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Recent changes in rice production in rainfed lowland and irrigated ecosystems in Thailand

Pichayanun Suwanmontri^a, Akihiko Kamoshita^a and Shu Fukai^b

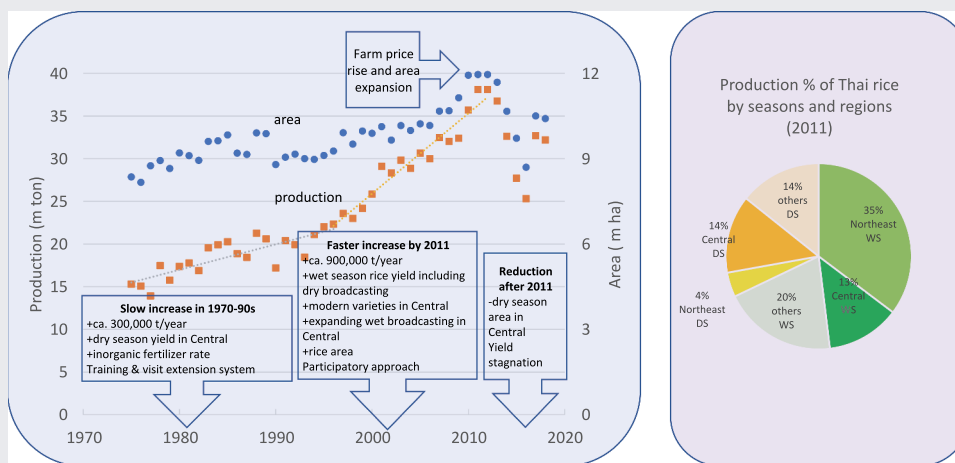
^aAsian Natural Environmental Science Center, The University of Tokyo, Tokyo, Japan; ^bSchool of Agriculture and Food Sciences, University of Queensland, Brisbane, Australia

ABSTRACT

While Thailand is a major rice exporting country in the world, the yield is low among Asian countries. In order to identify factors determining the changes in rice productivity in the country for the last 45 years (1974–2018), various data on production statistics from the Office of Agricultural Economics were analysed for two key regions of rainfed lowland-based Northeast Thailand and irrigated lowland-based Central Thailand. Rice yield increase in Thailand was slower in the first 16 years to 1989, but more rapid to 2011 followed by a large fluctuation in more recent time, and this pattern reflected in the pattern of rice production in the country. The changes in rice production were partly associated with the changes in irrigation water availability affecting dry season rice area and grain yield, thus increasing total production up to 2011, but thereafter decreasing production. The changes in production were also associated with other factors such as increased fertiliser application rate in early years, proportion of modern high yielding varieties adopted in Central Thailand in early years, and continuous agronomic improvement in Northeast Thailand throughout the whole period. In Northeast Thailand where the largest rice production takes place in the country, the same varieties of high grain quality but rather limited yield potential have dominated since 1974, indicating the importance of grain quality rather than high varietal yield in determining the total rice production in the country. Government policy has appeared to have affected the production, though it is not quantified in the study.

KEYWORDS

Rice; Northeast Thailand; yield; dry season; variety; extension




1. Introduction

While Thailand is one of the top rice exporting countries in the world, grain yield is low at around 3.1 t/ha compared to yield of other major rice producing countries such as China (6.9 t/ha), India (3.8 t/ha), Myanmar (3.8 t/ha), and Vietnam (5.5 t/ha). The mean yield increase in recent time is also low at about 25 kg/ha/year in Thailand according to

FAOSTAT, 2020. However this low rate of yield increase is compensated to some extent by increased rice area (Fischer et al., 2014).

In Thailand, rainfed lowland rice ecosystem is the largest in area, occupying more than 80% of total rice area of 12 m ha. Among 4 rice growing regions, 61% and 28% of rainfed lowland areas are located in Northeast and North regions, respectively (OAE, 2018d, 2018e). Rainfed

CONTACT Akihiko Kamoshita  akamoshita@anesc.u-tokyo.ac.jp

 Supplemental data for this article can be accessed [here](#).

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lowland rice in Thailand is characterised with its low yield (e.g. 2.3 t/ha, OAE, 2018a) due to the occasional drought or flood (Fukai & Ouk, 2012). However potential yield in the region is considered to be about 5 t/ha, resulting in the region one of the largest yield gap areas in the world (Fischer et al., 2014). In Northeast Thailand, rice cultivation is a part of the culture, and farmers grow rice primarily for home consumption and sell the surplus (Saisema & Pagdee, 2015). The uniqueness of the production of Northeast region is single planting only in wet season, a wide spread use of photoperiod sensitive aromatic varieties (e.g. RD6, KDML105, RD15), less input and low yield potential, and preference to high grain quality and taste for domestic consumption as well as for export (Grandstaff et al., 2008).

The second largest ecosystem in the country is irrigated lowland rice ecosystem which is mostly located in the Central region and yield level is higher. The production in the region is two to three cropping seasons per year under irrigated system, use of photoperiod insensitive and high-yielding varieties (HYVs) (i.e. modern varieties) responsive to high input of inorganic fertilizer, and greater orientation to rice marketing rather than self-consumption.

In recent time, the proportion of contribution from mainly rainfed Northeast and irrigated Central regions has been changed, as well as the yield level in these regions. Objectives of this work are to determine such changes in rice production in Thailand since 1974 and identify factors contributing to the changes with emphasis on the regional and seasonal differences in the country. Quantitative information is available in recent years from the Office of Agricultural Economics (OAE) for the proportion of dry season rice production, rice varieties, fertilizer application rate, and planting methods. Other factors such as government's agricultural extension system and also government's intervention in rice marketing possibly contribute to the changes in production, and they are also considered and discussed.

2. Materials and methods

2.1. Data source

Data used in this study was secondary data allocated from several sources shown in Table 1. The data of some parameters may not cover all the years since 1974 because the information was available only for a limited time period.

2.2. Data analysis

Some terms used in this paper are described below.

Annual rice production in 2016, for example, was sum of wet season rice in 2016 and dry season rice harvested in 2017.

Rice varieties are grouped into three groups of modern variety, improved variety, and traditional variety. Modern variety is a high-yielding variety (HYVs) with highly responsive to inorganic N fertilizer, typically having a semi-dwarf plant type and photoperiod insensitivity that can be grown all the year around. The first set of the modern varieties, RD1, RD2, RD3 were released in 1969 in Thailand in the national hybridization program under the collaboration with International Rice Research Institute (IRRI) (NSTDA, 2001) where IRRI varieties were used as donors for the breeding for higher yield. As in 2018, there are 38 rice varieties in the modern variety group, including widely grown SPR1, and CNT1. Improved variety is a photoperiod sensitive variety that has been improved by the breeding program without using the semi-dwarf HYVs from IRRI. KDML105 is an example of improved variety derived from line selection from traditional varieties. The other improved varieties, such as RD6 and RD15 were derived from a radiation mutation from KDML105. Traditional variety is local land-race variety that has been grown by farmers in local specific areas and not manipulated in plant breeding programs. There are still thousands of traditional varieties available at present.

Table 1. Data and source used for comparative analysis of rice production from 1974 to 2018.

Data	Source
World rice production statistics 1974–2018: average rice yield, harvested area, and production	FAO statistical database (FAOSTAT, 2020)
Farm harvest price and export value	FAO via IRRI-WRS http://ricestat.irri.org:8080/wrsv3/entrypoint.htm
Rice production in country and regional level 1974–2016: yield, harvested area, and production of (1) whole year (annual production) and (2) wet season and dry season	OAE (1984, 1986, 1995, 2018a, 2018d, 2018e, 2018f)
Rice production categorized by variety: yield, harvested area, and production of (1) wet season 1989–2015 and (2) dry season 1990–2015	OAE (2016, 2018g, 2018h)
Farm gate price of non-glutinous, hommali, and glutinous rice 2005 and 2011	http://www.oae.go.th/view/1/
Farm level inorganic fertilizer application rate (1) wet season from 1985 to 2015 and (2) dry season from 1990 to 2015	OAE (2018a, 2018f)
Rice production categorized by type of planting method: yield, harvested area, and production from 1989 to 2015.	OAE (2018b, 2018c)
Seed rate farmers applied by each planting method from 1989 to 2016	OAE (2018i)

/TH-TH

Inorganic fertilizer means chemically synthesized fertilizer, and rate of inorganic fertilizer application is a total amount of inorganic fertilizer (kg) per unit area that farmer applied (actual rate), which is higher than the average fertilizer rate of household as calculated per total harvested area (not used in this study).

Northeast region (NE) and Central region (CE) are used as a representative of rainfed lowland ecosystem and irrigated lowland system of Thailand respectively. All parameters used for calculation and analysis in the study had been converted into a common unit. For example, the unit used by Thai government statistics for the area is in 'rai', thus it was converted into 'ha' by dividing by 0.16.

Segmented linear regression analysis was conducted by SegRegA over the series of historical yield data to identify a breakpoint and 90% confidence intervals

(<https://www.waterlog.info/segreg.htm>, Smart, 1976). For the country's overall yield and wet season yield, the period from 1974 to 2011 was set with Type 2 function (two connected segments with sloping lines). For the country's dry season yield, the period from 1974 to 2016 was set with Type 4 function (a sloping segment followed by a horizontal line). After identifying the break point years, normal linear regression was conducted for each period and shown in the following figure (Figure 1).

3. Results

3.1. Rice production increase in Thailand since 1974

Rice production in Thailand increased greatly since 1974 (13.4 m tons) till 2011 (38.1 m tons) for about 40 years

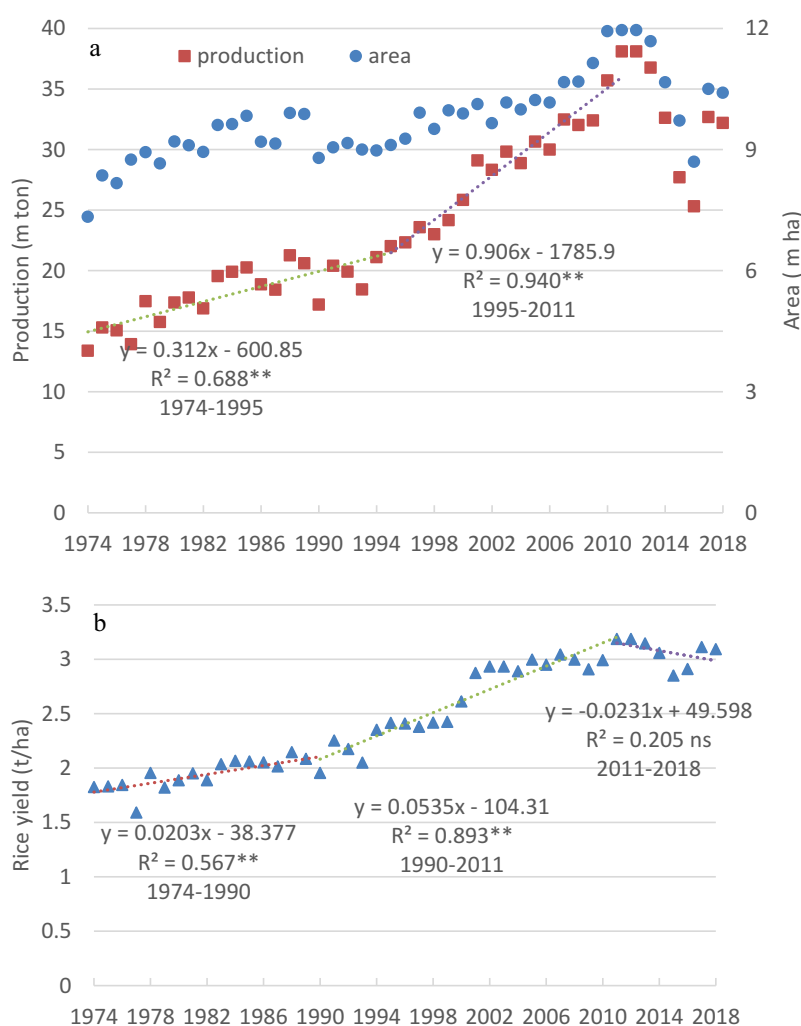


Figure 1. Rice production and area (a) and yield (b) in Thailand from 1974 to 2018.

(Figure 1(a)). The average annual increment was smaller in the first 21 years but nearly three times larger after 1995. The production decreased and fluctuated in most recent years after 2011. The production increment from 1974 to 2011 was due to increase in rice area from 7.3 to 12.0 m ha (64% increase) and yield from 1.8 to 3.2 t/ha (78% increase, with average annual increment rate of 35.9 kg/ha/year). Rice area increased during 1970s and relatively stable from 1980s to early 2000s but more rapidly increased from 2005 to 2011. Rice area fluctuated and dropped down thereafter to 8.7 m ha in 2016. Yield increase was slower in the first 16 years from 1974 to 20.3 kg/ha/year; 1.0% annual increase with 1.95 t/ha in 1990 (Figure 1(b)). The increase in the next 21 years till 2011 was 53.5 kg/ha/year; 1.7% annual increase. However there was no increase in yield in the most recent 7 years to 2018. Factors affecting these production changes are considered in the following sections.

3.2. Contribution of irrigated dry season production

From 1980 to 2011, proportion of dry season production increased from about 11% to 32% for the whole country, with slower increase to 1994 (14%), and faster increase thereafter (Figure 2(a)). The contribution of dry season (DS) production was at 30% in the Central region (CE) while only 5% in the Northeast region (NE) in recent years (Figure 2(b,c)). The proportion of DS production in the whole country declined and fluctuated since 2011, which came from the corresponding declines in CE (Figure 2(a,c)). In recent years, NE and CE share ca. 40% and 30% of country's production and 50% and 20% of country's rice area (data not shown).

In Thailand, the area of DS production has been gradually increased for almost half a century since green revolution; its increase was slower during early periods but faster after 1990 till 2011 (Table 2). The area of wet season (WS) rice also to a smaller extent increased from 1990 to 2011. As DS rice almost completely relied on irrigation, the increase in total rice area was mainly due to increase in the irrigated area. In the period of rapid yield increase between 1990 and 2011, yield increase was much faster in WS (1.82–2.85 t/ha) than in DS (3.93–4.25 t/ha). During the period, total rice production increased greatly from 17 to 38 m tons, with WS contributing slightly more than DS. For the WS production of ca. 26 m tons in 2011, NE contributed ca. 13 m tons whereas CE ca. 5 m tons (data not shown). For the DS production of ca. 12 m tons in 2011, NE contributed less than 2 m tons whereas CE more than 5 m tons (data not shown). Rice area greatly decreased from 2011 to 2016 in both wet and dry seasons, while yield also declined or stagnated during this period.



Figure 2. Contribution of dry season production to whole production from 1980 to 2016 of whole country (a), Northeast region (b), and Central region (c).

This led to the decrease in production in each season with the annual reduction from 38.1 million t to 25.3 million t from 2011 to 2016. The dry season production was reduced to less than half in this period.

During 1980's, NE had 40–50% of the country's rice area which increased over 50% by 2011 whereas CE decreased from ca. 25% to 20% during the corresponding period (Table 2). During 1980's, rice production of NE and CE were similar (each higher than 30% of the country's production), which increased to ca. 40% in NE while decreased less than 30% in CE.

Dissection of yield increase from 1974 to 2016 by rice cropping season and regions revealed the yield rank

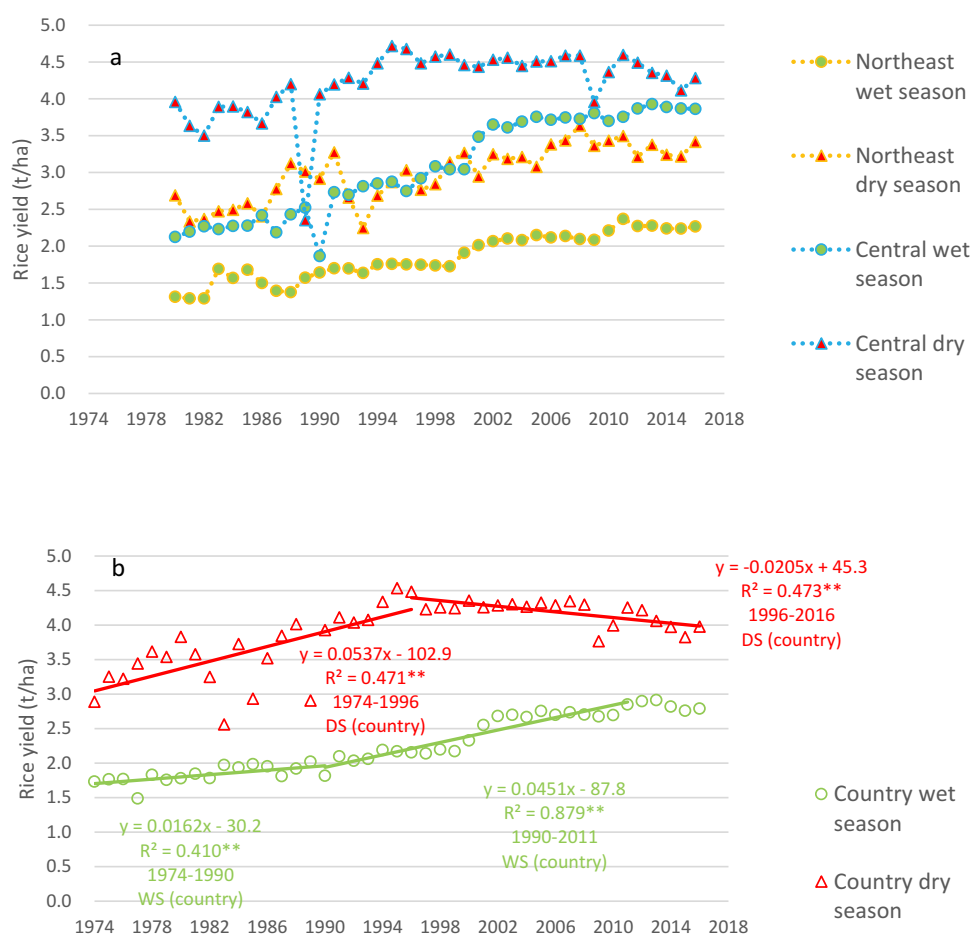
Table 2. Change in area (m ha), yield (t/ha), and production (m tons) in (a) wet season (WS) and dry season (DS) and (b) Northeast and Central regions in selected years between 1980 and 2016 (Whole year data are provided as Table S1 in Appendix).

	Total area	Yield (production)	WS area	DS area	Yield WS (production)	Yield DS (production)
1980	9.20	1.89 (17.37)	8.66	0.51	1.78 (15.40)	3.83 (1.96)
1990	8.79	1.96 (17.19)	8.21	0.58	1.82 (14.90)	3.93 (2.29)
2000	9.89	2.61 (25.84)	8.50	1.39	2.33 (19.79)	4.35 (6.06)
2011	11.96	3.19 (38.10)	9.08	2.88	2.85 (25.87)	4.25 (12.24)
2016	8.70	2.91 (25.31)	7.35	1.35	2.79 (20.49)	3.98 (5.38)
	NE area	CE area	Yield NE (production)	Yield CE (production)		
1980	4.41	2.24	1.32 (5.81)	2.47 (5.54)		
1990	4.80	1.67	1.66 (7.98)	2.37 (3.96)		
2000	4.92	2.21	1.95 (9.59)	3.52 (7.77)		
2011	6.14	2.42	2.46 (15.09)	4.15 (10.04)		
2016	5.87	1.97	2.31 (13.56)	4.01 (7.91)		

from DS in CE to WS in CE, DS in NE, and WS in NE in 2016 (from high to low) (Figure 3(a)). The mean increment rates over the period were highest for WS in CE as 58.7 kg/ha/year compared with the other three systems (21.7 and 28.2 kg/ha/year for DS in CE and NE, respectively, and 28.1 kg/ha/year for WS in NE) (data not shown). For the whole country, yield increase in WS was lower (16.2 kg/ha/year) from 1974 to 1989 (< 2 t/ha) but increased nearly 3 times more rapidly (45.1 kg/ha/year) from 1990 to reach close to 3 t/ha in 2011

(Figure 3(b)). The country's yield in DS increased from ca. 3 t/ha to close to 4.5 t/ha by mid-1990s, in spite of occasional large fluctuation, but no further increase in DS yield thereafter.

Thus overall slow yield increase in the country from 1974 to 1990 was due to slow increase in yield in WS, and also slow increase in DS area where yield was larger than yield in WS. The faster increase in crop yield and total production in the country between 1990 to 2011 over the earlier period was due to greater increase in dry season area with its

**Figure 3.** Changes in rice yield from 1974 to 2016 in 4 combinations of seasons and regions (Northeast (NE) and Central (CE) regions for wet (WS) and dry (DS) seasons) (a) and in the whole country with segmented regression lines (b). The regional data is available only from 1980.

higher yield though yield did not increase after late 1990s, and faster increase in yield in WS. After 2011, a tendency of small increment in WS in CE can be recognized but in all the other combinations of rice cropping seasons and regions, yield did not increase after 2011.

3.3. Proportion of modern varieties

For the whole country, the proportion of modern high yielding varieties in wet and dry season combined

increased from 1990 to 2013 followed by decline to 2015 (Figure 4(a)).

This earlier increase was associated with the decrease in traditional varieties, while improved varieties occupied about 60% of the total area during 1990–2013, with increase in the last 2 years. These changes in proportion were similar when only WS is considered for the whole country although the proportion of modern varieties was lower than the proportion for the two seasons combined (Figure 4(b)). The DS was almost solely planted with

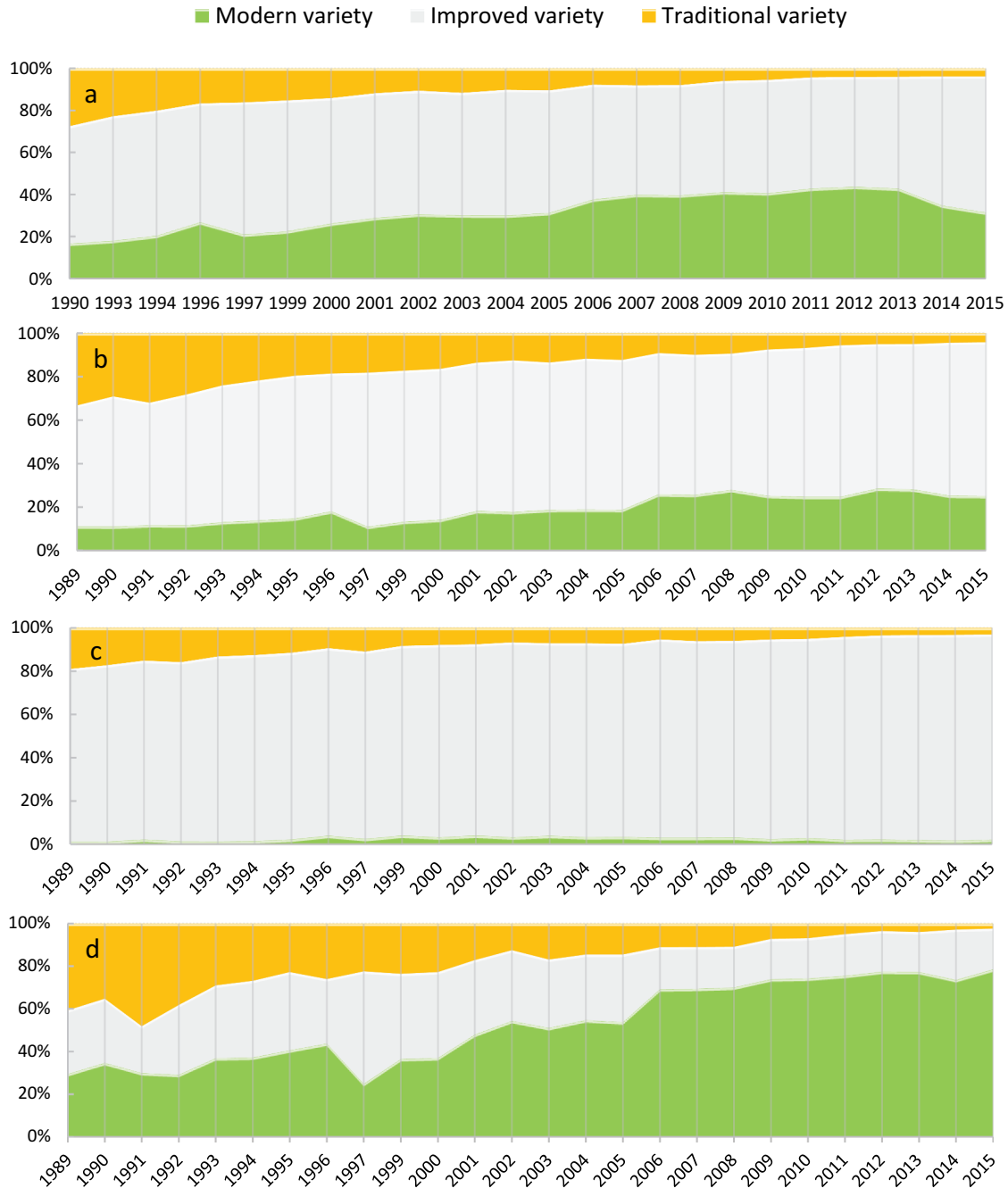


Figure 4. Proportion of the area harvested by each group of varieties from 1989–2015 in country's whole production (a), country's wet season production (b), Northeast (NE) wet season production (c), and Central (CE) wet season production (d).

modern varieties (data not shown). In WS, improved varieties occupied about 80% in NE in 1989 and this proportion increased to almost 100% in 2015, as the proportion of traditional varieties decreased to almost zero (Figure 4(c)). In WS in CE, the proportion of modern varieties increased from about 30% in early years to close to 80% in recent years, with associated decrease in improved and traditional varieties (Figure 4(d)).

3.4. Contribution of inorganic fertilizer

The rate of inorganic fertilizer input for WS rice in NE was less than 100 kg/ha in 1985 but reached 173 kg/ha till 1997 (similar level thereafter), while the rate used in CE was 177 kg in 1985, increased to reach plateau at 289 kg/ha in 2002 (data not shown). The increase in fertilizer in WS during the early stage (1985–1997 in NE, 1985–2002 in CE) was associated with yield increase. The rate of fertilizer used in DS was higher than WS in both regions. The yield was linearly related to the rate of inorganic fertilizer application in both NE and CE region in WS (Figure 6(a)) as well as in dry season (Figure 6(b)). However yield in NE in WS increased further in more recent time but there was no corresponding increase in fertilizer rate. The regression shows the effect of inorganic fertilizer on WS yield; the use of 1 kg/ha of inorganic fertilizer increased yield by 13.7 and 7.8 kg/ha in CE and NE respectively. For DS, the only small effect of inorganic fertilizer on yield was found (5.1–5.2 kg/ha) in both regions.

3.5. Planting method

In WS in NE, transplanting method (TP) exceeded 90% of total rice area in 1989, but decreased sharply to ca. 75% in mid-1990s, and then further gradually to almost 50% in 2015, as dry broadcasting (DBC) increased popularity during these periods (Figure 7(a)). In WS in CE, TP was about 30% in 1989, then decreased to about 10% in 1996, and was below 10% in recent years (Figure 7(b)). Both DBC and wet broadcasting (WBC) were common in earlier years (e.g. 25% and 39% in 1989), but gradually WBC replaced DBC as well as TP, and it occupied almost 80% of rice area in recent time.

In WS in NE, yield was lower in DBC than in TP in 1990s during the early stage of DBC adoption, but it became similar by 2001, and increased further together to 2.3 t/ha in 2011 (Figure 8(a)). In WS in CE, yield in WBC was 1.2–2.0 t/ha higher than in DBC, although there was no yield increase after 2002 at ca. 4.2 t/ha (Figure 8(b)).

Farmers used less seed in TP (43 and 61 kg/ha in NE and CE, respectively) than in DBC (106 and 145 kg/ha in NE and CE, respectively) or WBC (113 and 177 kg/ha in NE and CE, respectively) in both regions. Seed rate used

for DBC was lower in the early stage of adoption (1992–2000) but reached up to around 120 kg/ha and 155 kg/ha in NE and CE respectively, and as seed rate increased yield also increased with significant correlation between them (Figure 9). A higher seed rate of DBC in NE found to be associated with higher yield ($r = 0.91^{***}$); similar point was found in TP. Yield response to increased seed rate was found in both broadcasting in CE despite higher seed rate used in CE than in NE.

3.6. Agricultural extension methods

Rice production extension of Thailand had been under the training and visit system from 1976 to 1996 (Table 3). The system came together with the set of known green revolution technologies. Yield increased 34 kg/ha/year during the period. However, after 1997, the system has been changed to the participatory method which aims to make farmers to be more self-reliant. Several approaches such as farmer field school, participatory research project have been implemented. The yield increase rate from 2002 to 2016 after changing to the participatory approach was 3 kg/ha/year. Yield increase rates under training and visits and participatory systems were 32 kg/ha/year and 13 kg/ha/year respectively in NE, while they were 65 and 5 kg/ha, respectively in CE.

3.7. Farm harvest price and export values

Farm harvest paddy rice price fluctuated between 110 and 210 USD/t between 1991 and 2006, and then increased sharply to 326 USD/t in 2007, and the price over 225 USD/t was maintained for 7 years before returning to below 250 USD/t in 2014 (Figure 10(a)). Export values of rice increased gradually to about 3 billion USD in 2006 with sharp increase to over 6 billion USD in 2008 peaking in 2011, before falling to below 5 billion USD in more recent times (Figure 10(b)).

Broad comparison on total rice output values of farmers between NE and CE was made for year 2005 and 2011. We used the average annual farm gate prices for (i) special aromatic non-glutinous rice (for commonly export as called hommali, which consists of KDML105 and RD15), (ii) other ordinary non-glutinous rice, and (iii) glutinous rice available for the whole country for the two years (i.e. 192 USD/t, 166 USD/t, and 149 USD/t in 2005 and 434 USD/t, 305 USD/t, and 490 USD/t in 2011). The contribution to the total output values of farmers from NE and CE estimated with these assumptions changed during 2005–2011 from 36% to 47% in NE and 31% to 22% in CE, indicating greater relative importance of NE.

Table 3. The three periods of agricultural extension system in Thailand from 1967 to 2018.

Period	Extension system	Details of system
1967–1975	General agricultural extension approach	Department of Agricultural Extension (DOAE) was established in 1967 as a single agency from the three divisions of Departments of Rice and Agriculture, and the Office of Permanent Secretary. Main extension activities were establishing farmers' institutions, demonstration plots, exhibitions, fairs and contests. One extension agent was responsible for covering about 4,000 farm families.
1976–1996	Training and visit system (T&V)	The Training and Visit system (T&V) was adopted as the main extension approach in irrigated agroecosystems under a World Bank-financed project from 1977 to 1986. One extension agent was required to cover 1,000 farm families. The project funds also provided physical facilities like vehicles and equipment, and promoted regular training of extension staff, as well as scheduled visits by extension agents to the farmers. Starting 1987 more emphasis was laid on the development of small-scale farmers including in rainfed agroecosystem, as well as on marketing aspects. Many modern technologies of 'Green Revolution' were disseminated to farmers via increasing numbers of officers.
1997-present (2018)	Participatory system	DOAE has adopted bottom up concept in the extension system after the change of the 1997 Constitution of Thailand: 8th National Economic and Developmental Plan. In 1999, the government established sub-district level Service and Technology Transfer Centres (STTCs) nationwide with the aim to transfer agricultural knowledge and provide one-stop services of the Ministry to the farmers. Micro-enterprises of the community were promoted, local volunteers were brought on-board, and learning centres were established for farmer field schools. Farmer groups and village developmental plans were emphasized. Technologies suitable for the local environment and society were highlighted that would better manage natural resources and closely linked marketability.

Sources: DOAE (2011) and Ocharoen and Panichayothai (1998).

The proportion of contribution from the three rice groups was contrasting between NE and CE regions; in 2011 special aromatic non-glutinous rice, ordinary non-glutinous rice, and glutinous rice contributed 50%, 13%, and 37% of total rice output values in NE region, whereas they were 6%, 94%, and 0% in CE region.

4. Discussion

The analysis using information available for rainfed lowland based Northeast and irrigated lowland based Central Thailand shows several factors contributing to rice production changes in Thailand since 1974. One major factor is availability of irrigation water for dry season production, but other factors such as variety change, fertiliser input, and establishment methods had also effect.

The variation in yield increase is associated with the change in the proportion of irrigated rice in the total rice area, particularly in Central Plain where irrigation water is more available; Bhumibol Dam (completed in 1964) and Sirkit Dam (completed in 1972) together controlling 22% of the Chao Phraya's annual runoff, have helped to irrigate 1,200,000 ha in the wet season and 480,000 ha in the dry season in Central region (https://web.archive.org/web/20080917023206/http://www.rid.go.th/eng/kw-13_eg.htm). Thus, increased dry season production under irrigation with higher yield potential resulted in the higher increase rate to 2011. The analysis shows that the increased production is due to increased rice growing area and higher yield in dry season under irrigation. However, since 2011, there was shortage of irrigation water in Central Plain, and with the Government's policy, irrigated rice in dry season declined resulting in reduced rate of yield increase as well as decline in rice area. For example, due to the consecutive years of drought, Bhumibol reservoir had only 37% (ca. 4,000 million m³) of its normal expected capacity in Oct 2015 (USDA, 2015). The impact of irrigation water availability on cropping system intensification is also found in the Mekong River Delta in Vietnam (Nguyen et al., 2020).

Yield increase since 1990 and possibly earlier was also associated with increased adoption of modern varieties in Central Plain where irrigation was generally available (Figure 4). It should be pointed out however these modern high yielding varieties are little adopted in rainfed dominated NE Thailand. This is at least partly related to the current varieties' high grain quality despite their low yielding capacity. Note that KDML105, categorized as improved variety in this paper, was released in 1959, and is the main leading non-glutinous variety in the country, and its high aromatic quality grain is exported in a large quantity. Our analysis showed the increasing adoption of the improved varieties, as was also demonstrated over the 50 years since 1960 (Watanabe, 2017), but yield differences between the improved variety and traditional variety are small or little (Figure 5). Generally low yield increase in Thailand is related to low adoption

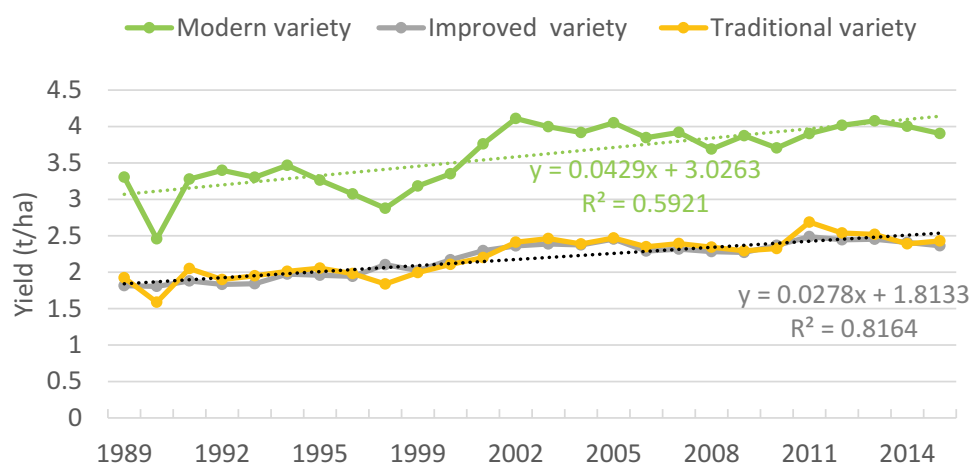


Figure 5. Yield growth of each variety group by year during 1989–2015 in wet season (OAE, 2016, 2018f). Linear regressions were drawn for modern and improved varieties.

of modern varieties or improved varieties with higher potential yield in rainfed lowlands which is the main rice growing ecosystem in the country. The old varieties dominating rice production in Thailand is in contrast to

some other countries such as China where new high yielding rice varieties were well adopted by farmers and they contributed to the country's increased production (Zhu et al., 2016). Studies in Philippines and Vietnam

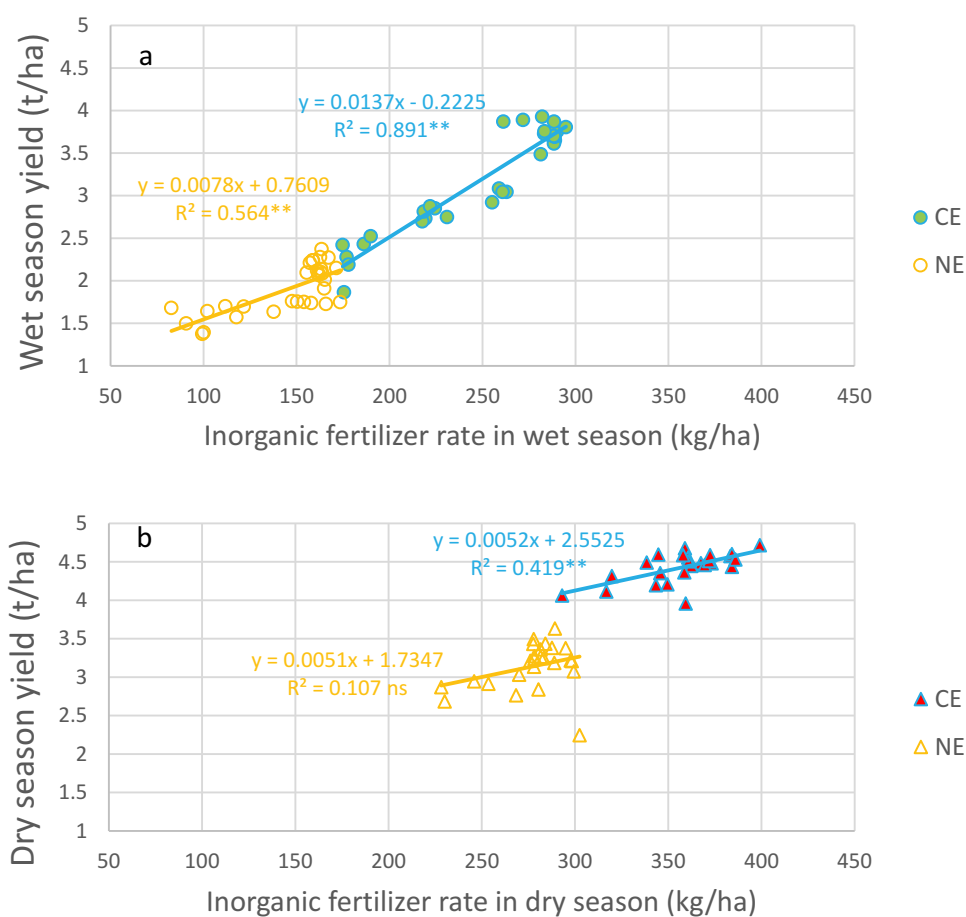


Figure 6. Relationship between yield and inorganic fertilizer application rate in wet season (a) and dry season (b) for Northeast region (NE) and Central region (CE) in Thailand from 1985 to 2015. Inorganic fertilizer application rate is based on the actually applied area.

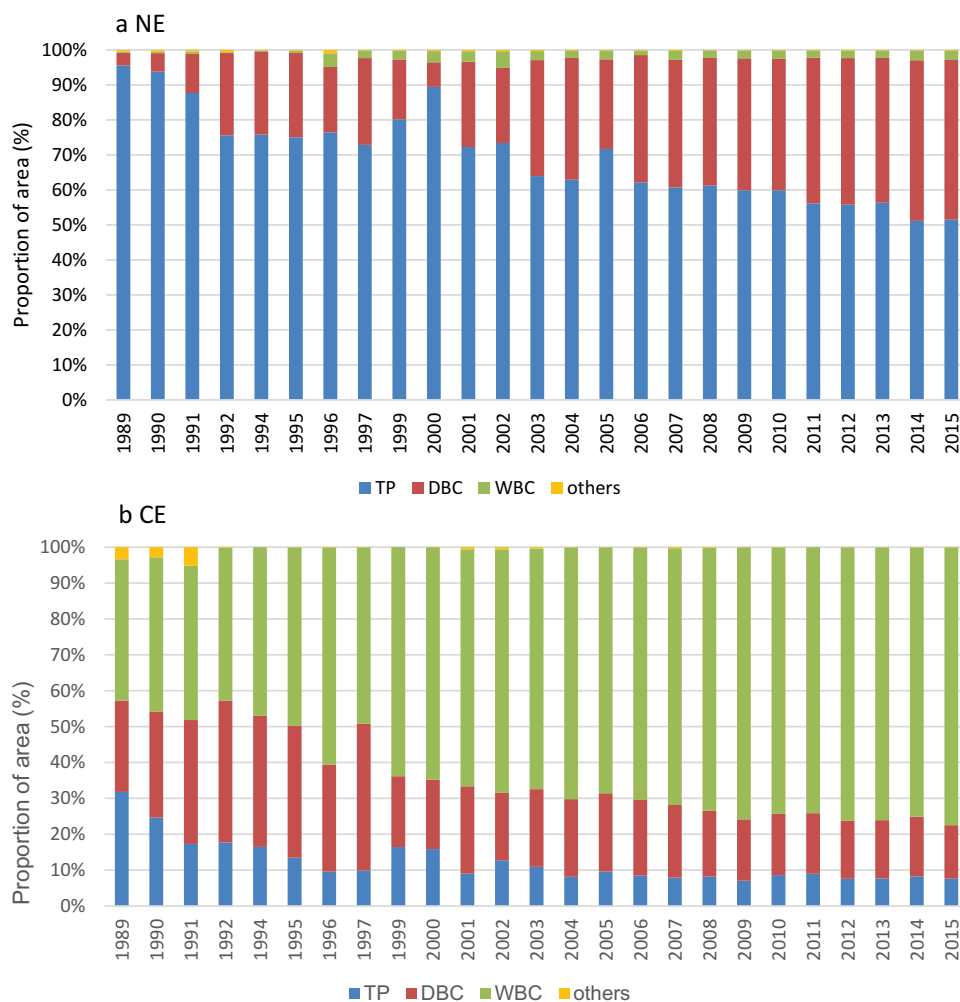


Figure 7. Proportion area of planting methods for wet season rice from 1989 to 2015: transplanting (TP), dry broadcasting (DBC), wet broadcasting (WBC) in Northeast region (NE) (a) and Central region (CE) (b). Drill seeding, for example, is included in the category 'others'.

also indicated adoption of modern varieties has spillover effect in rainfed lowland ecosystem (Estudillo & Otsuka, 2006; Tran & Kajisa, 2006).

Yield increase per unit increase of inorganic fertilizer during 30 years from 1985 to 2015 was 75% higher in CE than NE (13.7 vs 7.8 kg yield increase per 1 kg input of inorganic fertilizer, respectively), which can be estimated per unit inorganic N basis as 86 kg/kgN and 49 kg/kgN if assuming 16% of N element on average in inorganic fertilizer. With this assumption throughout the period, N fertilizer application rates, which were 28 and 13 kgN/ha in CE and NE, respectively in 1985, increased toward around by 2002 in CE and by 1997 in NE to reach plateau (i.e. 40–46 kgN/ha in CE and 24–27 kgN/ha in NE regions). Commonly recommended rates of N-P-K fertilizer application were 40–12–10 kg/ha for rainfed lowland in NE (Haelele & Konboon, 2009). In CE region, Attanandana et al. (2010) reported higher N-P-K application rates among farmer conventional practices (e.g. 96–46–3 kg/

ha) and possible reduction by site specific management (e.g. 61–24–7 kg/ha).

When dry direct seeding, i.e. broadcasting, was introduced in NE Thailand in late 1980s, its yield was lower than that of transplanted rice. However in the 1990s the rate of yield increase was faster in dry direct seeding than that of transplanting, and this was probably associated with improved weed control in dry direct seeding particularly with the wider adoption of the use of herbicides. Thus herbicide use in dry direct seeded rice in Thailand increased from 36% to 92% between 1998 and 2009 (Pandey et al., 2012). After 2001, the yield of crops established from these two methods were very similar in NE Thailand. It is also known that dry direct seeding in lower toposequential areas with more favourable moisture could obtain higher yield in rainfed lowlands in NE Thailand (Hayashi et al., 2007; Kamoshita et al., 2009). There was also increased adoption of wet direct seeding in Central Plain as irrigation areas increased and farmers

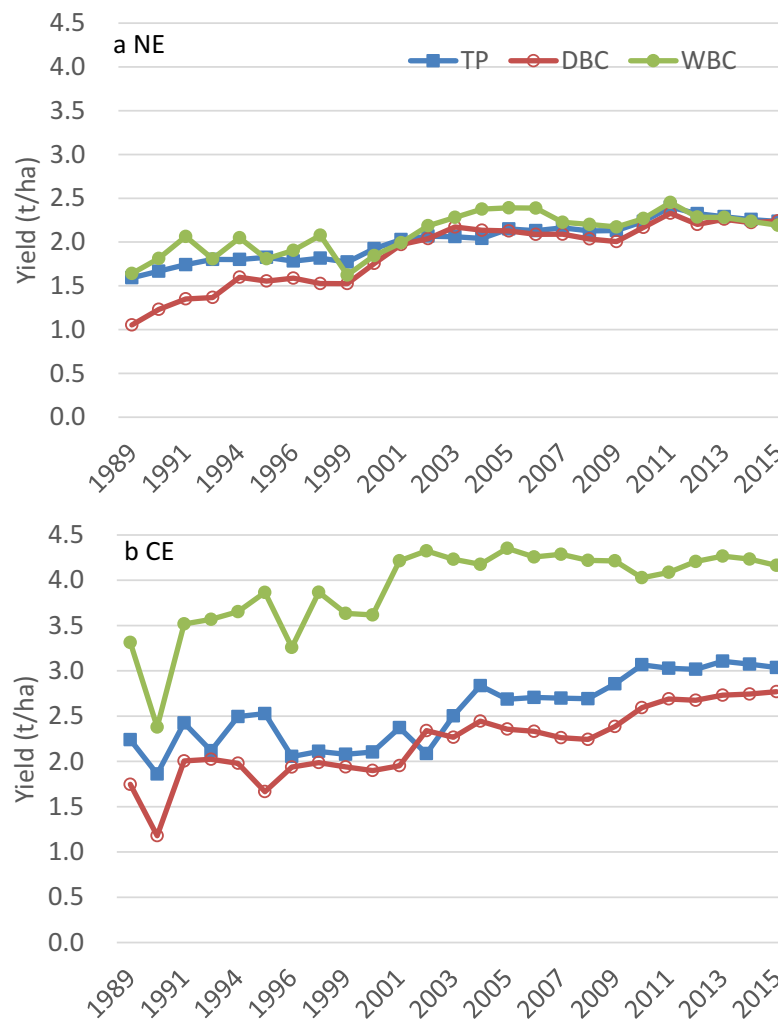


Figure 8. Yield trend by planting methods for wet season rice from 1989 to 2015: transplanting (TP), dry broadcasting (DBC), wet broadcasting (WBC) in Northeast region (NE) (a) and Central region (CE) (b).

realised yield advantage of wet direct seeding in irrigated area. It is known in other countries that wet direct seeding is preferred in irrigated conditions while dry direct seeding may produce lower yield than transplanting under rainfed lowland conditions (Kumar & Ladha, 2011). Advantage of direct seeding is primarily due to reduced labour requirement and hence cost, for example, in Laos (Xangsayasane et al., 2019).

Increased seed rate appears to have contributed to yield increase particularly in dry broadcasting, and this could be possibly related to better control of weeds as well as increased interception of solar radiation and canopy photosynthesis (Fukai & Ouk, 2012).

In early years (1974–1989), increased rate of fertiliser application appeared to have contributed to yield increase. Gradual increase in irrigated dry season crop also helped increase in production at this stage. Rapid production increase in the second period (1990–2011) was associated with rapid increase in irrigated rice and

adoption of wet broadcasting in dry season in Central Plain, and improvement in dry broadcasting in Northeast.

These changes in establishment methods and other agronomic improvement are likely to be associated with effective extension system adopted at the time. Total factor productivity of crops in Thailand during 1970–2006 was affected by agricultural extension in the short run (Suphannachart & Warr, 2010). Suphannachart (2015) reported rapid increase in public agricultural research and extension budget in Thailand by 2000. It is not easy to judge whether the participatory method adopted after 1997 was less effective in yield improvement compared with the training and visit system, partly because agricultural extension budget sharply declined from early 2000s (Suphannachart, 2015). Yield increase during the participatory method was not observed in the dry season rice in Central region, but visible in dry season rice in Northeast region as well as wet season rice in both regions where

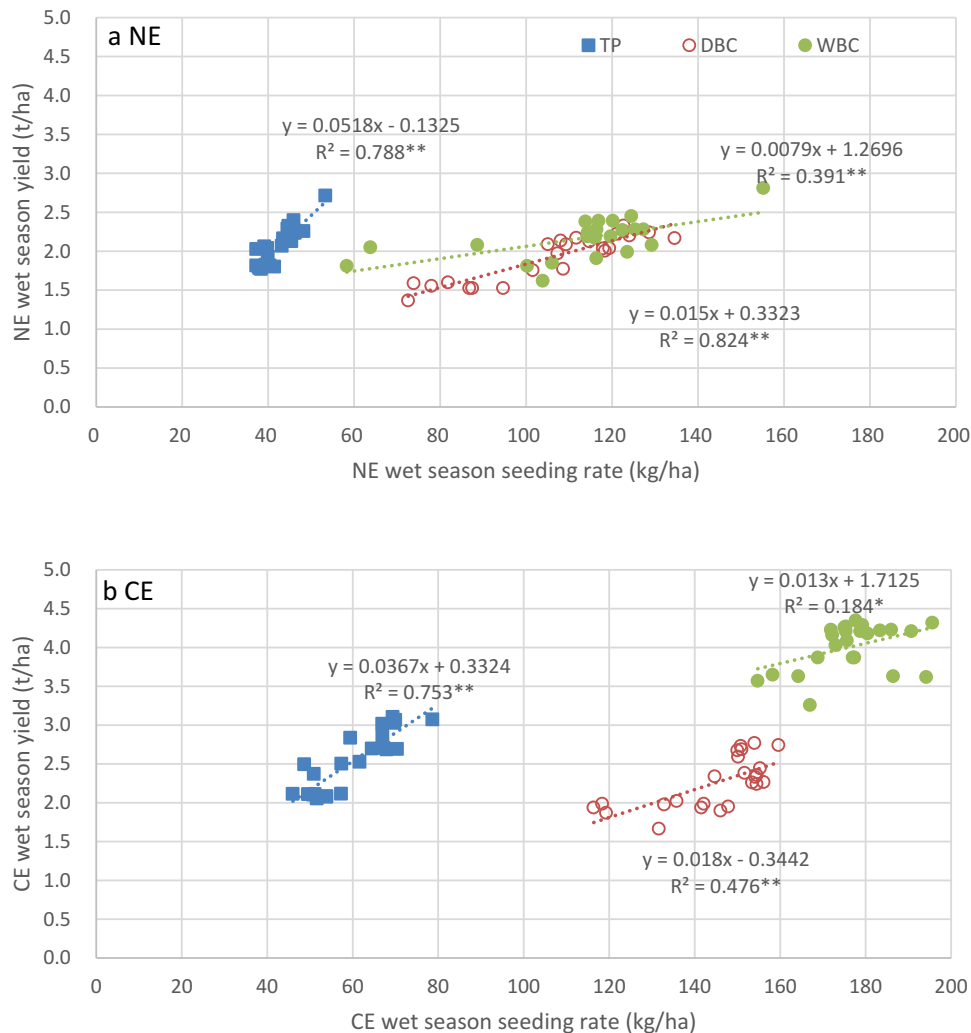


Figure 9. Relationship between seeding rate and yield by three planting methods (TP; transplanting, DBC; dry broadcasting, WBC; wet broadcasting) for wet season rice from 1992 to 2015 in Northeast region (NE) (a) and Central region (CE) (b).

statistical average yield levels were lower (Figures 3 and 8). Suwanmontri et al. (2018) showed large yield gap between the bottom 10 percentile farmers (0.63 t/ha) and the top 10 percentile farmers (4.05 t/ha), with an average yield of 2.18 t/ha in rainfed lowlands in Northeast region, and that higher yield was attained by market-oriented farmers (2.71 t/ha) than the subsistence farmers (1.66 t/ha). The participatory method may have contributed to have increased on-farm yield by reducing exploitable yield gap under lower yielding environments (Fischer et al., 2014; Manzanilla et al., 2011; Mitchell et al., 2014).

For the 10 years prior to 2018, rice area, rice yield, and hence production fluctuated yearly, and this is likely to be due to the instability on rice policy. Thus the Government's policy of rice farmer protection resulted in increase in production with increased area and yield, but also in large pile of rice stocks. This policy could not be maintained at the end, and production declined in

recent years. The Government intervention in rice production is practised in some countries, e.g. China (Nie & Peng, 2017). At the same time, the lack of irrigation water (USDA, 2015) forced to reduce dry season rice production in Thailand.

To make a short summary for future direction of rice production in Thailand from our analysis, yield enhancement would not come much from further expansion of dry season area due to water limitation, and yield increase of lower yielding NE in WS is crucial. Simple increase in application dose of fertilizers would be unlikely to contribute to higher yield, considering the recent stagnation of fertilizer response (Figure 6). Breeding of higher yielding varieties without losing grain quality characteristics should be a key as the modern variety group already showed superior yielding performance compared with the currently dominant improved variety in NE

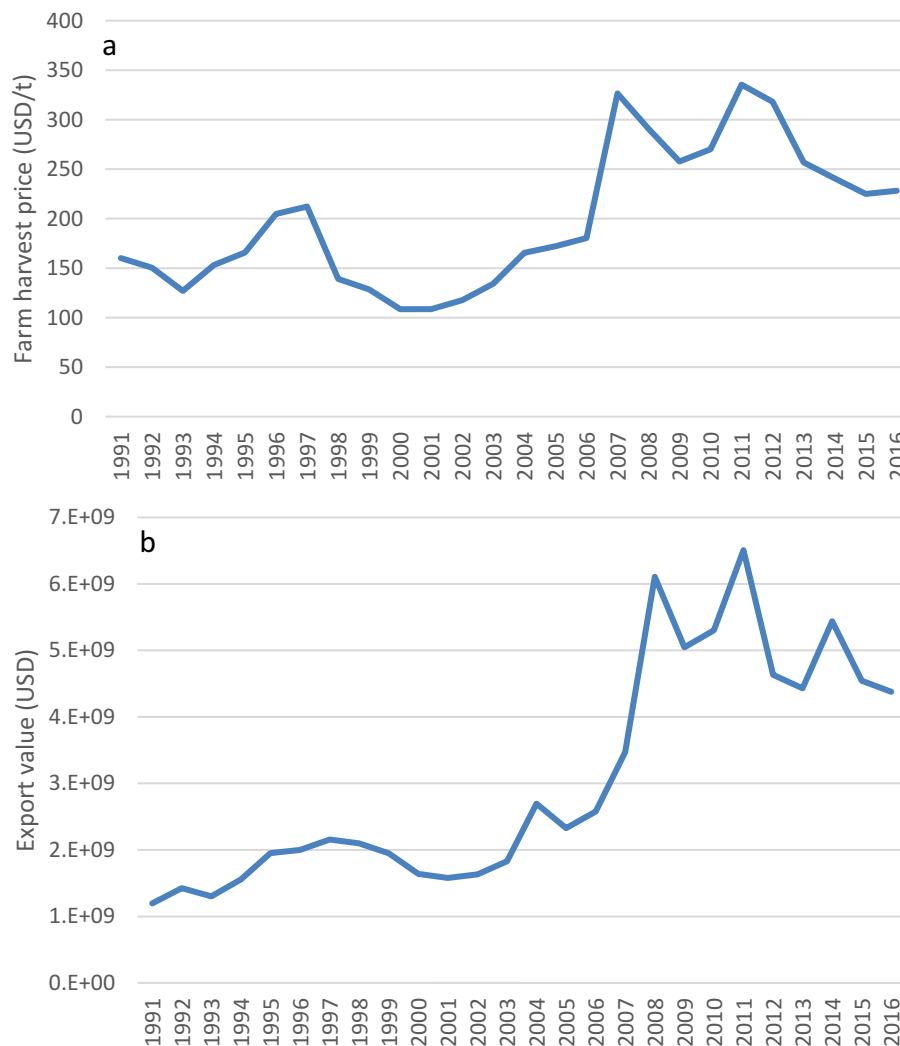


Figure 10. Farm harvest price for paddy (USD/t) (a) and rice export value (USD) (b).

such as KDML105 or RD6 (Figure 5). Direct seeding may increase and appropriate agronomy needs to continue to contribute to higher productivity (e.g. higher fertilizer use efficiency, higher labour productivity). Mechanisation of rice production, for example, combine harvesting, can become more important through saving time, enabling timely operation, and gaining greater profit, which was not covered in this paper but reported elsewhere (Fukai et al., 2019).

Disclosure statement

No potential conflict of interest was reported by the authors.

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