally, the literature on highland rice landraces (local varieties), a valuable resource, is reviewed.

4.1 Rice in rotational shifting cultivation

The rice-growing groups of the Lua, Karen, Khmu, and H'tin all practice some form of rotational shifting cultivation. A glimpse into the widespread indigenous knowledge associated with this practice is evident in the recognition of a common fallow-enriching tree, known as *pada* by the Skaw Karen, *letha* by the P'wo Karen, *teen tao* by the Khmu and H'tin, *tong coab* by the Lua, and *loom piah* by the Akha. It is variously referred to as *tong taeb*, *tong tao*, *tao meo*, *por khee haed*, or *bai hoo chang* in the lowlands, and has been taxonomically identified as *Macaranga denticulata* (Bl.) Muell. Arg. (Smitinand et al., 1978). In-depth studies of rotational shifting cultivation in northern Thailand, focusing primarily on the practices of the Lua and Karen, have shed light on their soil fertility management strategies that maintain rice productivity without external inputs. When rice is grown repeatedly on the same land without soil submergence, its yield declines after a few years due to soil fertility depletion (Zinke et al., 1978), weeds buildup (Becker and Johnson, 2001), and the accumulation of pests (IRRI, 2025). In contrast, wetland rice can be grown continuously on the same land without adverse effects. Soil submergence improves soil fertility by chemical changes (Ponnamperuma, 1972) and microbial activities (Ladha et al., 1998), while also creating an inhospitable environment for weeds, soil-borne pests and diseases. Root-knot nematodes and root aphids, as well as an unidentified "soil sickness," continue to pose challenges in aerobic rice, a version of upland rice intensified by the use of fertilizers and herbicides (IRRI, 2025; Yano et al., 1983; Kreye et al., 2009; Nie et al., 2014; Ruanpanun and Khun-In, 2015). A yield decline under continuous aerobic rice can be reversed by growing another crop or leaving the land in fallow. Nematode populations were significantly lowered and aerobic rice yield increased after 1–2 seasons of fallow or cowpea (Soriano and Reversat, 2003). In Brazil, the yields of aerobic rice lowered after 5 years of repeated cropping was most effectively restored after 3 years of soybean (Pinheiro et al., 2006). At the International Rice Research Institute (IRRI) in the Philippines, where aerobic rice yield had fallen to less than half that of wetland rice by the ninth season in a system with two crops per year, the decline was reversed after two seasons of fallow and even more effectively by two seasons of maize, sweet potato, or soybean (Nie et al., 2009). In the mountainous region of southern Yunnan, China, upland rice yield increases have been attributed to the cultivation of improved upland rice varieties on terraces rather than slopes (Wang et al., 2010). However, no information is available on how soil-borne pests, diseases, and soil fertility issues were managed.

For highland communities reliant on rice as their staple food, rotational shifting cultivation remains essential for sustainable food security. The fallow period eliminates soil-related problems, while regenerating vegetation restores fertility by accumulating nutrients that are subsequently released through slash-and-burn practices. Essential nutrients rapidly accumulate in fallow regrowth (Yimyam, 2006; Zinke et al., 1978). Careful fallow management, including fire prevention, protection from livestock damage, and controlled slash-and-burn, is a defining characteristic of Lua and Karen shifting cultivation (Kunstadter, 1978; Nakano, 1978). Some trees are deliberately left standing to enable rapid regeneration (Figure 4), even though this necessitates removal of the sprouts to prevent their shading and competing with the upland rice. The efficacy of the local knowledge of the fallow enriching *Macaranga* has been confirmed by research. In areas with high *Macaranga* density, upland rice yields were double or triple those where it was sparse, owing to the tree's exceptional ability to accumulate nutrients in symbiosis with arbuscular mycorrhizal fungi (Yimyam et al., 2003; Youpensuk et al., 2004; Youpensuk et al., 2005). The length of the fallow period was crucial for maximizing the benefits of *Macaranga*. Slash-and-burning the fallow after 4 years yielded only 30% of the grain

FIGURE 4
The slash-and-burn process at Huai Tee Cha village in northern Thailand. Source: adapted from Yimyam (2006).

and biomass as a full seven-year rotation. Beyond rice, rotational shifting cultivation contributes significantly to food and nutritional security through the diverse mix of plants intercropped with upland rice, as well as the wild edibles collected from fallow areas (Kunstadter, 1978; Yimyam, 2006). In each village, farmers cultivate between 50 and 100 different plant species, many with multiple varieties, while the fallow forests provide an additional hundred or more edible species. This diversity allows for continuous food availability throughout the growing season (Figure 5), as well as storable crops such as dried beans, chilies, perilla, sesame, pumpkins, and winter gourds.

The use of legumes, valuable sources of protein, illustrates the ingenious ways in which local plant genetic resources are integrated into cropping and food systems. Commonly grown legumes such as cowpea (*Vigna unguiculata*), rice bean (*Vigna umbellata*), and winged bean (*Psophocarpus tetragonolobus*) thrive independently of soil nitrogen through effective symbiosis with native nitrogen-fixing bacteria. Among these, cowpea, the most versatile in usage, is consumed as young pods, fresh full-grown seeds, and dry seeds. Rice bean is typically eaten as fresh full-grown seeds or dry seeds. Winged bean provides not only young pods as a vegetable but also edible, nutrient-rich roots in some varieties. Most local legumes exhibit a twining, climbing growth habit. Along with other vining crops such as cucurbits, yams (*Dioscorea* spp.), and yam bean (*Pachyrhizus* spp.), they are typically grown on stakes at field edges or in corners. However, a notable exception is a unique cowpea variety known as *tua-lod* or *tua-sod* ("crawling legume"), which is intercropped directly with upland rice (Rerkasem et al., 1995; Wongwai et al., 2014). Unlike climbing cowpea varieties, which smother upland rice and reduce yields, prostrate-growing cowpea spreads across the ground without interfering with the rice crop (Morris et al., 1990). Sown in a mixture of a handful of cowpea seeds to approximately 10 kg of upland rice, the crawling cowpea provides multiple benefits: its canopy suppresses weeds and mitigates the impact of raindrops, reducing soil erosion. Additionally, it ensures a continuous food supply through green pods and fresh or dried beans, all while having no detrimental effect on rice yield. The organic matter it produces and the nitrogen it fixes contribute to soil fertility and nutrient cycling within the system.

4.2 Highland paddies and local rice germplasm

Rice paddies, fields leveled and enclosed by low embankments to retain water, have been developed wherever feasible in the highlands. Their establishment depends on two key factors: a reliable water supply and land that can be leveled. Small paddies are often found scattering along mountain streams, while deposition fans at the base of slopes formed by soil erosion from shifting cultivation higher up are considered prime land for paddy development (Zinke et al., 1978). By 1990, a survey conducted by the Thai-Australia Highland Agricultural and Social Development Project found that virtually all terrain with slopes of 0–15% had long been converted into wetland rice paddies (Rerkasem and Rerkasem, 1994). Labor productivity in slash-and-burn rice cultivation is comparable to that of wetland rice (Kunstadter, 1978), but suitable land for paddies was scarce in the highlands, while labor was more abundant. Criticism of shifting cultivation, particularly from forestry officials often stemmed from its low rice yield per hectare when fallow land was factored into calculations (Komkris, 1978). However, the critical role of wetland rice in highland food security is evident in historical village settlement and land transactions. In the 1950s, decades before strict enforcement of opium eradication, former opium-growing villages had settled on land purchased from Karen and other rice-growing groups. These transactions not only secured paddy land but also facilitated the transfer of knowledge and skills in wetland rice and irrigation management, along with seeds of local rice varieties (Rerkasem and Rerkasem, 1994; Rerkasem et al., 2009).

The highlands of northern Thailand are home to some of the world's last remaining local rice varieties, or landraces, still cultivated by farmers. These local rice varieties are globally significant, as they are found within the Center of Diversity of *Oryza sativa* (Oka, 1988; Harlan, 1992), with on-farm crop diversity playing a vital role in the conservation of genetic resources (FAO, 2001). A survey conducted in the early 2010s by researchers from Chiang Mai University identified nearly 300 named landraces across highland villages in Chiang Mai, Chiang Rai, and Mae Hong Son. Around 70% were grown as upland rice, with distinct sets of varieties maintained by different ethnic groups, including former opium growers (Jamjod et al., 2017). The Karen, with their long history of rice cultivation and the largest share of the highland population, accounted for nearly half of the varieties.

Research focusing on the local rice germplasm of the highlands of Thailand and other agroecologically diverse regions has revealed that rice diversity extends beyond simple tallies of variety names (Pusadee et al., 2024). Local crop landraces are often better suited to specific ecological conditions and household needs (McCouch, 2004). In the highlands, this diversity is crucial for adapting to the region's varied micro-environments, and meeting requirements of an ethnically

FIGURE 5
Upland rice seed mixed with various seeds and propagules of swidden crops **(A)** and a farm household's harvest from the swidden during the rice growing season **(B)**. Source: adapted from Yimyam (2006).

diverse population. The characterization of crop landraces often emphasizes traits relevant to breeding programs (e.g., Graham et al., 1997; Krishnamurthy et al., 2011; Ali et al., 2014; Lopes et al., 2015), frequently overlooking their value to farmers. Studies based on materials sourced from gene banks can also be disconnected from their agroecological context. On-farm crop germplasm provides direct benefits to those who depend on them, not only due to their ready availability but also because of their unique functional traits. One such trait is higher densities of grain iron (Pintasen et al., 2007) and zinc (Jaksomsak et al., 2015) that would provide a higher dietary intake of these nutrients to the highland households consuming the rice they grow themselves compared with the population dependent upon lowland-grown mega-varieties with significantly lower grain contents of the nutrients. Furthermore, the highest quality purple rice with intense pericarp pigmentation valued as a special quality rice by consumers, and for the exceptional levels of anthocyanin by pharmacological and cosmetic industry, identified among local rice varieties grown in the highlands. It offers farmers an opportunity to cultivate purple rice with premium quality and price as a profitable cash crop (Jamjod et al., 2024).

Genetic diversity in rice landraces with morphologically uniform appearance has been revealed by analysis of microsatellite (simple sequence repeats, SSRs) markers. This diversity exists not only between similarly named seed caches maintained by different farmers, but also within individual caches or fields. *Bue Chomee*, a popular wetland rice variety in Karen villages at 600–700 m elevations, has most of its genetic variation within individual seed caches (Pusadee et al., 2009). *Muey Nawng*, a gall midge-resistant wetland rice variety grown from mid-elevation down to the foothill valleys, exemplifies both molecular and functional diversity. Its functional diversity spanning variations in growing season length, adaptation to a range of elevations, and endosperm starch composition allows it to thrive in diverse environments and satisfies different consumer preferences. A glutinous version with little or no amylose is the preferred staple rice among Khon Muang (northern Thais), while a non-glutinous form, with some 10% or more amylose is favored by Karen consumers (Supamongkol, 2006; Oupkaew et al., 2011; Pusadee et al., 2014). Variation in other key functional traits found within individual seed caches of local varieties from the highlands include micronutrient content such as iron (Pintasen et al., 2007) and zinc (Jaksomsak et al., 2015) often deficient in rice consumers as well as tolerance to soil acidity, a crucial trait for upland rice (Laenoi et al., 2015). These findings highlight the remarkable genetic and functional diversity embedded in highland rice landraces, underscoring their value for both conservation and utilization.

5 Future outlooks

Productivity of agriculture in the highlands has been significantly increased by commercialization with a direct impact on the local population. A survey of 28 highland villages in Chiang Mai, Chiang Rai, Nan, and Tak found approximately half of the households relying on the market for their rice supply and the other half producing rice for their own consumption (Ekasingh et al., 2017). Income from cash cropping has also provided the means for acquiring necessities of modern life from electricity to various consumer goods. The highland landscape and communities have also been transformed by infrastructure development, as exemplified by a report on several Karen villages in Mae Hong Son. All these villages are electrified and accessible by road, most of them have concrete paved lanes, and the majority of households have access to piped water. Nearly all households own a motorbike, and some have purchased pickup trucks. However, areas of concern associated with agricultural development in the highlands are the loss of forest cover and air pollution caused by residue burning by maize production.

Global deforestation is generally linked to agricultural expansion (FAO, 2021; Seub Nakhasathien Foundation, 2023; Goldman and Weisse, 2024). In Nan, a highland province that has experienced significant expansion of maize and rubber cultivation, forest cover declined from 92% in 1977 to 61% in 2016 (Trisurat et al., 2019). However, the forest cover in Nan stabilized at this level throughout the 2010s (RFD, 2025) and is likely to remain so, given the presence of extensive rugged and inaccessible terrain between the Nan Valley and the Lao border, as well as well-protected national parks and watershed Class 1 areas. The forest cover of the highland provinces all together has remained above 60% throughout the 21st century [computed from RFD (2025)]. Rises in maize and rubber prices are expected to drive further deforestation in Nan (Trisurat et al., 2019) and across Thailand's highland provinces. However, no official records exist on the extent to which highland agricultural expansion has encroached into national parks and primary watershed areas. Meanwhile, much of the maize and rubber nearly 60% of the rubber area in 2019 [computed from RAOT (2025a)], in the northern highland provinces are cultivated on land without formal land rights certification. This lack of land rights documentation raises concerns about the extent to which agricultural expansion has contributed to deforestation, including potential encroachment into protected areas.

Residue burning in maize cultivation is widely recognized as a major cause of air pollution. In Asia, maize residue burning contributes to greenhouse gas emissions, with annual emissions estimated at 160,875 tons of CO_2 equivalent and the practice contributes to the haze problem (Tippayawong et al., 2020). Moreover, residue burning significantly contributes to air pollution, including the release of volatile organic compounds (VOCs) and particulate matter (PM2.5; Sirithian et al., 2018). However, the burning is neither necessary nor common in Thailand's main maize-growing areas in the lowlands and the rolling terrain between mountains and lowlands (the uplands) as well as in the world's other maize-producing regions. In Brazil, one of the world's largest maize producers, most maize is grown using conservation agriculture, where crop residues are retained, and seeds are sown with minimal or no plowing (no-till; Fuentes-Llanillo et al., 2021). In northern Thailand's highlands, maize can be cultivated without residue burning or tillage. Sowing maize directly into crop residues without burning can significantly reduce soil erosion (Punyalue et al., 2018a; Boonyanuphap et al., 2018). Additionally, relayed cropping, where a grain legume is sown into the maize stand before harvest enhances biomass production, improves soil fertility, and contributes to long-term maize yield increases while providing an additional harvest of dry legume seeds (Punyalue et al., 2018b). However, this method is much more labor-intensive than residue burning, and the market for grain legumes remains limited. As a result, financial incentives may be necessary to encourage adoption. Afterall rice farmers in Thailand have been receiving cash payments since 2014 (Poapongsakorn, 2014), reflecting rice's central role as the nation's primary staple food and its cultural significance. Similarly, providing monetary incentives to eliminate residue burning in highland maize farming could be justified as a payment for maintaining clean air. Beyond simply highlighting the technical possibilities and challenges of reducing residue burning in maize cultivation, it is crucial to address the multifaceted social, economic, and policy dimensions involved. Widespread adoption of sustainable practices such as conservation agriculture or relayed cropping depends not only on demonstrating their environmental benefits but also on ensuring that they are viable and attractive for local farmers, many of whom may face constraints related to labor availability, land tenure, or access to markets for alternative crops such as grain legumes. Policy instruments, including targeted subsidies, training programs, and the development of robust supply chains for legume products, could help lower adoption barriers. Moreover, effective communication strategies are needed to convey the scientifically grounded impacts of residue burning on air quality to both policymakers and the public, countering misinformation and placing highland practices in the context of other pollution sources, such as urban and industrial emissions. Collaborations among government agencies, research institutions, and local communities should prioritize context-specific solutions, acknowledging the diverse environmental and socioeconomic conditions across Thailand's maize-producing regions. Ultimately, a holistic approach that integrates technological innovation, economic incentives, policy frameworks, and public awareness will be essential for achieving sustainable transitions away from residue burning and for ensuring that such reforms yield equitable and long-lasting benefits.

6 Conclusion

The highlands of northern Thailand have been substantially changed since the opium eradication decades at the end of the 20th century. Crop production has largely become commercialized. The area under rice is a fraction of the total cash crop area dominated by maize and rubber. The expansion of highland agriculture has been driven externally by demand from the lowlands and internal shift from subsistent to commercial production, facilitated by infrastructure development that integrates the highlands into Thailand's national economy and global markets. In contrast, direct financial support and subsidies have had a minor influence on this growth. Technology and management have been crucial, from high yielding hybrids for maize, a broader adaptation in rubber, to purchased inputs and exploitation of the cooler temperatures at higher elevations for temperate crops such as arabica coffee, cool season vegetables, tea and potato. Contractual arrangements provide essential technical support as well as market stability for crops such as ginger, green soybean, hybrid maize seed and processing potato. However, subsistence rice production, primarily upland rice in rotational shifting cultivation, remains central to food security for many communities, so providing conditions for the sustainable on-farm preservation of rice genetic diversity. In the highlands where farming is part of the forest landscape it is important to recognize the roles of communities and farmers in forest management and conservation. In the meantime, the air pollution affecting northern Thailand every winter due to residue burning in highland maize cultivation urgently requires practical and sustainable solutions. Air pollution in northern Thailand, driven by burning maize residues on highland farms, demands practical and policy-driven solutions. On-farm approaches include composting residues, using them as animal feed or mushroom substrate, producing biochar, and employing mechanical tools for residue management. Community-based cooperatives can help collect and add value to maize waste, while crop rotation and agroforestry reduce residue buildup. At the policy level, supportive actions like subsidies for sustainable practices, enhanced agricultural extension services, research funding, regulatory enforcement, and the development of markets for residue-derived products are crucial. Raising public awareness and fostering regional cooperation also play important roles. Integrating these practical and policy strategies can significantly reduce burning, benefiting both the environment and local livelihoods.

The transformation of highland agriculture in northern Thailand offers important lessons for agricultural development worldwide, particularly in balancing local livelihoods with ecological services. Key lessons from this transition include the shift from subsistence to commercial agriculture, driven primarily by market integration and technological innovation rather than government subsidies. Furthermore, contract farming has played an essential role in providing technical support and ensuring crop price stability. Despite the move toward commercialization, subsistence rice production remains vital for food security in highland communities. Additionally, highland communities have made significant contributions to forest management and conservation. Finally, the experience highlights the urgent need for practical solutions to address air pollution caused by the burning of maize residues.

Author contributions

BR: Conceptualization, Formal analysis, Investigation, Supervision, Validation, Visualization, Writing – original draft. NY: Conceptualization, Data curation, Formal analysis, Investigation, Resources, Validation, Writing – review & editing. CP-u-t: Conceptualization, Resources, Visualization, Writing – review & editing.

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