The Patterns of Spread and Economics of a Labor-Saving Innovation in Rice Production: the Case of Direct Seeding in Northeast Thailand

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Abstract

Direct seeding of rice, a method that saves labor relative to the traditional labor-intensive practice of transplanting, is spreading in tropical rice areas of Asia in response to rising scarcity of farm labor. The current paper, based on farm-level data, provides an updated analysis of the patterns of spread of direct seeding and its economics in northeast Thailand, a major rainfed rice-growing area. The results indicate that direct seeding accounted for 38% of the rice area in 2009, with the rate of spread during 1996-2009 being about one percentage-point per year. The yield of direct-seeded rice increased over time with farmer experience with this method. This has led to improvements in profitability and technical efficiency of direct-seeded farms. Despite the underlying trend towards expansion of direct seeding, there are considerable seasonal fluctuations and spatial variations in the spread of the method. Implications of this for further technological development are derived.

Keywords: rice, dry seeding, northeast Thailand, farm labor shortage, technical efficiency
JEL: O33

1 Introduction

Labor is an important agricultural input but it is rapidly moving out of the farm sector in the process of economic growth and structural transformation of Asian economies. The rising scarcity of farm labor is inducing various labor-saving adjustments in agricultural production. These include mechanization of farm operations for land preparation, harvesting and threshing. In the context of producing rice, a major staple of Asia, an important labor-saving method is direct seeding in which farmers establish rice seeds directly as opposed to the labor-intensive traditional practice of transplanting[1]. Although transplanting remains the dominant method of establishing rice in large parts of Asia (PANDEY and VELASCO, 2002), there has been an increasing adoption of the direct seeding method for reducing labor use in rice-growing areas of tropical Asia. Mechanical transplanting is another such labor-saving method, but its use has been limited mainly to temperate rice-growing areas of Asia such as Japan, Taiwan, Korea and parts of China. It is also beginning to spread in tropical Asia but the spread is mainly limited to irrigated areas with good land levelling and drainage. Mechanical transplanting is less suited to rainfed areas where these conditions generally do not exist (BALASUBRAMANIAN and HILL, 2002).

Direct seeding methods, although economically more profitable than transplanting in most cases due to labor saving, may result in a lower yield and a loss in efficiency under farmer field conditions. This is due to a number of reasons including non-uniform planting density, increased weed problems and potential increases in risk, especially under rainfed conditions (PANDEY and VELASCO, 2002). In addition, direct seeding may not be feasible in some areas, especially in bottomlands where poor drainage conditions make transplanting the only viable method. Given the rising labor scarcity and the trend towards expansion of direct seeding methods, it is important to identify the key priorities for technology development for attaining a higher efficiency of rice production in areas that are likely to shift to direct seeding.

Thailand, the top rice exporter in the world and a country experiencing a fast economic growth, provides an excellent example of a rapid shift from traditional transplanting to direct seeding. In the intensively cultivated irrigated rice bowls of central Thailand, the traditional manual transplanting method has largely given way to direct (wet) seeding. In the largely rainfed areas of northeast Thailand, such shifts have been slower, with farmers practicing direct (dry) seeding which is more suited to rainfed conditions (BALASUBRAMANIAN and HILL, 2002). These kinds of adjustments in crop establishment methods and labor use in rice production that are taking place in Thailand are also likely to occur in other parts of Asia with economic growth. An analysis of factors driving the shift in crop establishment method and the consequences of such shifts in Thailand could provide important insights for other countries in the region also.

[1] Transplanting is a traditional method of rice establishment which involves replanting of rice seedlings grown in nurseries on puddled fields. Dry direct seeding (commonly known as “dry seeding”) involves sowing of dry seeds on dry (unsaturated) soils. Wet direct seeding (commonly known as “wet seeding”), on the other hand, involves sowing of pre-germinated seeds in wet (saturated) puddled soils. Dry seeding is mostly practiced in rainfed areas whereas wet seeding is practiced mostly in irrigated areas (BALASUBRAMANIAN and HILL, 2002). Dry seeding can save as much as 50% of the total labor used in a typical farm relative to transplanting (PANDEY and VELASCO, 2002). For a technical review of these and other related labor-saving methods for establishing rice, please refer to BALASUBRAMANIAN and HILL (2002).

An earlier study by PANDEY et al. (2002) analyzed the spread of dry seeding in northeast Thailand. The area under dry-seeded rice increased from less than 5% in 1989 to around 24% of the total rice area in 1995 as farm labor became scarcer in the wake of rapid economic growth. Most of this increase occurred between 1989 and 1992, with the area of dry-seeded rice remaining more or less stable afterwards. In the immediate aftermath of the 1997 financial crisis, the labor supply in Thailand underwent a major change as jobs in the urban and industrial sectors shrank rapidly. Many laborers returned back to their rural base and this increased the supply of agricultural labor. This was a temporary situation that spanned several years but, eventually, the growth of the Thai economy picked up again. The direct-seeded rice area can be expected to have expanded with this. However, there are no recent updates on the nature of adjustment in crop establishment methods and their consequences that occurred in the course of these economic changes.

Theoretical and empirical studies have shown that variations in technology adoption among farm households are generally a function of household characteristics, farm characteristics and policy factors (FEDER et al., 1985; JOSHI and PANDEY, 2006; DOSS, 2006; SUNTHORNPITHUG and KALAITZANDONAKES, 2009; AKINOLA et al., 2010; FOSTER and ROSENZWEIG, 2010; SIMTOWE et al., 2011). An earlier study on the household-level variations in adoption of direct seeding in northeast Thailand also established some of these variables as important determinants (PANDEY et al., 2002). A dynamic process involving farmer learning, adaptation, adoption and dis-adoption takes place as farmer exposure to new technologies increases over time (ROGERS, 2003). In this process, some technologies spread widely, some remain confined to a smaller domain while others are discarded. Typically, the spread of successful innovations follows a sigmoid pattern over time (LIN, 1991; SUNDING and ZILBERMAN, 2001; ROGERS, 2003). This involves an initial uptake by a limited number of farmers who are early adopters and is followed by a phase of rapid spread among the majority of farmers. The spread slows down after this phase of rapid uptake as a ceiling level of adoption is approached, thus producing a typical S-shaped diffusion curve. Based on this process of innovation diffusion, the spread of dry seeding technology, which has been available to farmers in northeast Thailand for over 20 years, could have reached a slowdown phase.

The objective of the current paper is to provide an up-to-date assessment of the economics of direct seeding and the nature of spread of the dry seeding method during wet season – the main rice growing season - in northeast Thailand. Northeast Thailand is a major rice-growing area in Thailand accounting for almost 5 million ha of rice (or about 50% of the total rice area of the country) and about 33% of the total annual rice production in Thailand. Specifically, the objectives of this paper are to (i) provide an update of the extent and patterns of dry seeding in northeast Thailand, (ii) analyze the changes in yield and technical efficiency of dry-seeded rice farmers and (iii) draw implications for rice research for Thailand and broadly for tropical Asia.

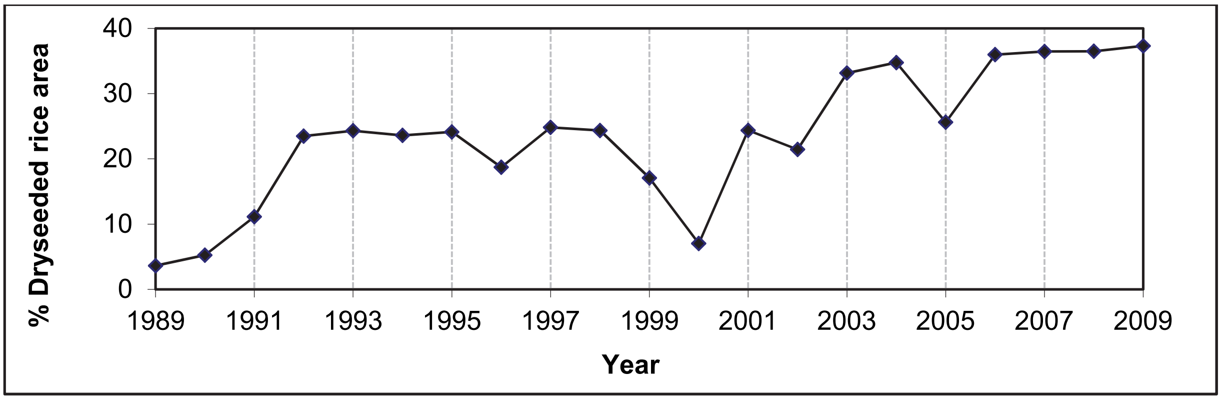
The paper is organized as follows. The first section provides an analysis of the recent trends and pattern of changes in area under dry-seeded rice. This includes both the spatial variations and temporal changes at aggregate and provincial levels. The second section includes a quantitative analysis of factors explaining such changes using pooled provincial cross-sectional and time-series data. The subsequent section includes an analysis of changes in farmer practices, yields, costs/returns and technical efficiency. The final section includes a discussion capturing the research issues related to technologies for improving crop establishment methods for northeast Thailand and broader implications for other rice-growing countries that are likely to undergo similar shifts in crop establishment methods.

2 Trends and Patterns of Dry Seeding in Northeast Thailand

The area under dry-seeded rice in northeast Thailand has expanded over time (Figure 1). The figure shows a clear upward trend in the area of dry-seeded rice but with some sharp drops along the way. Overall, the dry-seeded area is estimated to be around 37% of the total rice area in northeast Thailand in 2009. This long term expansion of dry-seeded area is correlated with the increasing rural wage rates (Figure 2).

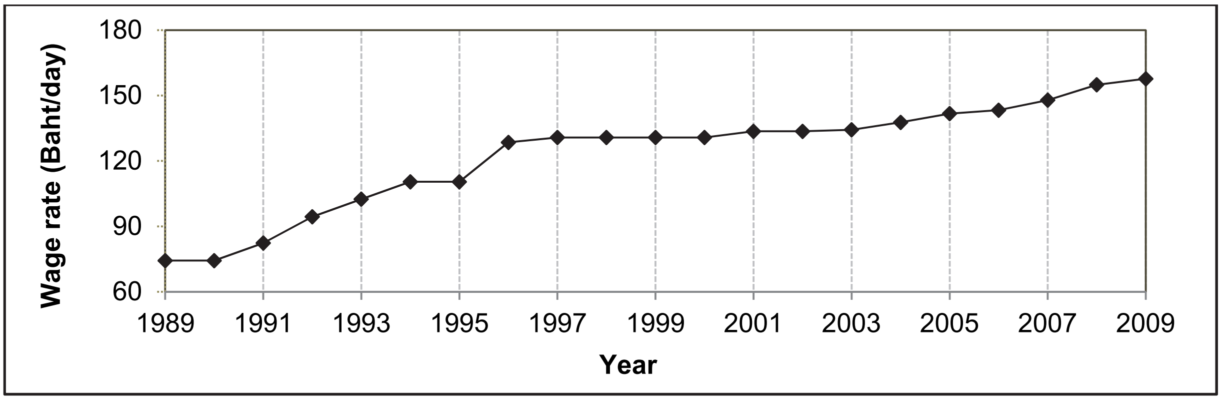
Four distinct phases can be observed in the temporal patterns of change. The first phase covers the period 1989-1992 during which area under dry seeding expanded rapidly from around 4% of the rice area in 1989 to almost 24% in 1992. This expansion took place in response to labor scarcity arising from rapid growth of the non-farm sector in Thailand. In addition, the government actively promoted dry seeding technology during these initial years of adoption (PANDEY et al., 2002). The second phase consists of a stable area of around 24% up until 1998. The third phase started in 1998 with a continued drop in dry-seeded area up until 2000. This decline was mainly in response to the lagged effect of the 1997 financial crisis which saw the return of large number of laborers from urban to rural areas. This influx of labor back to the farm increased the labor supply and transplanting became once again quite attractive. In addition, this phase is characterized by a higher than average rainfall making transplanting a more desirable option due to flooded field conditions. As a result, direct-seeded area in 2000 dropped to just a few percentage points above the 1989 level. This third phase was followed by the final phase of a consistent upward trend in the area under dry seeding as labor began to flow out of the farm sector once again.

Figure 1. Expansion of dry-seeded rice area in northeast Thailand



Data source: Office of Agricultural Economics (Thailand), www.oae.go.th

Figure 2. Trend in nominal wage rate in northeast Thailand



Data source: Ministry of Labour, www.MOL.go.th

3 Spatial Pattern of Change

The spatial pattern of change in dry seeding is depicted graphically in Figure 3. During 1989-1991, the spread of dry seeding was limited to three provinces in the south-western corner of the region (Figure 3a). The three provinces (Chaiyaphum, Nakhon Ratchasima and Buri Ram), which together account for about 1 m ha of rice area, had about 19% under dry seeding over the period 1989-1991. The remaining four million ha of rice area in northeast Thailand were mostly transplanted. The spread of dry-seeded area is depicted in Figures 3b and 3c which show that the practice continued to spread to adjacent provinces. By 2007-2009, dry seeding had spread to the entire southern half of the region. The coverage of dry seeding during this period for the whole of northeast Thailand averaged at 37% of the total rice area.

Figure 3. Percentage area grown to dry-seeded rice in different provinces of northeast Thailand

Figure 3a

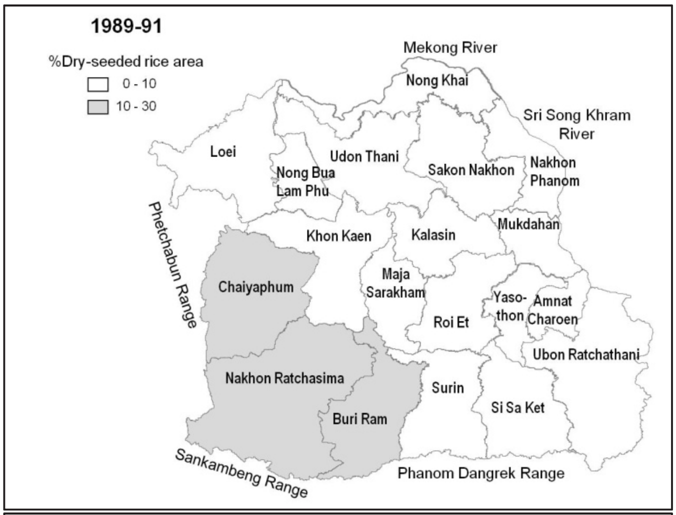


Figure 3b

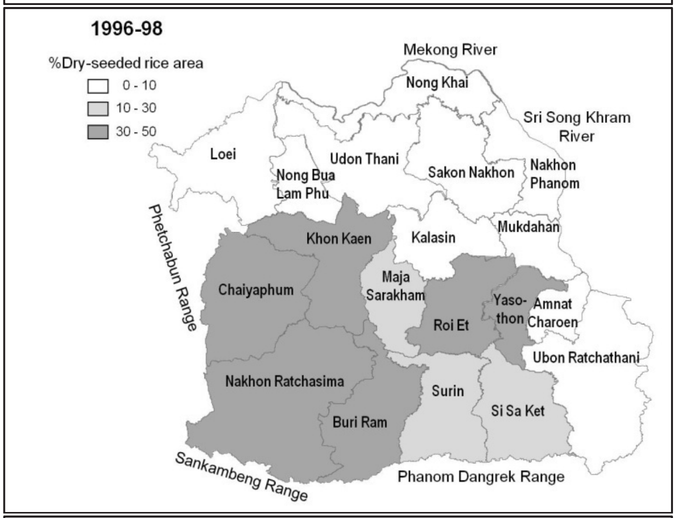
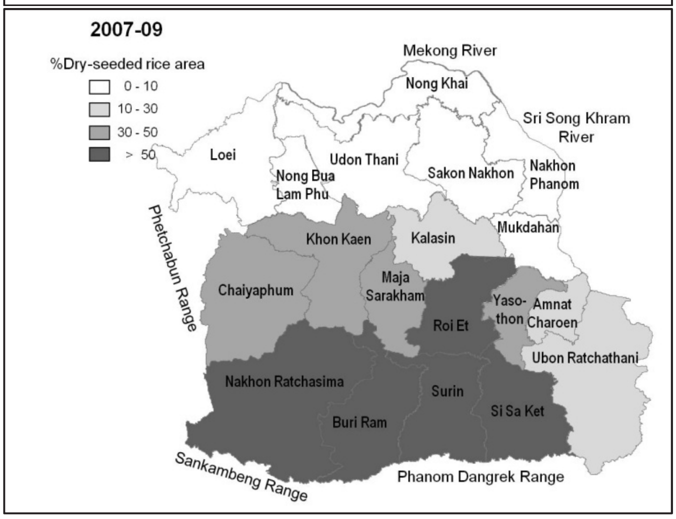


Figure 3c



Note: Nong Bua Lam Phu and Amnat Charoen were formerly part of Udon Thani and Ubon Ratchathani, respectively.

Data source: Office of Agricultural Economics (Thailand), www.oae.go.th

The figures indicate both the spatial spread of dry seeding across provinces and the increased intensity of adoption within a province. Dry-seeded rice covered about 63% of the total rice area in the southern provinces of Nakhon Ratchasima, Si Sa Ket and Surin during 2007-2009 (Figure 3c). In other provinces, the extent of spread was less and with a decreasing gradient towards the northerly direction.

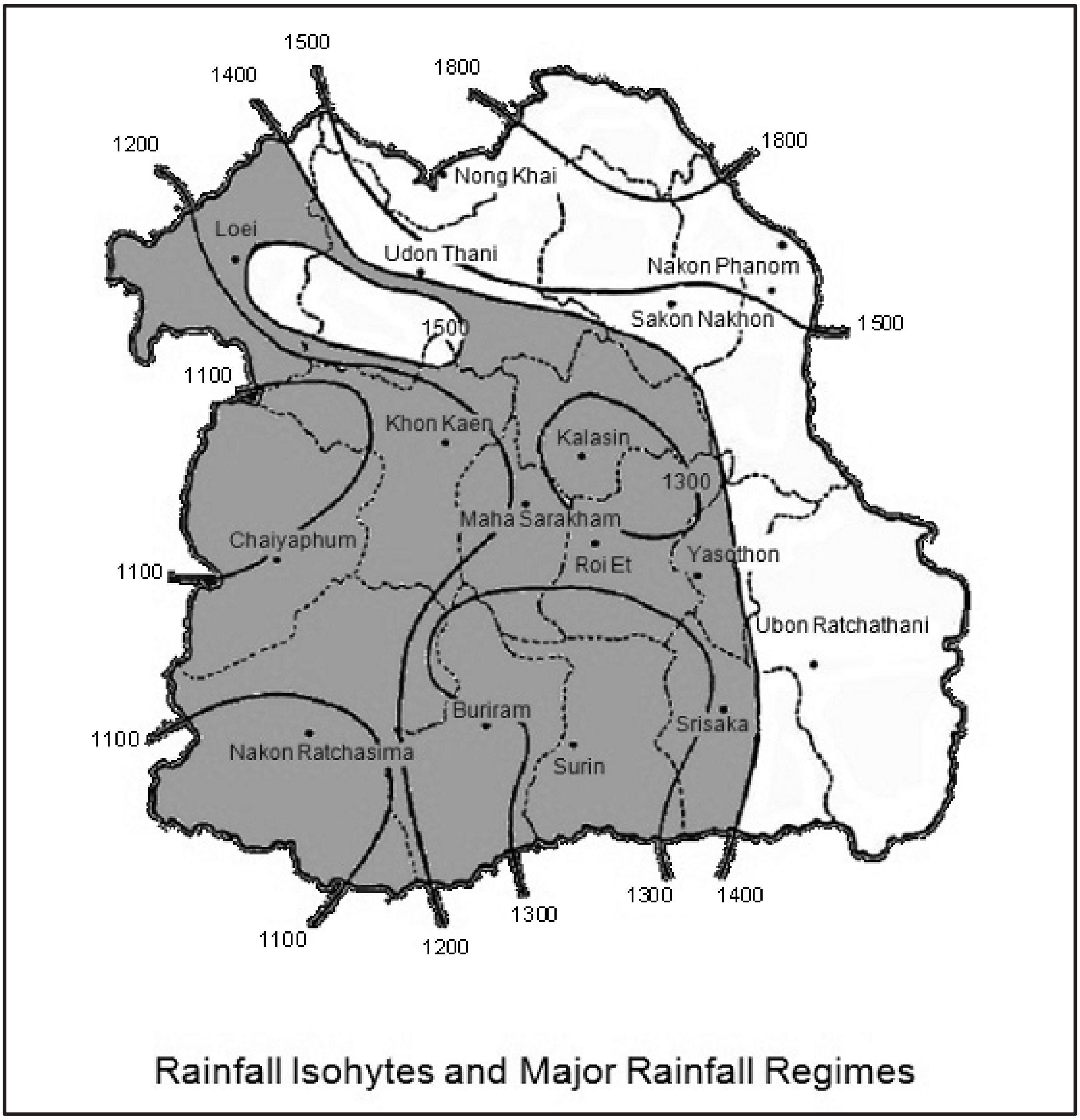
Overall, the above analysis indicates that northeast Thailand separates clearly into two zones; the northern part which has remained predominantly transplanted and the southern part where transplanting has largely given way to dry seeding. Although scarcity of labor is a common phenomenon in the whole region, the existence of the northern zone where transplanting remains the dominant method of crop establishment indicates the presence of some other factors conditioning the spread of dry seeding.

In fact, the relative availability of water (through rainfall and supplemental irrigation) is one of such conditioning factors. If heavy rains are received during seeding time, dry seeding is not suitable due to flooded soils. The only viable option when this happens is to transplant. Although wet seeding is also an option but only in areas with good water control and is generally not feasible in rainfed flooded fields. In the southwestern part of the region, the average rainfall in provinces such as Nakhon Ratchasima, Chaiyaphum and Buri Ram is much lower than in the northern provinces (Figure 4). These southwestern provinces are under the rain shadow of the Phetchabun and Sankambeng mountain ranges. The hydrological conditions are thus more favorable for dry seeding in these provinces and it is no surprise that dry seeding spread in these provinces first and the extent of adoption is also higher.

The provinces located along the Mekong River in the northern part of the region have higher average rainfall and also have some supplemental irrigation that can be obtained by pumping water from the river. These factors favour the transplanting method. Experience from other countries also clearly indicates that farmers prefer to transplant whenever possible due to better weed control and higher farm-level yields (PANDEY and VELASCO, 2002). The dominance of transplanting in the northern provinces, where annual average rainfall is greater than 1,400 mm, indicates a negative correlation association of rainfall and the extent of dry seeding.

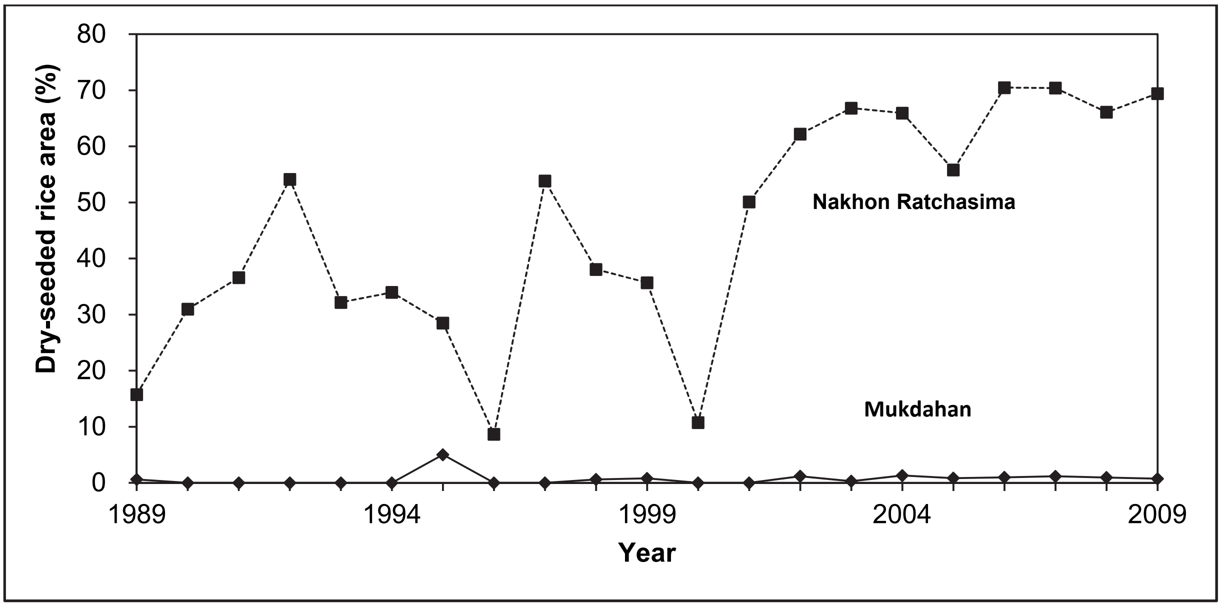
The temporal patterns of changes in the relative importance of dry-seeded rice in these two regions are exemplified in Figure 5 which shows the trend for two provinces, one from the northern part (Mukdahan) where transplanting is dominant and the other from south-western part (Nakhon Ratchasima) where dry seeding has now become the dominant method. Clearly, there has been very little change in the method of crop establishment in Mukdahan over the past two decades. In the case of Nakhon Ratchasima, there has been a major expansion of dry-seeded area but this long-term trend is characterized by substantial fluctuations. Transplanting method continues to remain important in some years even when dry seeding has expanded substantially "on average". Such temporal changes reflect attempts by farmers to adjust their method of crop establishment to fluctuations in rainfall and other dynamic factors such as weed infestations.

Figure 4. Rainfall isohytes and major rainfall in northeast Thailand



Source: KKU-Ford Cropping Systems Project (1982). An Agro-ecosystem Analysis of Northeast Thailand, Khon Kaen University, Khon Kaen, Thailand

Figure 5. Trend in dry-seeded rice area in Nakhon Ratchasima and Mukdahan provinces in northeast Thailand



Data source: Office of Agricultural Economics (Thailand), www.oae.go.th

4 Expansion in Dry-Seeded Area between Two Periods

The extent of change in the average dry-seeded area during the period 1989-1996 and the period 1997-2009 is analyzed by grouping the provinces into four categories. These categories are based on the initial average percentage area under dry seeding during 1989-1996 and the average percentage point change in 1997-2009 compared to the 1989-1996 level. The results are summarized in Table 1. In the table, provinces are grouped into two categories: those with “low” and those with “high” proportionate area under dry seeding. The grouping is based on the coverage of dry seeding being below 20% of rice area (or “low” category) and above 20% of rice area (or “high” category) for the initial period of 1989-1996. Similarly, the extent of change during 1997-2009 relative to the 1989-96 average is considered to be “low” or “high”, depending on whether the magnitude of change is less than or more than 10 percentage points. Note that although the choice of the cut-off values is somewhat arbitrary, the values chosen are adequate to highlight the broader patterns.

It is clear that most provinces belonging to the Type 1 category (or “Low-Low” – implying a low initial value and a low level of change) are located in the upper part of northeast Thailand where the annual rainfall levels are higher. The average extent of dry seeding during 1997-2009 was 7% of the total rice area in this group of provinces.

Basically, dry seeding is relatively unimportant in this category. This group of provinces together accounts for 40% of the total rice area in northeast Thailand.

In the Type 2 category, the initial value was "high" but the extent of change is "low". The initial value for the period 1989-1996 for this group was 26% but this increased by only 6 percentage points to reach 32% in the second period. The provinces belonging to Type 2 category (or High-Low) account for about only 15% of the total rice area.

Table 1. Changes in dry-seeded rice area in different provinces of northeast Thailand

%Dry-seeded rice area in 89-96	Percentage-point change in dry-seeded rice area (between average of 89-96 & average of 97-09)	
	Low (<10%)	**High (>10%)**
Low (<=20%)	**Type 1** Kalasin Loei Mukdahan Nakhon Phanom Nong Khai Sakon Nakhon Ubon Ratchathani Udon Thani	**Type 3** Si Sa Ket Yasothon
	%Share in total rice area = 40 *%Dry-seeded rice area = 7*	*%Share in total rice area = 10* *%Dry-seeded rice area = 43*
High (>20%)	**Type 2** Chaiyaphum Khon Kaen Maha Sarakham	**Type 4** Buri Ram Nakhon Ratchasima Roi Et Surin
	%Share in total rice area = 15 *%Dry-seeded rice area = 32*	*%Share in total rice area = 35* *%Dry-seeded rice area = 46*
Total rice area = 4.879 million ha		

Data source: Office of Agricultural Economics (Thailand), www.oae.go.th

In the case of Type 3 group (or "Low-High"), the initial proportion of dry-seeded area was low at 15% and this increased by as much as 28 percentage points to reach 43% in the second period. Thus, these are the provinces where the expansion of dry seeding has been quite rapid. The two provinces belonging to this group (Si Sa Ket and Yasothon), however, account for only 10% of the total rice area in northeast Thailand.

Finally, the initial value of dry-seeded area in the Type 4 group (or "High-High") was high at 28% and this increased further by 18 percentage points to reach 46% in the second period. The provinces belonging to this group are located in low rainfall zones of the lower part of northeast Thailand and account for a total 35% of the total rice area.

In summary, the provinces belonging to Type 1 and Type 4, which together account for over 75% of the total rice area in northeast Thailand, present a good contrast. The Type 1 group remains largely transplanted with very slow expansion of dry-seeded area while the Type 4 group in which dry seeding was important earlier has further increased the area under dry seeding. Obviously, factors determining the shift to dry seeding and factors conditioning such shifts are different between these two groups. Future technological needs for these two groups will vary accordingly.

5 Association between Varietal Characteristics and Extent of Dry Seeding

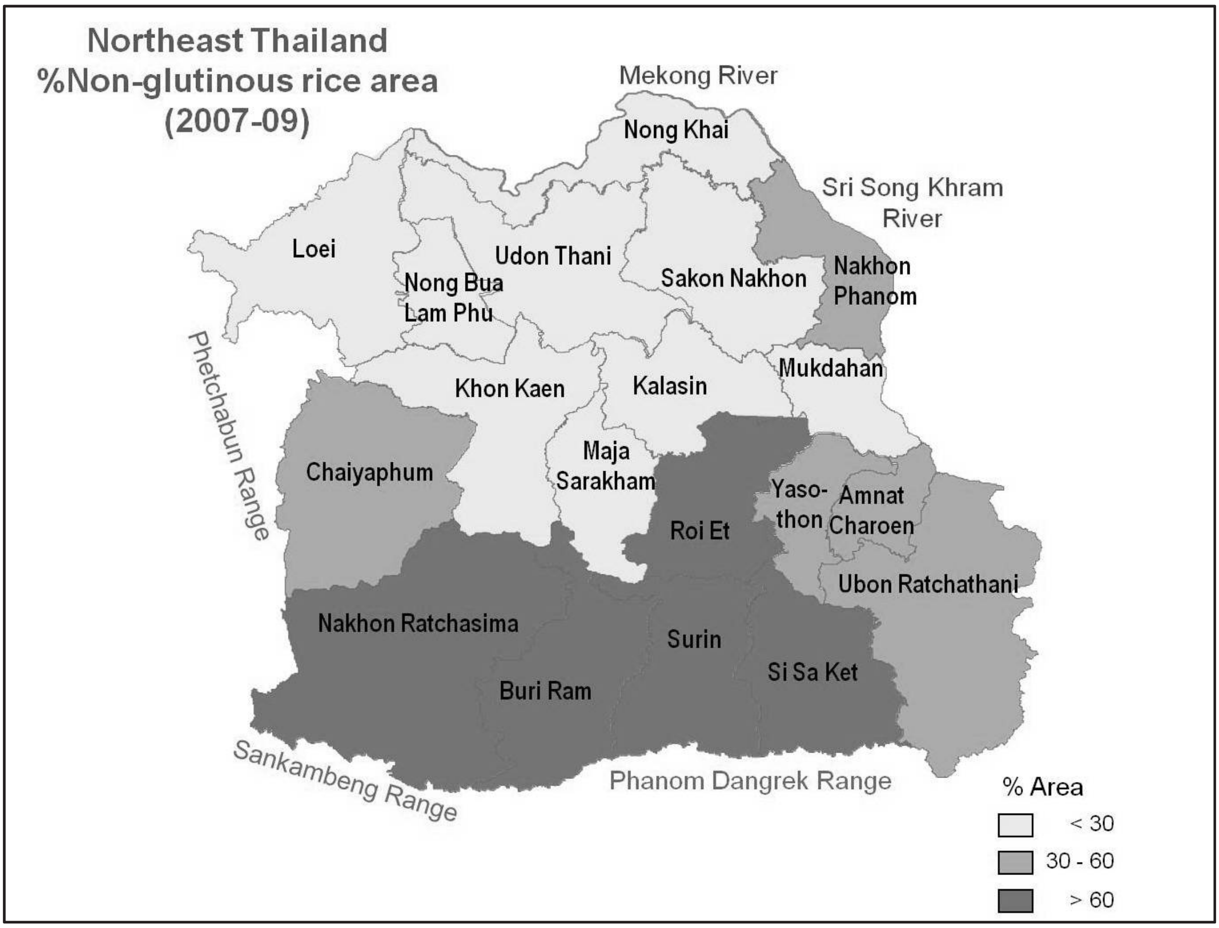
Rice varieties grown in northeast Thailand can be grouped into two categories: glutinous and non-glutinous[2]. The popular glutinous variety is RD6 and the popular non-glutinous variety is KDML105. Glutinous varieties accounted for 46% of the total rice area in northeast Thailand during 2007-2009. Glutinous varieties are mainly used for home consumption while non-glutinous varieties are mainly sold.

Figure 6 shows the proportionate area under non-glutinous rice across provinces of northeast Thailand which indicates an association with the extent of dry-seeded rice area. This association is clearly demonstrated in the scatter plot in Figure 7. The variation in dry-seeded rice area is positively correlated with the proportionate area under non-glutinous rice (and, hence, is negatively correlated with the proportionate area under glutinous rice).

The non-glutinous popular varieties such as KDML105 which is derived from the glutinous variety RD6 is of slightly shorter duration. It matures about two weeks earlier than RD6. As a result, KDML105 is mostly grown in areas with lower rainfall (so that fields are not wet at harvest time) or in fields that drain easily such as those that have lighter soils or those that are located in upper parts of the toposequence. These conditions also favor dry seeding. This partly explains the positive correlation between the proportion of non-glutinous rice area and the proportion of dry-seeded rice area at the provincial level.

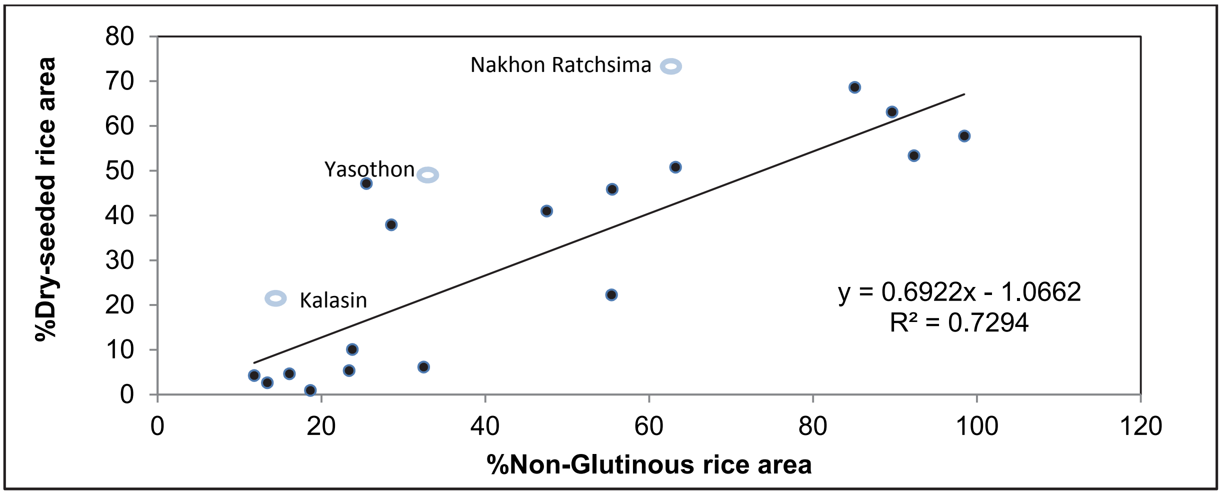
2 Improved varieties grown in northeast Thailand are inbred as hybrid rice has not spread in northeast Thailand, especially in the wet season. Hybrid rice is invariably transplanted in countries in Asia where it is currently grown. So, one can expect some pressure to maintain transplanting if hybrid rice area increases in future in northeast Thailand. However, this is unlikely to be an important factor in the study region as Thai farmers and consumers value their rice for high quality in the market where traditional and improved inbred varieties are well established in this top rice exporting country.

Figure 6. Proportion of non-glutinous rice area in the provinces of northeast Thailand, 2007-2009



Data source: Office of Agricultural Economics (Thailand), www.oae.go.th

Figure 7. Association of area grown to non-glutinous rice and dry-seeded rice area in northeast Thailand provinces (2007-2009 average)



Data source: Office of Agricultural Economics (Thailand), www.oae.go.th

6 Cross-Sectional and Temporal Variations in Dry Seeding

The above discussion identified several factors that are likely to explain the variations in the extent of dry seeding over time and across provinces. The available data at the province level permit a pooled time-series and cross-section regression analysis to clearly identify the effect of these factors on the extent of dry seeding. Such an analysis is conducted here using province-level data for 17 provinces over the period 1989-2009.

The extent of dry seeding (measured as % rice area dry-seeded in each province in each year) is hypothesized to depend on the following variables:

1. Rainfall: Rainfall over the period when land preparation and crop establishment is carried out is an important determinant of whether dry seeding or transplanting will be more suitable. High rainfall during this period (May to July) will make dry seeding impractical in wet soils. So, dry seeding is likely to be more prevalent in provinces with low rainfall and/or in years with low rainfall. The sign of the coefficient associated with rainfall during May to July is expected to be negative.

2. Wage rate: dry seeding is a labor-saving method and the area under dry seeding is likely to expand with a rise in labor cost over time. Thus, the expected sign of the coefficient associated with the wage rate is positive. A limitation to the use of wage rate in explaining variations in the extent of direct seeding is that variations in wage rate across provinces in a given year are likely to be small.

3. Growth rate of the provincial gross product: this is an indicator of the overall economic growth and the growth of employment opportunity in the non-farm sector. Farm labor supply is likely to be tighter in provinces in which the economic growth is faster than in those where the growth is slower. However, it is to be recognized that the movement of wage labor may reduce the wage rate differential among provinces in the long run, although some wage differentials may exist on a seasonal basis due to frictional elements. The effect of this variable is similar to that of rising wage rate and the expected sign of the coefficient is positive. However, this variable is included as an additional variable since wage rates may respond to labor scarcity with some time lag.

4. Proportion of non-glutinous rice area: as discussed, this is likely to have a positive impact on the extent of dry seeding. Unfortunately, the data series for this variable was incomplete except for the most recent years. Hence, this variable could not be used in the regression analysis.

The results indicate that all these three variables have statistically significant effects on the proportion of dry-seeded rice area (Table 2). The directions of effects are also as expected.

Table 2. Factors affecting adoption of dry seeding in northeast Thailand

	Coefficient[a]
Wage rate (Baht/day)	0.307 ***
Annual growth rate in gross provincial product (%)	0.195 *
Total rainfall in May-Jul (mm)	-0.030 ***
Intercept	-0.775
No. of observations	306
R-square	0.24
Adjusted R-square	0.23
MSE	292

[a] *** imply statistical siginificance at 1% level
Dependent variable: share of dry seeding in total rice area (%)

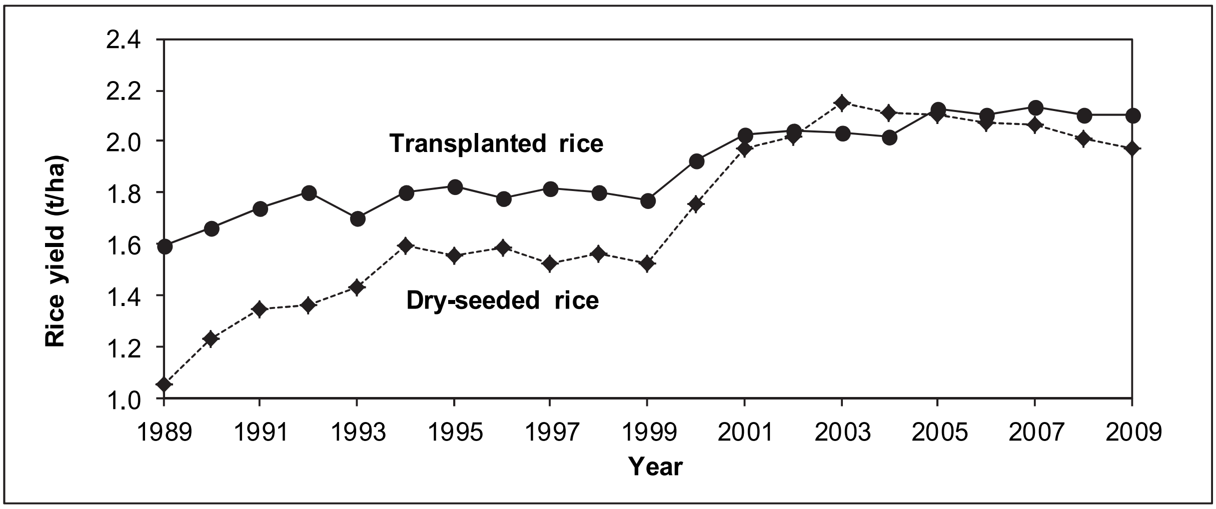
Data sources:
Area by method of establishment: Office of Agricultural Economics (Thailand), www.oae.go.th
Wage rate: Ministry of Labour, www.MOL.go.th
Gross provincial product: National Social and Economic Development Board, www.nesbd.go.th
Rainfall: Thai Metrological Department (unpublished database)

7 Changes in Aggregate Rice Yield over Time

Dry-seeded rice generally has a lower average yield on farmers' fields than transplanted rice. Under experimental conditions, the yield of dry-seeded rice is equal to that of transplanted rice indicating that the crop establishment method itself does not result in a yield difference (ALI et al., 2006). Under farmer field conditions, several factors such as non-uniform crop density and high incidence of weeds in direct-seeded rice generally result in a lower yield.

The yield trend of transplanted and dry-seeded rice in northeast Thailand over 1989-2009 indicates that the yield of dry-seeded rice in the early 1990s was substantially lower than that of transplanted rice (Figure 8). The difference in yield has, however, decreased over time as the yield of dry-seeded rice increased faster than that of transplanted rice. The yield difference of about 0.5t/ha observed in 1989 more or less vanished after 2001. This is an indication that farmers have, over time, learned to manage the dry-seeded fields better and are able to raise the yield level to be comparable to that of transplanted rice. Farmer feedback regarding changes in land preparation, crop establishment, weed control, and fertilization practices supports this hypothesis.

Figure 8. Trend in rice yields of dry-seeded and transplanted rice in northeast Thailand



Data source: Office of Agricultural Economics (Thailand), www.oae.go.th

A resurvey of the previously surveyed villages in Khon Kaen was conducted in 2010 to collect information on changes in dry seeding and associated practices pertaining to the wet season of 2009. The resurvey included a subset of villages and farmers that were surveyed in 1998. The original survey included 173 farmers from Khon Kaen but the resurvey included only 46 farmers from Ban Pumoolbao Mu 4 and Mu 16, Tambon Non Tong of the district Nong Ruan. Out of 46 farmers, 22 were the same that were surveyed in 1998. Thus, these 22 farmers constitute a small sample of two-period panel. Some of the results presented pertain to this panel but others pertain to the full sample of 46 farmers in the resurvey.

The results indicate that farmers have made several changes in the practice of dry seeding. Better land preparation is done now using four-wheel tractors instead of hand tractors used earlier. Increased availability of four-wheel tractors has made the land levelling operation easier and the use of rotovators more common. Extra passes are now made for developing good soil tilth which helps in better and more uniform crop establishment. The use of four-wheel tractors has also enabled farmers to carry out an earlier cultivation of dry soil for timely sowing of rice seeds. The better land levelling that farmers are doing now must have also contributed towards increased productivity through improved field water management.

Another major change in crop management practices is the increase in the use of herbicides to control weeds in dry-seeded rice. Most farmers now reported using herbicides for weed control. The use of herbicides was not very popular in the early 1990s. For dry-seeded rice, the proportion of farmers using herbicides increased substantially from 36% to 92% (Table 3). Farmers also used slightly more manual labor for weeding. Together, this change must have contributed to the increase in yield of dry-seeded rice.

Table 3. Weed control practices by method of establishment during wet season in rainfed area of Khon Kaen

	1998	2009
Dry-seeded rice		
Proportion of farmers using herbicide	36	92
Cost of herbicide applied by users (Baht/ha, in 1998 prices)	210	250
Transplanted rice		
Proportion of farmers using herbicide	25	35
Cost of herbicide applied by users (Baht/ha, in 1998 prices)	120	280

Source: household survey in 1999 and 2010

The responses also indicated that farmers have, over time, learned to improve the uniformity in seed placement while broadcasting seeds. In the early 1990s, when the broadcasting method was just being introduced, farmers reported having difficulties in achieving uniformity in planting density. This together with difficulties in controlling weeds would have resulted in a substantial yield reduction of dry-seeded rice. In addition, the practice of gap-filling by transplanting new seedlings from small nurseries prepared specifically for this purpose has now become more common. Farmers also reported some increase in fertilizer use over time in dry-seeded rice. The earlier survey indicated that the yield difference between transplanted and dry-seeded fields was, on average, 0.9 t/ha. The yield difference was found to be lower at 0.1t/ha in the resurvey. The above factors must have contributed to the reduction in yield difference.

Thus, it can be concluded that farmers have learned over time to manage the dry-seeded crop better and reduce the yield difference between transplanted and dry-seeded rice. The yield increase over time in northeast Thailand cannot be attributed to varietal changes as the varieties grown have remained essentially the same.

8 Changes in Farm-Level Yield, Profitability and Technical Efficiency

The average yields of transplanted rice in 1998 and in 2009 were almost equal but that of dry-seeded rice increased by 47% (Table 4). This is equivalent to an increase of about 0.8t/ha in absolute terms. This increase in farm-level yield is consistent with the changes in aggregate yield levels discussed earlier. In 1998, the yield of transplanted rice was 51% higher than that of dry-seeded rice.

Table 4. Rice yield by method of establishment during wet season in rainfed area of Khon Kaen

	1998	2009
Dry seeded rice		
No. of plots	24	14
Mean	1.66	2.43
Standard deviation	1.04	0.86
Coefficient of variation (%)	63	35
Transplanted rice		
No. of plots	21	26
Mean	2.51	2.55
Standard deviation	1.43	0.68
Coefficient of variation (%)	57	27

Source: household survey in 1999 and 2010

In terms of the overall profitability, the returns over cash costs (expressed in rice equivalent) of dry-seeded rice increased by 743kg/ha which is almost 250% higher than the 1998 net returns (Table 5). This increase in net returns is mainly due to the increase in yield. Hence, the increase in the yield of dry-seeded rice over time has made this practice economically more profitable than before.

Does the increase in the average yield of dry-seeded rice reflect an increase in the average technical efficiency of dry-seeded rice farms or does it reflect an increase in the use of inputs only. Technical efficiency is a measure of how close a yield obtained by a farmer is to the highest yield attainable for the same level of inputs. An improvement in technical efficiency implies an increase in output at a given level of inputs. In effect, this is equivalent to an upward shift in production function.

Table 5. Costs and returns (in paddy rice equivalent, kg/ha) of rice production by method of establishment during wet season in rainfed area of Khon Kaen[a]

	1998	2009
Dry-seeded rice		
No. of plots	11	13
Gross income	1670	2410
Cash costs[b]	1340	1240
Net returns above cash cost	330	1170
Transplanted rice		
No. of plots	12	20
Gross income	2390	2520
Cash costs[b]	2260	1590
Net returns above cash cost	130	930

[a]Paddy rice equivalent of costs and returns were obtained by dividing the cost and return by the price of rice in order to address inflation rates during the 2 periods without having to use CPIs.

[b]Cash cost includes cost of material, power and labor inputs.

Source: household survey in 1999 and 2010

Following the standard approach, the average technical efficiency was measured by estimating the stochastic frontier production function (BATTESE and COELLI, 1995; HASSAN and AHMAD, 2005). The production function of the "best practice" farmer is often know as a production frontier since it is an outer envelope of all other production functions. Stochastic production frontiers that account for random variations caused by climatic and other stochastic factors are best suited for estimating technical efficiency of agricultural production process. In simple terms, technical efficiency is measured as the ratio of yield produced by a farmer using a certain level of input to the yield of the "best practice" farmer who uses the same level of input. A stochastic production frontier is specified as

$$Y_i^* = f(X_{ij})\exp(v_i - u_i)$$

where Y_i^* = rice yield of the i^{th} farm,
$f(.)$ = functional relationship between the dependent and the independent variables,
X_{ij} = the value of the j^{th} independent variable for the i^{th} farm,
v_i = random error which captures the effects of random shocks beyond farmers' control and other measurement errors. It is assumed to be $\mathrm{NID}(0, \sigma_v^2)$,
u_i = non-negative unobservable random variable which represents the level of inefficiency. It is assumed to be $\mathrm{NID}(E(u_i), \sigma_u^2)$.

Technical efficiency (TE_i) for the ith farmer is measured as

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{f(x)\exp(v_i)}{f(x)\exp(v_i)\exp(-u_i)} = \frac{1}{\exp(-u_i)} = \exp(u_i)$$

where Y_i is the yield obtained by i^{th} farmer and Y_i^* is the corresponding yield obtained from the frontier production function. Estimation of the frontier production function and technical efficiencies were done using the FRONTIER program developed by COELLI (1996).

Initially, two separate stochastic frontier production functions, one for each of the two years, were estimated for each crop establishment method. Statistical tests (Chow Test) indicated that these production functions for each method are not significantly different. Similarly, the frontier functions were found to be not significantly different for the two time periods. Thus a single overall frontier production function was estimated from the pooled data that included observations for both methods (transplanting and dry seeding) and for both years (1998 and 2009).

The estimated parameters of the frontier production function indicate that the date of crop establishment, the amount of labor used and field types are significant determinants of yield variations captured in the sample[3] (Table 6). The coefficient associated with the date of establishment has a negative sign indicating that the fields that are established later have lower yield. The pre-harvest labor input has a positive sign. This probably captures the effect of greater use of labor on better establishment and more effective weeding, both of which are labor-intensive operations. The coefficient of low-elevation fields is positive. This captures the better weed control achieved in flooded low-lying fields. The quantity of N-use has a positive but statistically insignificant effect on yield. This somewhat unexpected result merely implies that the variations in fertilizer use across plots in the sample are too low to pick up any statistically significant effect.

Plot-specific technical efficiency levels were derived from the estimated frontier production function. The estimated average technical efficiency for dry seeding in 2009 was found to be higher than for 1998 (Table 7). The increase in the mean technical efficiency of dry seeding is estimated to be 22 percentage points. This is a substantial increase relative to the base value of technical efficiency in 1998. In comparison, the technical efficiency of transplanted rice has remained unchanged. In addition to an increase in the average technical efficiency, the standard deviation of the plot-specific

3 Although land preparation is now mostly mechanized in northeast Thailand, we did not include machine hours in the production function due to incomplete data and the difficulties with standardization as some farmers use small hand-tractors, some use large 4-wheel tractors and others use a combination of both types of tractors.

efficiency is lower in the second period. This indicates that the distribution of plot-specific efficiency levels is centred more tightly around the mean as the frontier production function itself has not shifted upwards in 2009 relative to 1998. In other words, the increase in the average efficiency is due to improvements in the efficiency of the farms that had low levels of efficiency earlier. This increase in the mean technical efficiency is consistent with the increase in the yield of dry-seeded rice over time discussed earlier.

Table 6. Frontier production function of rice yield (dry-seeded rice and transplanted rice) during wet season in rainfed area of Khon Kaen (1998 and 2009 combined)

	Coefficient[a]
Seeds (kg/ha)	-0.018
N (kg/ha)	0.051
Pre-harvest labor (days/ha)	0.358 ***
Date of establishment	-1.199 ***
Dummy for glutinous rice	0.074
Dummy for low elevation	0.162 *
Intercept	10.508 ***
Sigma-squared	35.246
Gamma	0.998 ***
Log likelihood function	-207
LR test of the one-sided error	106
Sample size	190

[a]***, **, and * denote statistical significance at 1%, 5% and 10%, respectively.

Definitions: Date of establishment = 1, if 1st week of April; = 2, if 2nd week of April, etc.
Dummy for glutinous rice = 1, if plot was grown to glutinous rice; = 0, otherwise.
Dummy for low elevation = 1, if plot is in the low elevation; = 0, otherwise.

Source: household survey in 1999 and 2010

Table 7. Technical efficiency of farmers in rice production during wet season in rainfed area of Khon Kaen

	1998	2009
Dry-seeded rice		
Mean technical efficiency	0.41	0.63
Standard deviation	0.28	0.17
Transplanted rice		
Mean technical efficiency	0.68	0.68
Standard deviation	0.21	0.15

Source: household survey in 1999 and 2010

In summary, this analysis indicates that the technical efficiency of dry-seeded rice has improved over time. Essentially, it appears that farmers have gained in experience in dry seeding over time as they have learned how to apply this method more effectively and are managing the dry-seeded fields better.

9 Discussions and Implications

The above analysis highlights several characteristics of shifts in crop establishment methods in northeast Thailand. There has clearly been an increase in the spread of dry seeding in this important rainfed rice-growing area of Thailand as the labor scarcity continues to increase. The aggregate area under dry-seeded rice for the whole region increased from 25% in 1996 to 38% of the total rice area in 2009. The average growth over this 13-year period is thus one percentage point per year. This is much slower than the rate of expansion that took place between 1989 and 1992. This slowdown in the rate of spread is consistent with the literature in the spread of agricultural innovations referred to in the first section of this paper. A main difference, however, is that this slowdown seems to have occurred at a relatively lower level of spread (25-30%), indicating that this technology, as practiced currently, is probably already approaching its ceiling level of diffusion.

The results also show considerable annual fluctuations in the proportion of dry-seeded area. The observed decreases in the proportionate area dry-seeded in some years are partly in response to an increase in rural labor supply induced by economic crises. This was the case following the 1997 financial crisis which saw the return of large number of labor from urban to rural areas. There was a lagged response and the effect persisted for several years, but this effect dissipated ultimately as the economic growth picked up again. The second important factor leading to fluctuations in the dry-seeded area over time is the changes in annual rainfall. In years with high rainfall during May - July, the flooded fields are invariably transplanted as dry seeding under flooded conditions is not feasible. When the early rainfall is low, the effect is reversed with some formerly transplanted area being direct-seeded. These effects can be quite substantial as illustrated by the case of Nakhon Ratchasima. Farmers also tend to switch to transplanted culture after several years of dry seeding to better control the build-up of weed infestation. The ability to switch between the two methods provides the flexibility needed to adapt to seasonal fluctuations that are inherent in agriculture. This implies that new technological interventions that preserve/enhance such flexibilities are clearly desirable. It also implies that, in rainfed areas that have high temporal variability of field hydrological conditions, efforts are needed to improve the productivity of transplanted rice culture also as this method is unlikely to be completely replaced by dry seeding.

The patterns of spread of dry seeding in northeast Thailand also demonstrate the spatial variability. Although the scarcity of labor is a common phenomenon in the whole region, the existence of the northern zone where transplanting remains the dominant method of crop establishment indicates that the shift to dry seeding may not occur in all areas to the same extent. Location specific agro-biological factors condition such shifts despite the economic pressure. The spatial variations in crop establishment methods may be observed along the toposequence at the field level or at the aggregate level across districts/provinces. In addition, the observed annual switch between the two methods will result in a mosaic of dry-seeded and transplanted fields. In other areas where field hydrological conditions do not vary much spatially, large areas are likely to remain under one or the other method of crop establishment.

The results also indicated that farmers have learned to manage the direct-seeded rice better than in the past. This is reflected in the rising yield trend and the decreasing gap between the yield of dry-seeded and transplanted crop over time. When dry seeding started to spread initially in 1989, the yield of dry-seeded rice was almost 40% lower than that of transplanted rice. However, this yield difference almost vanished by 2007 as the yield of dry-seeded rice continued to increase at a rate faster than that of transplanted rice. This clearly implies that farmers have learned to dry seed and manage the crop better over time and are able to obtain yield levels that are similar to that of transplanted rice. The repeat survey of farmers, in fact, indicated that they now prepare the land earlier and better using more powerful four-wheel tractors as opposed to the commonly used hand tractors previously, establish the crop earlier in the season, achieve a more uniform planting density by mastering the broadcasting technique, and control weeds better through the increased use of herbicides. These changes have also resulted in a substantial improvement in the technical efficiency of dry-seeded rice.

The implications of these findings for technology development are several. Although dry-seeded rice area may continue to expand, a substantial proportion of rice area will remain under transplanting culture for the foreseeable future if the current slow rate of expansion of 1 percentage point per year continues. Besides, there are annual fluctuations as farmers switch from one method to the other depending on rainfall, build-up of weed infestations and short-term changes in labor availability. Thus, efforts to increase the productivity of transplanted rice and reduce the cost are also needed. This is even more important in the context of climate change induced by the global warming as extreme rainfall events resulting in drought or submergence are more likely to occur. The overall rice productivity and efficiency of production would be higher if improvements in both methods allow farmers a greater flexibility in adapting to seasonal fluctuations. A major problem with dry-seeded rice is the increased incidence of weed infestation. Better approaches that integrate chemical and cultural methods for a long term weed management are needed. Another area, although not investigated in this paper, but worth pursuing is examining the feasibility of mechanical transplanting as this method is being practiced in some areas of Thailand and is showing promising field performance.

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