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REGULAR RESEARCH ARTICLE

Impacts of Urbanization on the Use of Soil Amendments by Rice Farmers Along a Rural-Urban Continuum in Northeast Thailand

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ABSTRACT

This study investigated the impact of urbanization on use of soil amendment by rice farmers in three villages along a rural–urban continuum in Northeast Thailand. It shows how urbanization influences their use of types and quantities of soil amendments. Data were collected by interviewing 150 farmers, focusing on types, quantities, sources, costs, and perceived effects of nine different amendments, including rice straw, chemical fertilizers, manures, and green manure. Results revealed significant declines in organic amendment use as villages become more urbanized, with rural farmers employing more diverse and greater quantities of organic amendments while periurban and urban farmers predominantly rely on chemical fertilizers. Quantitative analysis shows that livestock manure use diminishes sharply from over 80% of farmers in rural villages to around 30% in more urbanized communities, reflecting reduced livestock numbers. Discriminant analysis compared the three villages in terms of three dependent variables. (area of paddy fields, quantities of chemical fertilizer and organic amendments applied) showed clearly that all the group means were significantly different. Analysis of quantities of chemical fertilizer and organic amendments applied by individual farmers in all three villages revealed that farmers applying higher amounts of organic matter tended to use less chemical fertilizer. Constraints, including limited supplies, high costs, and labor shortages, inhibited organic amendment application among urbanized farmers. These shifts pose a serious threat to long-term soil quality. The findings underscore the urgent need for policy interventions to promote sustainable organic soil management practices in urbanizing communities to improve soil health and food security.

KEYWORDS

Urban agriculture; Urban-rural gradient; Farmer soil management; Organic agriculture; Chemical fertilizer use; Sustainable agriculture.

1. INTRODUCTION

This paper examines how urbanization is affecting the use of soil amendments by rice farmers in villages situated at different points along a rural-urban continuum in Northeast Thailand. This is an important topic because the number of people living in cities is increasing everywhere in the world. In 2023, 57 percent of the total human population was estimated to be urbanized (World Bank, 2023), with this share projected to reach 68 percent by 2050 (United Nations, 2018). In the East Asia and Pacific region, the share of people living in cities was 63 percent in 2023, and, in Thailand, the site of this study, the urban population was 53 percent in that year (World Bank, 2023) and still growing rapidly. Indeed, Ratanawaraha (2023) has referred to Thailand as “an urban country” considering the recent growth of large cities and the considerable extent to which the rural population has been economically and culturally incorporated into the urban sphere. Urbanization and the associated spread of urban lifestyles into

the countryside are integral aspects of the agrarian transformation of Northeast Thailand (Rambo, 2017).

Not surprisingly, in view of the rapid growth of cities, the impact of urbanization on agriculture has become an important topic for agricultural researchers and policymakers, particularly in Africa and Asia. The rapid increase in urban populations, and the consequent spatial expansion of cities, is having profound impacts on agriculture (De Bon et al., 2010; Follmann et al., 2021; Hamilton et al., 2014). Urbanization affects farming in several different ways. Farmers living in the fringes of expanding cities either lose their land to urban uses or find their access to traditional resources limited as they become increasingly encapsulated by suburban housing estates (Beckers et al., 2020; Bren d'Amour et al., 2017; Pribadi & Pauleit, 2015; Yodda et al., 2025). They may suffer labor shortages as more workers are employed in urban jobs, leading to a rise in wages for farm workers as Preusee et al. (2024) found in periurban areas of Bangalore, India. Both urban farmers and those living in periurban communities often become weekend farmers who are employed in jobs in the city and only farm in the evenings and weekends. At the same time, income earned from urban employment can be used to purchase chemical fertilizer and other inputs that can increase agricultural productivity. Even farmers in rural villages are increasingly involved in the urban-based market economy and may purchase increasing quantities of commercial inputs, particularly chemical fertilizers. They may also suffer from labor constraints resulting from out-migration of young people to seek employment in the cities (Shirai et al., 2017).

Although many studies on urban and periurban agriculture have been published in recent years, most have focused on the impact of urbanization on patterns of land use, food security, and the environmental, social and economic aspects of urban farming (De Bon et al., 2010; Follmann et al., 2021; Hallett et al., 2016; Hamilton et al., 2014; Orsini et al., 2013; Preusse et al., 2024; Vagneron, 2009). Much less attention has been paid to how urbanization affects farming practices, including changes in the ways that urbanizing farmers manage their soils. We have identified only a handful of papers that discuss this issue. These include a study on how urbanization affected the intensity of chemical fertilizer use in Henan province, China (Jiang & Li, 2016), an analysis of the effects of urbanization on farmer adoption of sustainable management practices in Bangalore, India (Preusee et al., 2024), and a study of adoption of soil amendments by urban horticulturalists in Ghana (Vicker et al., 2016). With the exception of a recent study of a single urbanized village in Northeast Thailand by the present authors (Yodda et al., 2025), there is a notable scarcity of comprehensive studies describing how farmers change their use of soil amendments in response to urbanization.

Historically, rice cultivation In Northeast Thailand was highly sustainable. Yields were low so relatively small amounts of nutrients were removed in the harvest and, until the 1970s, farmers almost exclusively relied on plentiful supplies of locally available organic materials, mostly in the form of tree leaf litter and livestock manure, to maintain soil quality in their paddy fields. The rural population was quite small and, as recently as the 1940s, more than 90 percent of the region was covered by natural forest (Pendleton, 1943). As the population gradually increased, farmers created new paddy fields in forested areas. They purposefully left many forest trees growing within the new fields. The leaves from these trees, along with litter washed into the fields from surrounding forests, helped to maintain soil quality in the paddies (Pendleton, 1943, Vityakon, 1993). Gradually, however, the remnant forest trees died or were cut down by the farmers, reducing the supply of leaf litter. Today, the density of trees in paddy fields is generally much lower in long settled areas than in frontier areas (Watanabe et al., 2014, Watanabe et al., 2017). Manure from the large numbers of buffalo and cattle

kept by most households was the other major source of organic soil amendments. The animals were stabled in the house compounds at night but were taken into surrounding forests to graze freely during the wet season when the paddy fields were occupied by rice. After the harvest, livestock were allowed to freely graze on the straw and stubble remaining in the fallow fields. In the 1970s and 1980s, widespread forest clearance to create upland fields to grow kenaf and cassava reduced the area available for grazing in the wet season, leading to a decline in the number of livestock while adoption of two-wheeled hand tractors during the same period reduced the need for draft animals. At about the same time, farmers began purchasing chemical fertilizer, which they often substituted for more labor-intensive application of manure to the paddy fields (Grandstaff et al., 2008, Rambo, 2017, Simaraks et al., 2003). As will be shown in this paper, on-going rapid urbanization has exacerbated both these trends, contributing to major changes in the use of soil amendments by Northeastern rice farmers.

To better understand how urbanization is affecting soil management practices, we undertook a comparative study of the use of soil amendments in their paddy fields by farmers in three villages located at various points along a rural-urban continuum in Northeast Thailand. The three villages include a highly urbanized community inside the Khon Kaen metropolitan area, a periurban community that is increasingly integrated into the urban economy, and a fully rural community where the impacts of urbanization are still quite limited and farmers mostly continue to employ amendments in traditional ways. In addition to describing the types and quantities of soil amendments used by farmers in these communities, farmers' perceptions of their effects on soil quality and growth of the rice plants, and how use of these amendments has changed during the past decade, we describe changes in the use of soil amendments associated with increasing urbanization, identify factors that influence farmer decision-making about the types and quantities of soil amendments to apply in their paddy fields, and suggest ways to overcome these limits and expand use of locally sourced organic amendments.

2. METHODOLOGY

2.1 Research design

The conceptual framework for this research was provided by the concept of the rural-urban continuum. This continuum is also referred to as the "folk-urban continuum" by anthropologists (Cattaneo, 2022; Miner, 1952; Redfield, 1947), and the "urban-rural gradient" by geographers (Li et al., 2023). Developed by anthropologists and sociologists in the first half of the 20th century as a way to study the direction of social and cultural change, this approach employs space as a surrogate for temporal depth. It is based on the assumption that technological and social innovations first emerge in urban centers and then gradually spread out from these centers to surrounding communities, initially impacting periurban communities and ultimately affecting rural ones. The continuum is like a time machine in that by looking at what is presently going on in urban centers one can predict what will be happening in rural communities in the future. Conversely, by comparing cultural and technological traits in remote rural communities with those in the urban center one can identify the nature of changes resulting from urbanization. The anthropologist Robert Redfield's *Folk Culture of Yucatan* (1941) is one of the best-known examples of the use of the folk-urban continuum as a conceptual framework. Although the concept of the rural-urban continuum has been criticized as overly simplistic, particularly with regard to changes of lifestyles (Pahl, 1966), we believe it remains a useful framework for studying how urbanization affects the agricultural practices and environmental adaptations in communities at various points along the continuum. For example, Nansaior et al.,

(2011; 2013) employed this framework for their research on changing patterns of household energy use in rural, suburban, and urban communities in Northeast Thailand. They showed that more modern types of energy (electricity, LPG) were gradually spreading outward from the urban center along the continuum, but also that traditional energy sources (firewood, charcoal), which were still relied on by most rural households, were still used to a limited extent by urban households. Li et al., (2023) employed the urban-rural gradient as the framework for studying the impacts of land use transitions on habitat fragmentation and degradation in Hangzhou, a rapidly urbanizing area in China. We have been unable to identify any published studies that employed this conceptual framework to the study of changes in agricultural technology, however.

Based on our previous research on agriculture in villages in this region (e.g., Rambo, 2017; Watanabe et al., 2017; Yoda et al., 2021), we expected to find that the farmers in the rural community used larger quantities and a greater variety of organic amendments but less chemical fertilizer than the farmers in the periurban and urban ones. They would also make more use of locally sourced organic materials. Farmers in all three communities who used larger quantities of organic amendments were expected to use less chemical fertilizer.

To implement our research design, we selected three villages based on their distance from the center of the nearest major urban center, in this case Khon Kaen city, the provincial capital of the province of the same name, and their degree of urbanization, measured by the proxies of population density and built-up area. The rural village was 57 km from Khon Kaen city, the periurban village was 25 km from the city, and the urban village was only 7 km from the center of the city. Their population densities were 75, 173, and 1885 people per km^2 respectively, and their built-up areas covered 2 percent, 6 percent, and 26 percent respectively. The communities were similar in having the growing of rain-fed rice as their main agricultural activity. In this regard they are representative of the great majority of Northeastern villages. The three communities are described in the following section.

2.2 Description of the study sites

Three villages at varying distances from a major urban center were selected for study. Two villages were in Khon Kaen province and one in Mukdahan province (Figure 1). Phu village, which will henceforth be referred to as Rural village, is inhabited by members of the Phu Thai ethnic group, Non Ku village (Periurban village) and Nong Kung (Urban village) are both inhabited by members of the Thai-Lao ethnic group. The main agricultural activity in all three villages is cultivation of wet season rain-fed rice.

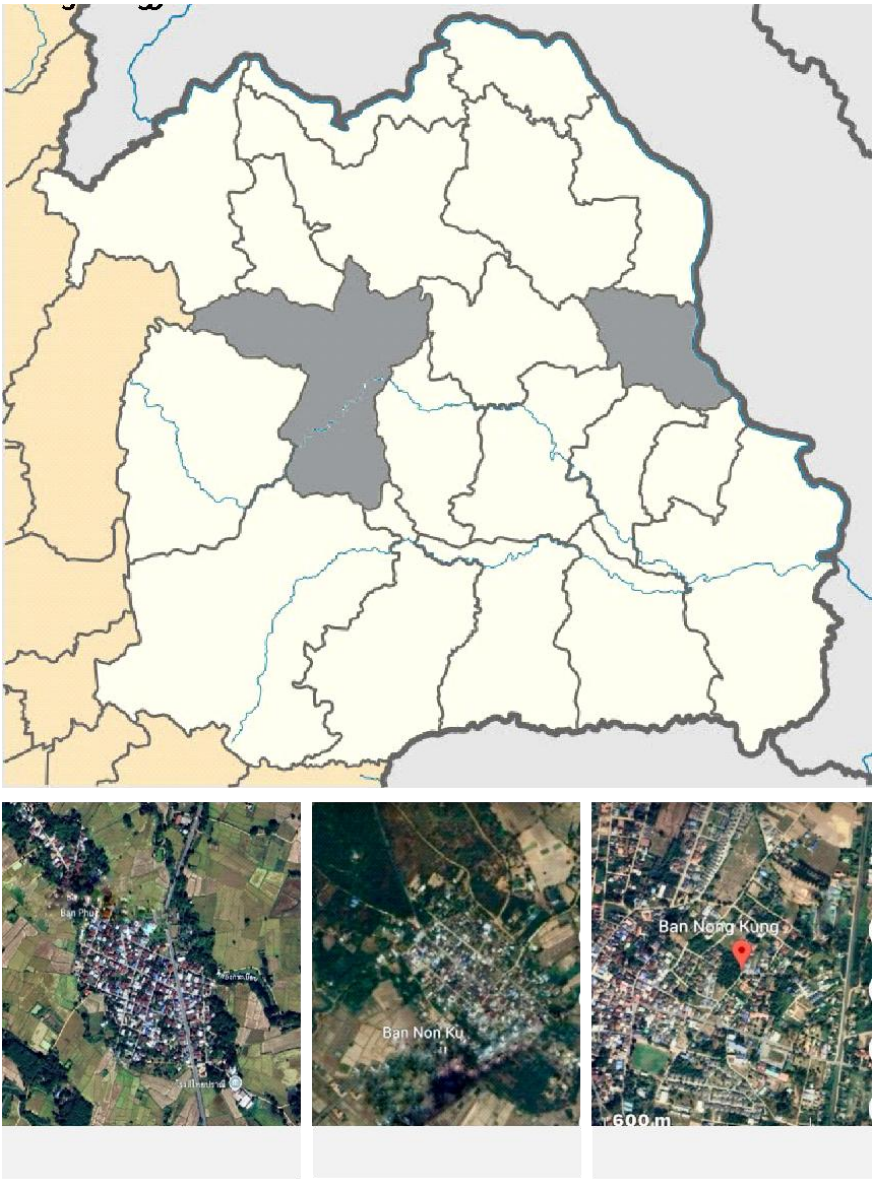


Figure 2. Maps showing the locations of the study sites
[Sources of maps: Thailand: https://shorturl.asia/tQM1Z; Northeast Thailand: https://shorturl.asia/nXx0Z; Village maps: Google Earth images]

Basic information for the study villages is presented in Table 1.

Table 1. Characteristics of the study communities in Northeast Thailand

Village Characteristics	Phu (Rural Village)	Non Ku (Periurban Village)	Nong Kung (Urban Village)
Location	Ban Pao sub-district, Nong Sung	Sawathee sub-district, Mueang	Sila Municipality, Mueang district,

Village Characteristics	Phu (Rural Village)	Non Ku (Periurban Village)	Nong Kung (Urban Village)
	district, Mukdahan province	district, Khon Kaen province	Khon Kaen province
Geographical Coordinates	16°26'27"N, 104°20'03"E	16°30'37"N, 102°39'56"E	16°29'57.36"N, 102°50'19.02"E
Elevation (m amsl)	230	195	177
Landform	Hills and valleys	Undulating terrain	Gently undulating terrain
Distance from the Center of the Nearest Large City (km)	57	25	7
Dominant Ethnic Group	Phu Thai	Thai-Lao	Thai-Lao
Population	755 (2019)	1,059 (2017)	8,333 (2021)
Population Density (people/km²)	75	173	1,885
Total Area (ha)	1,004	613	442
Built-up Area (ha, % of total area)	21 ha (2%) (2024)	38 ha (6%) (2024)	116 ha (26%) (2024)
Paddy Area (ha)	636 (2019)	472 (2017)	87 (2021)
Avg. Paddy Field Area per Farming Household (ha)	1.4	1.2	0.9
Range of Paddy Field Areas (ha, sample of 50 farmers)	0.2–4.0	0.3–3.0	0.2–3.5
No. of Households	264 (2019)	290 (2017)	4,656 (2021)
No. & % of Rice Farming Households	195 (74%)	217 (75%)	88 (2%)
Soil Series	1) Renu (Rn) 2) Warin (Wn) 3) Satuk (Suk) 4) Bang Nara (Ba) 5) Korat (Kt)	Roi-et	Roi-et
Average Annual Rainfall during 1981-2010 (mm)	1,480	1,246	1,246
Main Crops	Rain-fed rice	Rain-fed rice	Rain-fed rice

[Sources of data: Phu village: Phupuak, 2023; Non Ku village: Village records Nong Kung village; Soil series: Phu village; Non Ku village and Nong Kung village]

2.3 Selection of samples of farmers in the three villages

A random sample of 50 farmers was selected for interviewing in each village. Selection criteria were: 1) They were actively engaged in rice farming; and 2) Their fields were located in their village of residence. After the purposes of the study were explained to them and they were assured that their anonymity would be protected, all gave their informed consent to participate in this research. The demographic characteristics of the samples are presented in Table 2.

Table 2. Characteristics of samples of farmers in the rural, periurban and urban villages in Northeast Thailand

Characteristics	Rural village	Periurban village	Urban village
Percentage of all farm households included in sample	25.6	23.0	56.8
Percentages of females/males in the sample	70/30	48/52	66/34

Characteristics	Rural village	Periurban village	Urban village
Age ranges of sample farmers	49-85	44-79	34-81
Average age of sample farmers	64.9	60.2	61.6

2.4 Data collection and analysis

Informants were individually interviewed using a standardized questionnaire about their use of soil amendments in their paddy fields. Data were collected on the types and quantities of soil amendments they applied, the sources and costs of these amendments, methods of applying them, and perceived effects on the rice plants and soil. Limiting factors on the use of different amendments were also identified. Data were entered into an Excel database, and the SPSS program was used for statistical analyses.

In order to identify trends of change along the rural-urban continuum, discriminant analysis was employed. This analysis used data of multiple variables that we had collected from the samples of farmers in each of the villages. This multivariate analysis technique helped to minimize the differences within each village and maximize differences among the three villages. Area of paddy fields, quantity of chemical fertilizer used per hectare, and quantity of organic amendments applied per hectare were identified as three key variables that contributed to the two discriminant functions that can be used to show that these three villages were statistically distinct. The primary goal was to create linear combinations of these predictor variables to maximize the separation between the three villages.

2.5 Limitations on this research

There are some limitations on the extent to which the findings of this research can be generalized. Because of time and budgetary limitations, it was possible for us to study only three villages. These were selected as representatives of the universe of villages within the broad categories of rural, periurban and urban communities. However, given the paucity of reliable data on urbanization in the northeastern region, the extent to which each of the study villages is representative of all villages within its category is unknowable. Indeed, it is not even known how many of the more than 20,000 villages in the Northeast fall into each of these categories. This is a matter for further research. The small sample size also precludes the use of some common statistical techniques, such as regression analysis.

Although the large samples of farmers in each village gives us confidence in the extent to which our findings accurately represent the use of soil amendments in each community, it should be recognized that quantitative data on amounts and costs of amendments used are derived from recall interviewing rather than from direct measurements. However, since errors in farmer responses are likely to be random, without any directional bias, we are confident that the major differences we found among the communities are valid.

An inherent problem in using the rural-urban continuum as a research framework is the difficulty of distinguishing the effects of urbanization from those of more general modernization. In Northeastern Thailand, as in many parts of Southeast Asia, even remote rural villages are affected by the forces of modernization, and are developing many characteristics of urban centers, a process sometimes referred to as “rurbanization.” Thus, many goods and services (e.g., convenience stores, clinics and pharmacies, mobile phones and internet connections, chemical fertilizer and pesticide shops), that were formerly only accessible to urban dwellers, are now routinely used by rural villagers (Rambo, 2017). Rural industrialization is also impacting nearby villages

in ways that resemble the effects of urbanization, as has occurred in villages within commuting distance of several large factories in Nam Phong district, Khon Kaen province, in Northeast Thailand (Shirai et al., 2017). Although there is no certain way to distinguish the effects of modernization from those of urbanization, comparison of communities at various points on the rural-urban continuum may provide a partial solution to this problem. For example, use of chemical fertilizer occurs at relatively high frequencies in all communities, although higher percentages of farmers in the periurban and urban villages apply it then in the rural village, and they also tend to use larger quantities. All farmers in all of the villages have tried using chemical fertilizer and only a few have discontinued using it and its widespread adoption occurred before the effects of urbanization were widely felt so its use can be attributed to modernization. Indeed, the Thai government agricultural extension agents have been vigorously promoting chemical fertilizers throughout the country since the 1980s. In contrast, the recent sharp decline in the share of farmers applying livestock manure has occurred only in the periurban and urban villages, but not the rural ones, so can confidently be attributed to the impact of urbanization.

3. RESULTS AND DISCUSSION

3.1 Soil amendments used by farmers in rural, periurban, and urban villages

Farmers in all three villages used the same nine types of amendments, including rice straw and stubble, chemical fertilizer, tree leaf litter, livestock manure, chicken and pig manure, rice husks, homemade compost, sunn hemp, and commercial compost. For each kind of amendment, we will describe how it is used, its effects on the soil and rice plants as perceived by the farmers, the number of farmers in each village who used it, and constraints on the quantities used by farmers:

1) Rice straw and stubble: After the rice harvest, those farmers who own livestock collect some of the straw to use later to feed their animals. During the fallow period, buffalo and cattle are allowed to freely graze on the straw and stubble remaining in the fields. At the beginning of the rainy season, all the farmers in all the villages plowed under the rice straw and stubble that remained in their fields from the previous harvest. They believe that these residues make the soil softer and less compact, so the rice plants grow better. At the time when the data were collected no farmers burned their fields but recently several farmers in the periurban village were observed burning straw and stubble in their fields to destroy weeds. A few farmers in the periurban village and one farmer in the urban village reported that they had sold some of their straw to owners of livestock. There are no constraints on the use of this amendment by farmers.

2) Chemical fertilizer: Most farmers in all three villages applied chemical fertilizer in their fields. The most used fertilizers were urea and various mixtures of nitrogen (N), phosphorus (P), and potassium (K). They hand broadcast fertilizer twice, once before tillering and a second time before the rice plants enter the flowering stage. On average, farmers in more urbanized villages applied more chemical fertilizer than those in the rural village: The farmers in the rural village applied an average of 100 kg/ha, those in the periurban village applied 155 kg/ha and those in the urban village applied 160 kg/ha. The farmers said that fertilizer promotes the growth of healthy green rice plants but that excessive use made the soil harder. The main constraint on the amount of chemical fertilizer used by farmers is its high cost. Elderly farmers also are unable to carry heavy bags.

3) Tree leaf litter: Some farmers in all three villages used tree leaf litter as a soil amendment. This is a traditional practice of farmers in Northeast Thailand (Vityakon, 1993). The litter has two sources: Trees growing in the paddy fields and on the paddy bunds and trees growing in the house compounds of the farmers. In the former case,

the leaf litter falls naturally into the fields during the dry season and is later plowed into the soil before the rice is planted. In the latter case, the farmers pick up the fallen leaves and transport them from their houses to their paddy fields. Farmers in all three villages observed that the leaf litter made the soil less compact and that the rice plants looked healthy and had a deep green color. A larger share of the farmers used tree leaf litter in the rural villages (84%) than in the periurban (66%) and the urban (48%) villages. The number of trees in the paddy fields of the 50 sample farmers is also much larger in the rural village (1,719 trees), than in the periurban village (285 trees), and the urban village (246 trees). On an areal basis this is an average of 24.9 trees per hectare in Rural village, 4.6 trees/ha in periurban village, and 5.6 trees/ha in Urban village. Only a few farmers collected leaf litter from the trees in their house compounds. The amount of tree leaf litter used by farmers is limited by the relatively small number of trees in the paddy fields and house compounds and the extra labor required to collect tree leaves from their compounds.

4) Livestock manure: Some farmers in all three villages applied livestock manure to their paddy fields. Most obtained it from their own cattle and buffalo; others obtained it for free from relatives who owned livestock or bought it from neighbors. The manure is applied during the dry season before plowing. Some farmers spread the dry manure by dragging open bags of it across their fields, others deposited it in small piles scattered around the fields and others broadcast it by hand. The farmers said livestock manure makes the soil less compact and easier to plow, and the rice plants have a deep green color and tiller well. A much larger share of farmers in the rural village (70%) applied manure than in the periurban (32%) and urban (34%) villages. The rural farmers also applied much larger quantities of manure per hectare (an average of 1,272 kg/ha) than farmers in the periurban (651 kg/ha) and urban (647 kg/ha) villages. The number of livestock kept by sample farmers in the rural village was much larger (140 cattle) than in the periurban (38 cattle and 17 buffalo) and the urban (28 cattle and 38 buffalo) villages. The average number of livestock per hectare of paddy field was much larger in the rural village (2.03 head/ha) than in the periurban (0.89 head/ha) and in the urban (1.49 head/ha) ones. The main constraints on use of livestock manure are the insufficient supplies of this material, its high cost, and the extra labor needed to transport and spread manure in the paddy fields.

5) Chicken and pig manure: Some farmers in all villages applied chicken or pig manure to their paddy fields. In the rural village, chicken manure was purchased from brokers who transported it to the village from commercial poultry farms. A few farmers in all three villages obtained it from their own chickens. Pig manure was obtained from their own pigs or given to them for free by relatives. The farmers applied these manures by dragging open bags across their fields before the first plowing. They said that it makes the soil softer and easier to plow and the rice plants grow well. Eighteen households (36%) in the rural village applied chicken and/or pig manure in their paddy fields, while three households (6%) in the periurban village and only two households (4%) in the urban village used it. The limited supply and high cost of these materials are the main constraints on the amount used by farmers.

6) Rice husks: Farmers in all three villages used rice husks as a soil amendment. They purchased rice husks from the village rice mills. They only applied rice husks in plots where the soil had become too compact. Farmers spread it on the soil surface by dragging open bags of it across these plots before the first plowing. They said that it made the soil softer and easier to plow. Sixteen households (32%) in the rural village applied rice husks while only four households (8%) in the periurban village and two households (4%) in the urban village applied it. The main constraints on the use of rice husks are the limited available supply and high cost. Although the rice mills formerly

gave rice husks for free to farmers, now they sell most of the rice husks to brokers who resell them to commercial customers.

7) Homemade compost: Some farmers in all three villages received training from the Land Development Department (LDD) and others watched videos on social media about how to produce their own compost from kitchen wastes. The liquid is poured into water flowing into the paddy fields after the rice is already growing there. They said the rice plants grow vigorously and have a deep green color. Homemade compost was used by 10 households (20%) in the rural village, seven households (14%) in the periurban village and five households (10%) in the urban village. Because homemade compost is very difficult to make, and the quantities produced are very small, use of this amendment remains limited.

8) Sunn hemp: In all three villages the growing of sunn hemp (*Crotalaria juncea*) as a green manure crop after the rice harvest has been promoted by LDD, which in some years provided small quantities of free seed to some farmers. The sunn hemp seed is broadcast by hand on fields which have been plowed immediately after the rice harvest. At the beginning of the rainy season the sunn hemp plants are plowed in before planting the new rice crop. Farmers said that the rice plants had a healthy green color for the whole growing season and tillered vigorously in plots where the sunn hemp had been plowed in. However, only a few farmers in each village planted sunn hemp: Only four households (8%) in the rural village, three households (6%) in the periurban village and four households (8%) in the urban village grew sunn hemp in the study year. The main constraints on the amount of sunn hemp grown are difficulties in obtaining seed and the extra costs to the farmers of plowing the field after the rice harvest and sowing the sunn hemp seed.

9) Commercial compost: Some farmers in all three villages used commercial compost as a soil amendment. They broadcast it by hand either before the second plowing or about one month after planting the rice. The farmers said that the rice plants grew well and had a deep green color. Commercial compost was applied by three households (6%) in the rural village, six households (12%) in the periurban village, and 11 households (22%) in the urban village. The main constraints on the use of commercial compost are its high cost and difficulties faced by elderly farmers in handling the heavy bags in which it is sold.

3.2 Differences among the villages in the use of different kinds of amendments

Although farmers in all three villages made use of the same kinds of soil amendments, there was considerable variation among the villages in the number of farmers using each kind of amendment (Figure 2). Only rice straw and stubble were used by all farmers in all villages. Chemical fertilizer was used by almost all farmers in all the villages, although a significant minority in the rural village (16%) did not use this amendment. Except for commercial compost, which was used by a larger share of farmers in the urban (22%) and periurban (12%) villages than in the rural (6%) community, all other kinds of organic amendments were more widely used in the rural village than in the periurban and urban villages. For example, tree leaf litter was used by 84 percent of rural farmers but only 66 percent and 48 percent of periurban and urban farmers, respectively, and livestock manure was used by 70 percent of rural farmers, but only 32 percent of periurban and 34 percent of urban ones. These differences reflect, to a large extent, the position of the villages on the rural-urban continuum.

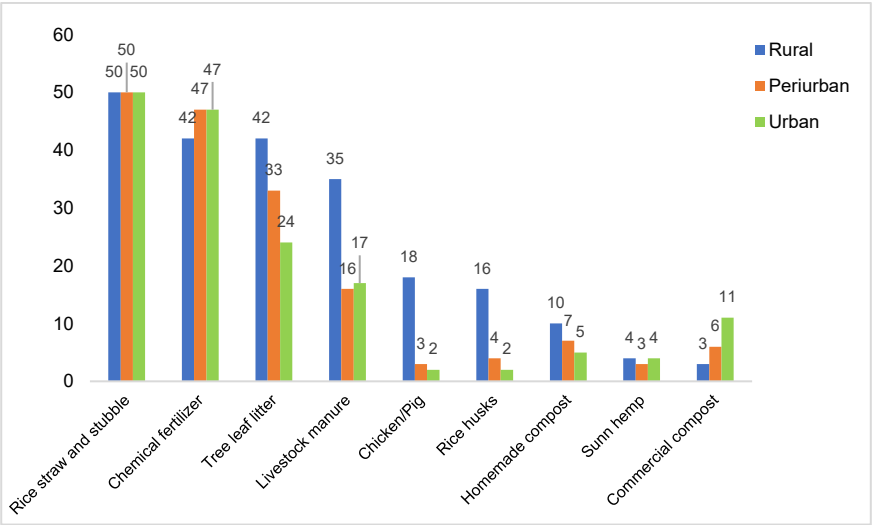
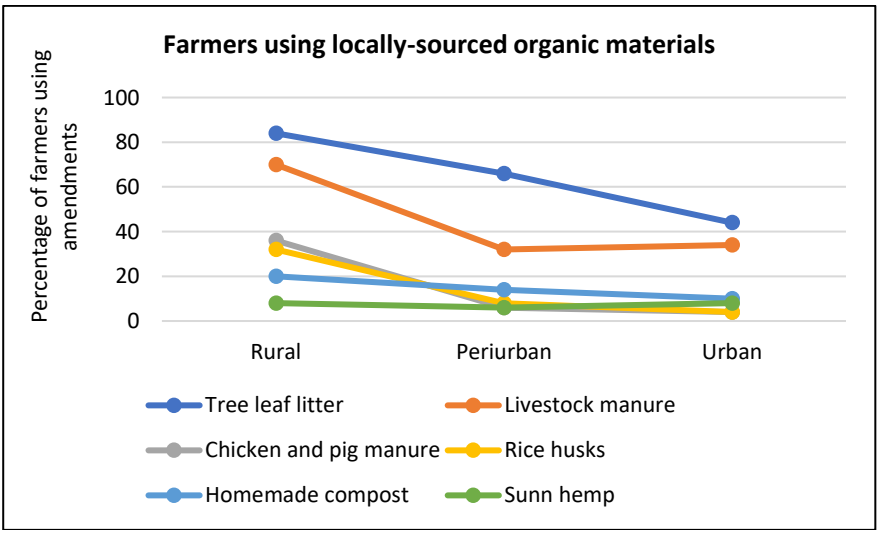


Figure 2. The number of farmers currently using each kind of soil amendment in the three villages.

Two trends are evident as one moves along the continuum from rural to urban (Figure 3). The first trend is a decline in the share of farmers applying locally sourced organic amendments: Tree leaf litter, chicken and pig manure, rice husks, and homemade compost show a linear decline as one move toward the urban end of the continuum. Use of livestock manure drops sharply from the rural village to the periurban village but then essentially levels off. The second trend is the increased use of industrially produced amendments as one moves from rural to urban communities. Chemical fertilizer and commercial compost are used by larger shares of farmers in the periurban and urban villages than in the rural ones. Both trends are causally related to the differential impacts of urbanization in the communities.



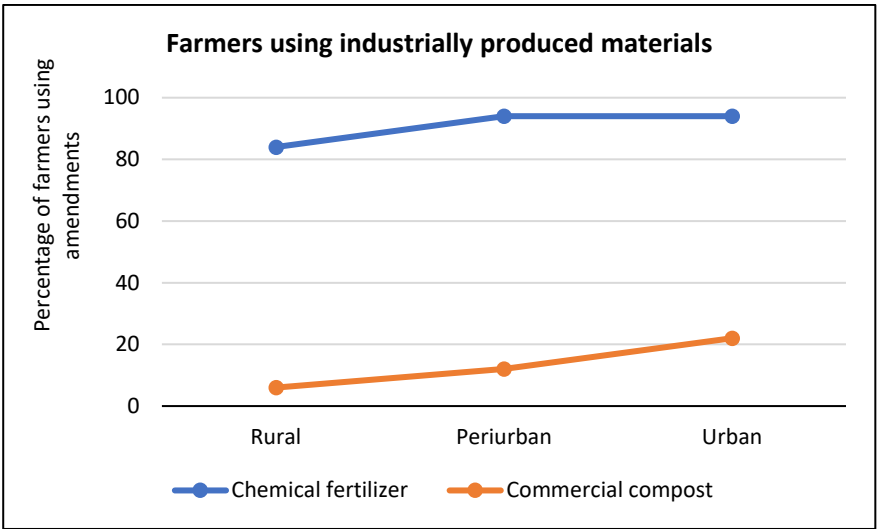


Figure 3. Trends in the share of farmers using locally sourced organic amendments and industrially produced materials in villages along the rural-urban continuum

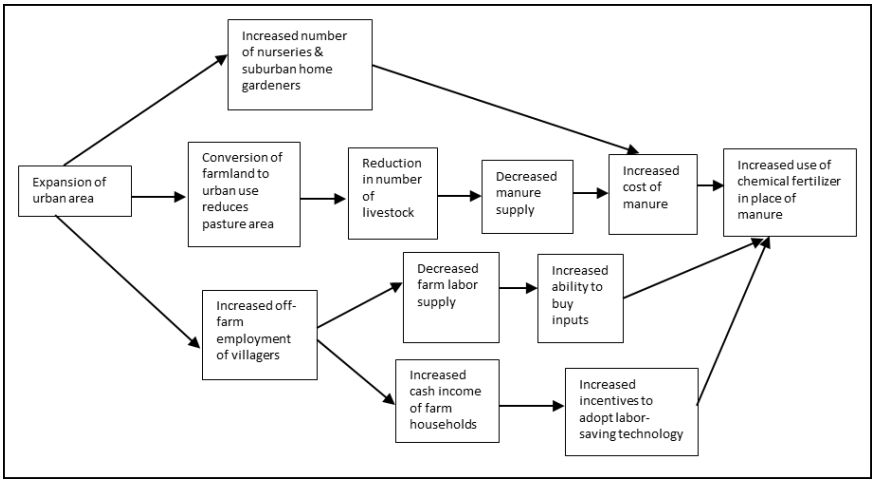


Figure 4. Linkages between urbanization and changes in the number of farmers using manure and chemical fertilizer in Urban village.

These trends reflect farmer responses to several interrelated changes associated with urbanization, including changers in the availability and cost of amendments, changes in labor costs, and changes in the financial resources of farm households. Figure 4 depicts the complex causal chain through which urbanization causes farmers to substitute chemical fertilizer for livestock manure in Urban village. The decline in the number of farmers using livestock manure can be attributed to the reduction in the number of cattle and buffalo which reflects the decrease in grazing area resulting from conversion of paddy fields to housing estates and other urban uses. This has resulted in a reduced supply of manure at the same time as there is increased demand for this resource from nurseries and suburban home gardeners causing its price to rise making it too expensive for many farmers to buy. At the same time, agricultural labor shortages resulting from the increased number of villagers having off-farm employment in the urban sector are an incentive for farmers to adopt labor-saving technologies like

chemical fertilizer. Farm households can afford to purchase fertilizer with cash earned by members with off-farm employment in the urban sector.

3.3 The number of different amendments applied by individual farmers in the three villages

Individual farmers commonly used more than just one type of amendment. Table 3 shows the number of different amendments used by individual farmers in each village.

Table 3. Number and percentage of farmers using different numbers of organic amendments

Village	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)	6 (%)	Average
Rural	1 (2)	6 (12)	16 (32)	11 (22)	8 (16)	8 (16)	3.8
Periurban	11 (22)	20 (40)	8 (16)	6 (12)	4 (8)	1 (2)	2.5
Urban	9 (18)	19 (38)	13 (26)	6 (12)	2 (4)	1 (2)	2.5

Farmers in all three villages used from one to six types of organic amendments but individual farmers in the rural village tended to use more different types of amendments than those in the periurban and urban villages. On average, farmers in the rural village used 3.8 different amendments while farmers in the periurban and urban villages used an average of 2.5 types. More than half (54%) of rural farmers applied four or more types of amendments, whereas only 22 percent of periurban farmers and 18 percent of urban ones used four or more different amendments. In contrast, more than half of the farmers in the periurban and urban villages, but less than one-quarter of the rural farmers, used only one or two kinds of amendments. These differences may reflect the greater ease with which rural farmers can obtain diverse types of organic amendments.

3.4 Changes over the past decade in the use of different kinds of soil amendments

There have been several changes during the past 10 years in the popularity of soil amendments used by the farmers in all the villages (Table 4).

Table 4. Changes in the percentages of farmers using different soil amendments in the three villages during the last 10 years

Soil amendment	Rural village (n=50)	Periurban village (n=50)	Urban village (n=50)
Rice straw and stubble	C = 100%	C = 100%	C = 100%
	F = 0%	F = 0%	F = 0%
	N = 0%	N = 0%	N = 0%
Chemical fertilizer	C = 82%	C = 94%	C = 94%
	F = 18%	F = 6%	F = 6%
	N = 0%	N = 0%	N = 0%
Tree leaf litter	C = 84%	C = 66%	C = 48%
	F = 8%	F = 10%	F = 10%
	N = 8%	N = 24%	N = 42%
Livestock manure	C = 70%	C = 32%	C = 34%
	F = 20%	F = 60%	F = 52%
	N = 10%	N = 8%	N = 14%
Chicken manure	C = 26%	C = 4%	C = 2%
	F = 12%	F = 12%	F = 10%
	N = 62%	N = 84%	N = 88%
Pig manure	C = 10%	C = 2%	C = 2%
	F = 10%	F = 14%	F = 16%
	N = 80%	N = 84%	N = 82%
Rice husks	C = 32%	C = 8%	C = 4%
	F = 44%	F = 18%	F = 12%

Soil amendment	Rural village (n=50)	Periurban village (n=50)	Urban village (n=50)
	N = 24%	N = 74%	N = 84%
Homemade compost	C = 20%	C = 14%	C = 10%
	F = 14%	F = 2%	F = 6%
	N = 66%	N = 84%	N = 84%
Dolomite	C = 22%	C = 4%	C = 8%
	F = 40%	F = 22%	F = 44%
	N = 36%	N = 74%	N = 48%
Sunn hemp	C = 8%	C = 6%	C = 8%
	F = 48%	F = 28%	F = 10%
	N = 44%	N = 66%	N = 82%
Commercial compost	C = 6%	C = 12%	C = 22%
	F = 4%	F = 18%	F = 20%
	N = 90%	N = 70%	N = 58%

Note: C = Currently use; F = Formerly used; N = Never used

Some farmers in all the villages have ceased applying formerly popular amendments while starting to use new types but the changes are most pronounced in the urban and, to a somewhat lesser extent, the periurban villages. Changes have also occurred in the rural village, but to a much lesser extent. Only use of rice straw and stubble has not changed, with all farmers in all three villages using these residues 10 years ago and all continuing to do so now. Use of livestock manure has suffered the greatest decline. Whereas the share of farmers using this amendment formerly exceeded 80 percent in all three villages, it has fallen to 70 percent in the rural village, and 32 percent and 34 percent in the periurban and urban villages, respectively. This reflects the sharp decreases in the number of livestock in both communities during this period. Use of tree leaf litter has declined in all villages but most markedly in the periurban and urban villages. Use of rice husks has declined markedly in the rural village, where 22 farmers (44%) who formerly used this amendment have discontinued using it, while nine farmers (18%) in the periurban village, and six farmers (12%) in the urban village who used to apply it have discontinued using this amendment because supplies are limited and the rice mills, that formerly allowed farmers to take it for free, now charge them for it. The number of farmers growing sunn hemp declined most in the rural and periurban villages, but not in the urban village, where few farmers ever grew this green manure crop. Farmers cited difficulties in obtaining seed and the cost of the extra plowing required to prepare the fields before seeding as the main reasons for abandoning use of sunn hemp.

3.5 Quantities of organic amendments and chemical fertilizer used by farmers in the three communities

With the exception of rice straw and stubble, which were used by all of the farmers, the share of farmers applying organic amendments varied greatly among the villages (Table 5). Most farmers (84 %) in the rural village applied one or more types of organic amendments while only about half of the farmers in the periurban and urban communities applied these materials. Eight farmers (16%) in the rural village relied entirely on organic amendments while only 6% of farmers in the periurban and urban villages relied exclusively on organic amendments. In contrast, only 14% of farmers in the rural village relied exclusively on chemical fertilizer whereas 48% of farmers in periurban village and 46% of farmers in Urban village did so.

On average, farmers in the rural village applied much greater quantities of organic materials (1,945 kg/ha) and considerably lower quantities of chemical fertilizer (100.3

kg/ha) than farmers in the periurban and urban villages, who applied 451.5 kg/ha and 737 kg/ha of organic amendments and 155.4 kg/ha and 160.1 kg/ha of chemical fertilizer, respectively. Several factors may contribute to these differences including the greater ease with which rural farmers can obtain organic materials, the higher labor costs faced by periurban and urban farmers, and their greater affluence than rural farmers which allows them to purchase more chemical fertilizers.

Table 5. Quantities of organic amendments and chemical fertilizer by farmers in the three villages (n=50 per village)

	Rural village	Periurban village	Urban village
No. of farmers applying organic amendments (other than rice straw and stubble)	42	26	25
No. of farmers relying exclusively on organic amendments	8	3	3
Range of amounts of organic amendments applied in kg/ha	150-10,228	9-3,000	38-3,516
Average amount of organic amendments applied in kg/ha	1,945	542	737
No. of farmers applying chemical fertilizer	42	47	47
No. of farmers applying only chemical fertilizer	7	24	23
Range of amounts of chemical fertilizer applied in kg/ha	1-313	52-469	63-375
Average amount of chemical fertilizer applied in kg/ha	100	155	160
No. of farmers applying both organic amendments and chemical fertilizer	35	23	24

Note: Weights of organic amendments includes only those materials for which farmers could tell us the quantities they used. It does not include rice straw and stubble, tree leaf litter, sunn hemp, and homemade compost.

3.6 Relationship between quantities of organic amendments and chemical fertilizer used by farmers in the three villages

In order to determine if there was a relationship between the amounts of organic materials and chemical fertilizers used by the same farmers in each village, we first constructed scatter diagrams and plotted trend lines (Figures 5a, 5b, and 5c). The trends were similar in all three villages, e.g., farmers who used more organic amendments used less chemical fertilizer. When the data from each village were subject to T-tests, the periurban and urban villages were found to be statistically significant at the 95% level of confidence (P = 0.05) while the rural village was weakly significant at the 90% confidence level (P = 0.10). The weaker association found in the rural village may reflect the fact that most farmers there applied relatively low levels of chemical fertilizer regardless of how much organic material they used.

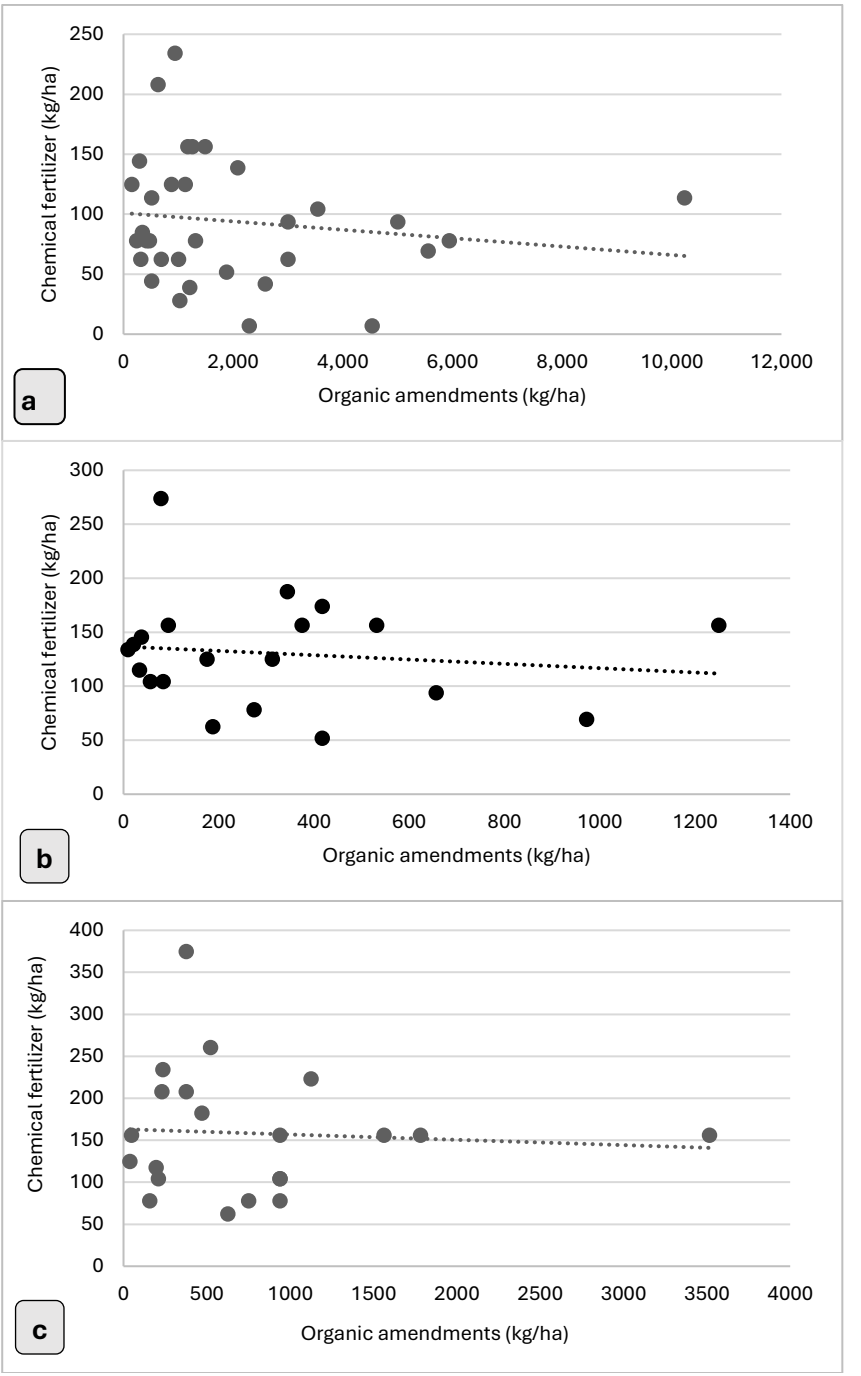


Figure 5. Scatter diagrams showing the relationship between quantities of organic amendments and chemical fertilizer used by farmers in the three villages: [a] Rural village (N=33); [b] Periurban village (N=20); [c] Urban village (N=24).

3.7 Changes in the quantities of organic amendments and chemical fertilizer applied by farmers in communities along the rural-urban continuum

We employed discriminant analysis to compare the three villages in terms of three dependent variables: 1) Area of paddy fields of all farmers, 2) the quantity of organic amendments (in kilograms per hectare) they applied, and 3) the quantity of chemical fertilizer (in kilograms per hectare) they applied. When the equality of group means is tested to determine whether the mean of the dependent variable was significantly different across the villages, it showed clearly that all the group means for paddy field area, quantity of organic fertilizer applied, and quantity of chemical fertilizer applied, were significantly different. (Table 6)

Table 6. Discriminant Analysis of the Three Villages: Tests of Equality of Group Means

Variable	Wilks' Lambda	F	df1	df2	Sig.
Paddy field area	0.933	5.296	2	147	0.006
Organic fertilizer	0.806	17.638	2	147	0.000
Chemical fertilizer	0.873	10.658	2	147	0.000

These three variables are strongly correlated with the position of the communities on the rural-urban continuum. As one moves along the continuum from the rural end to the urban end, the paddy area decreases, the amounts of organic amendments applied decreases, and the amounts of chemical fertilizer applied increases. However, the rate of change along the continuum does not appear to be perfectly lineal. As Figure 6 shows, the periurban village is more similar to the urban village than it is to the rural one. This suggests that the rate of change is not constant along the rural-urban continuum but instead is faster in villages closer to its urban end.

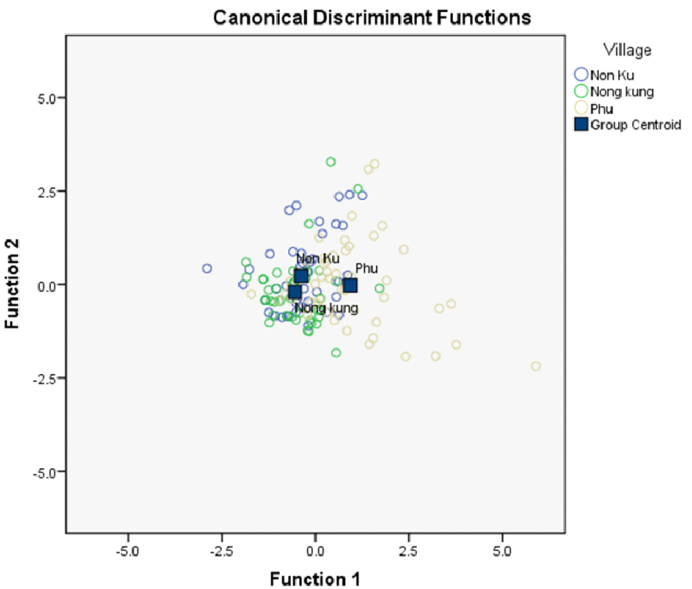


Figure 6. Relative similarity of the three villages in terms of mean paddy areas and application rates of organic amendments and chemical fertilizer.

3.8 Factors influencing farmer use of soil amendments

Multiple factors influence farmer decision-making about use of soil amendments. There is a large body of literature about farmer decision-making (see Taramuel-Taramuel et al., 2023 for a review of different factors) but relatively little attention has been paid to factors influencing their use of soil amendments. However, several of the general factors that have been identified have evident relevance to decision-making about use of soil amendments, including the availability and cost of material inputs and labor, the personal capacities of the farmers, the opportunity cost to the farmers, the financial assets of farm households, and the availability of government technical and financial support. These factors are all in play in our study villages. The availability of many organic amendments has declined. For example, the supply of tree leaf litter has been reduced by cutting of large trees in paddy fields to allow use of labor-saving machinery (Watanabe et al., 2017) and the supply of livestock manure has decreased due to the steep fall in the number of cattle and buffalo in the region (Simaraks et al., 2003) with consequent increase in the price of this material. In their review of studies of periurban and urban agriculture worldwide, Follmann et al., (2021) found that shortages of natural organic materials was commonly a constraint on use of these materials by urbanized farmers. Labor shortages due to out-migration of young working age villagers, expansion of off-farm employment of remaining farmers, and aging of the rural population have increased the cost of agricultural labor and motivated farmers to adopt labor-saving technology (Rambo, 2017). In our more urbanized study sites, labor shortages and resulting increased costs of hiring agricultural workers have encouraged farmers to decrease their use of organic materials and apply greater quantities of chemical fertilizer. A similar finding was reported by Presuse et al. (2024) in their study of the effects of urbanization on adoption of sustainable agricultural practices, including soil fertility management using organic measures; they found that adoption rates were negatively correlated with increased wages in areas closest to Bangalore City. Follmann et al., (2021) reported that agricultural labor supply was affected by two contradictory trends, with labor shortages due to young people taking jobs in the urban sector which were sometimes offset by migration of rural people into urban areas increasing the farm labor supply. Only the former trend is evident in our study communities. At the same time as farm households in Northeast Thailand are facing higher labor costs, many of them have greater cash income provided by remittances from young members working in urban jobs and local off-farm employment which allows them to buy chemical fertilizer and other inputs (Grandstaff et al., 2008).

These factors are operative in our study villages. For example, use of chemical fertilizer is limited by cost, although this was particularly true in the rural village where fewer farmers earn cash from off-farm employment that they can use to buy agricultural inputs. In the periurban and urban villages use of many organic amendments is limited by supply shortages. Supplies of livestock manure have fallen due to the decline in numbers of cattle and buffalo in these communities. Tree leaf litter has become scarcer due to the decreased number of trees in paddy fields in these communities, and rice husks, which used to be given to the farmers for free by the rice mills, are now sold because of demand from commercial users of this material. In all three villages planting of sunn hemp as a green manure is limited by difficulties in obtaining seed and the extra cost of growing this crop. Some elderly farmers reported that they lacked the strength to carry the heavy bags of chemical fertilizer and commercial compost which limited their ability to use these materials.

4. CONCLUSION

In the latter third of the last century and continuing at an ever-accelerating rate until the present, the rural population of Northeast Thailand became caught up in a process commonly referred to as agrarian transformation. This transformation is driven by the shift from subsistence-orientation to cash orientation of farm households, the replacement of human and animal power with mechanization, the adoption of modern technology including improved crop varieties and chemical fertilizers and pesticides. It involves a major restructuring of agriculture and rural society with changes in all components of the agricultural system, including technology, economic orientation, social relations, and cultural values (Rambo, 2017). It also involves a profound change in the relationship of farmers to their environment as locally produced resources are replaced with manufactured ones, wholesale destruction of biologically diverse natural ecosystems, particularly forests, and their replacement with monocultural agroecosystems, and the areal expansion of the resource base of rural households from a few square kilometers to virtually the entire globe. It is in this context that the changes in use of soil amendments by Northeastern rice farmers described in this paper are occurring. Thus, they are not random or isolated occurrences but are part of a general process of agrarian transformation that is occurring everywhere in the developing world.

Expansion of cities into the surrounding countryside is transforming agriculture, not just on surviving farms in the urban fringe, but in periurban and rural communities as well. Our study of the use of soil amendments by rice farmers living at various points along a rural-urban continuum in Northeast Thailand, has revealed that the direction of change is clear. As their villages become more urbanized, farmers apply lower amounts of organic amendments, and larger amounts of chemical fertilizer to their paddy fields, and a growing share of farmers apply only chemical fertilizer. This shift reflects supply shortages of organic materials, their high costs, and the lack of labor to apply these materials in urbanizing villages. Even those urban farmers who still use organic amendments tend to make use of fewer types and are more likely to purchase these materials from commercial sources outside their community instead of obtaining them from local natural sources. This shift reflects the declining number of cattle and buffalo and the decreasing number of trees as well as farm labor shortages in urbanizing villages. These trends, although resulting from rational decision making by individual farmers, are contrary to the Thai government's agricultural policy to implement "environmentally friendly agriculture" and promote organic farming in order to increase rural incomes and ensure sustainable use of agricultural resources (Office of Agricultural Economics, 2017). This is a laudable goal, but policy makers need to take full account of the actual situation in which farmers operate. In their current situation, the majority of urbanizing farmers will have great difficulty in fully adopting organic farming. Policy makers need to be concerned with finding ways to overcome the constraints on use of organic amendments in periurban and urban villages.

A serious consequence of these changes in the use of soil amendments by urbanizing farmers is likely to be the long-term degradation of soil quality in paddy fields in urban and periurban communities. Finding ways to reverse this trend and increase the quantity of organic materials applied by urbanizing farmers should be a research priority. This is easier said than done, however. For example, it is well established that sunn hemp sown after the rice are harvested can improve soil quality but few farmers in the urban and periurban villages planted this green manure crop because of difficulties in obtaining seed and the extra costs associated with its cultivation. Alternative green manure species that minimize these constraints should

be identified and tested on urban farms. Research should also be pursued on identifying fast-growing leguminous trees that can be planted on paddy bunds to provide more tree leaf litter. Species with narrow canopies that do not cast a wide shadow that reduce rice yields are needed. Developing composting methods for agricultural residues that are not labor intensive could boost the local supply of organic amendments. Vermiculture may be one useful method although its scalability remains in question. If these research initiatives are successful, they can increase the quantities of organic amendments that farmers can produce themselves, thus boosting the self-reliance of these farmers, which is a key aspect of resilience and adaptability in the face of unpredictable economic and environmental changes. Although the specific solutions to countering soil degradation resulting from urbanization are likely to differ in different parts of the world, and will vary according to local environmental, economic, and sociocultural characteristics, the challenges presented to agricultural sustainability by increased urbanization are not restricted to Northeast Thailand, they are universal.

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