Chapter 5. General discussion and conclusions

In this study, farmers' fields investigation (Chapter 1), and field experiments under favourable water conditions (Chapters 2 and 3) and late season drought condition (Chapter 2) were conducted, and they supplied the 22 data sets of yield components of KDML105 across the wide range of environments (Table 5.1). Results of these 22 data sets and 210 data sets from grid cells in 3 broadcasting plots in 2005 in Chapter 4 were analyzed to clarify the relationships among seeding rate, emerged plant number, grain yield and yield components for the wide range of growing conditions. Genotypic performance and requirements were also analyzed. Finally, cultivation methods to achieve higher grain yield under various environmental conditions with different water availability and weed infestation are discussed.

Table 5.1. Initial stem number, shoot dry matter at maturity, grain yield, harvest index and yield components of 22 data sets of KDML105 in Chapter 1 to 3.

	Initial stem number (m^{-2})	Shoot dry matter $(g\ m^{-2})$	Grain yield $(g\ m^{-2})$	Harvest index (%)	Panicle number (m^{-2})	Spikelet number $(panicle^{-1})$	Spikelet number (m^{-2})	Percentage of ripened grains (%)	Grain weight (mg)
Chap. 2 Upper field Low density	**148**	**585**	**98**	**15**	**133**	**56**	**7123**	**63**	**21.2**
Chap. 3 2005 CM1 May-sowing	*527*	*328*	*143*	*39*	*197*	*35*	*6927*	*78*	*26.3*
Chap. 1 2005 Koei 1	*315*	*404*	*155*	*33*	*87*	*72*	*6221*	*85*	*28.0*
Chap. 3 2006 CM1 May-sowing	*484*	*635*	*178*	*25*	*229*	*47*	*10822*	*69*	*27.4*
Chap. 2 Upper field High density	**401**	**807**	**179**	**19**	**275**	**40**	**10680**	**74**	**22.6**
Chap. 2 Upper field Middle density	**225**	**801**	**199**	**22**	**190**	**66**	**12604**	**71**	**23.1**
Chap. 3 2005 CM1 June-sowing	440	554	227	36	333	36	11960	77	26.6
Chap. 3 2006 CM1 June-sowing	544	609	231	33	239	47	11327	76	26.8
Chap. 3 2006 CM2 May-sowing	*133*	*841*	*256*	*27*	*141*	*86*	*12037*	*76*	*28.1*
Chap. 3 2004 -TD High density	458	758	270	33	420	27	11323	86	28.5
Chap. 3 2005 CM2 May-sowing	*105*	*640*	*307*	*42*	*165*	*85*	*14016*	*81*	*27.0*
Chap. 3 2004 +TD Low density	143	724	313	39	163	93	15067	74	28.2
Chap. 3 2004 +TD High density	458	828	323	34	301	47	14066	84	28.0
Chap. 2 Lower field Middle density	216	1251	325	23	224	67	14990	81	26.6
Chap. 3 2004 -TD Low density	143	721	327	40	148	95	14119	79	29.2
Chap. 3 2004 -TD Middle density	262	808	342	37	243	55	13380	88	29.0
Chap. 3 2006 CM2 June-sowing	149	957	372	34	180	102	18304	76	27.7
Chap. 3 2004 +TD Middle density	262	950	382	36	297	58	17228	81	28.2
Chap. 2 Lower field High density	563	1409	385	24	363	51	18522	83	25.0
Chap. 2 Lower field Low density	123	1382	394	25	187	101	19064	78	26.0
Chap. 3 2005 CM2 June-sowing	111	955	419	38	231	87	20179	75	26.7
Chap. 1 2005 Don Chi 1	*261*	*1295*	*514*	*35*	*184*	*101*	*18644*	*95*	*29.0*
Mean	294	829	288	31	224	66	13573	79	26.8

Data sets are put in order of grain yield. Data sets written in **bold** and *italic* colour indicates **under late season drought** and *seeded in May*, respectively.

1. Relationships among seeding rate, plant number, grain yield and yield components

1.1. Combined analysis of 22 data sets

Initial stem number (stem number in the first measurement on about 35 to 45 days after seeding for Chapter 1, or emerged plant number on about 25 to 30 days after seeding for Chapters 2 and 3), shoot dry matter, grain yield, harvest index and yield components of 22 data sets are shown in Table 5.1. Mean grain yield was 294 g m^{-2}. Data sets from Koei 1 in Chapter 1 (early seeding), the upper field in Chapter 2 (under the late season drought) and CM1 in May-sowing in Chapter 3 (early seeding) had lower grain yield, and these data sets were grouped into the lower-yielding conditions (n = 6). The other 16 data sets were grouped into the higher-yielding conditions. The water conditions of the data sets in the higher-yielding conditions were in general favourable (except for CM2 in May-sowing in 2005 with longer non-flooded period in early season). Analysis was conducted for all of the 22 data sets and separately for the higher- or lower-yielding conditions.

In the higher-yielding conditions, the three highest grain yields (394 to 514 g m^{-2}) were obtained from lower seeding rate (31 to 47 kg seeds ha^{-1}), but low seeding rate resulted in the lowest grain yield (98 g m^{-2}) and higher seeding rate tended to achieve higher grain yield in the lower-yielding conditions (red regression line; for the lower-yielding conditions) (Fig. 5.1a). Higher seeding rate resulted in larger initial stem number (black regression line; for all of the 22 data sets) (Fig. 5.1b), and larger panicle number was obtained from larger initial stem number (although the correlation was not significant in the lower-yielding) (blue regression line; for the higher-yielding conditions) (Fig. 5.1c). The slope of regression line was more gentle in the lower-yielding conditions than in the higher-yielding. This indicated more stems or plants died and could not produce panicles in the lower-yielding conditions (mean panicle-to-initial stem number ratio was 59 and 105% in the lower-and higher-yielding conditions, respectively). Both under the higher- and lower-yielding conditions, smaller panicle number was compensated by larger spikelet number per panicle, and spikelet number per panicle increased more sharply with smaller panicle number in the higher-yielding conditions than in the lower-yielding (Fig. 5.1d). The regression line between panicle number and spikelet number per area or grain yield (combined analysis of all of the 22 data sets) indicated that spikelet number per area or grain yield increased with the increasing panicle number up to around 200 panicles m^{-2} and then got constant (Fig. 5.2a,b). This general trend in combined analysis was similar with the relationships between seeding rate or plant number and grain yield in irrigated direct seeded rice in Japan (Akamatsu, 1968a; Kobayashi and Washio, 1975; Kobayashi and Wada, 1979; 1980; Sekiyama and Shigenaga, 1980). Under the lower-yielding conditions, spikelet number per area tended to increase with larger panicle number. This result suggested that panicle number was important to achieve larger sink size (spikelet number per area) under the lower-yielding conditions. In the upper field in Chapter 2, spikelet number per area and grain yield in the low seeding rate was almost half of that in the higher seeding rates, owing to its smaller panicle number. Phuong et al. (2005) (for wet seeding) and Zhao et al. (2007) (for aerobic rice) also reported that higher seeding rate resulted in larger panicle number and higher grain yield under lower-yielding (weedy) conditions. Advantage of higher seeding rate in DS under weedy condition in Northeast Thailand was also reported by Romyen et al. (2002), although they did not show the relationships between seeding rate and panicle number or panicle number and grain yield. Panicle number did not affect spikelet number per area or grain yield under the higher-yielding conditions, but larger spikelet number per panicle resulted in larger spikelet number per area and higher grain yield (Fig. 5.2c,d). These results indicated that larger panicle number was necessary for higher grain yield under lower-yielding conditions, and the importance of panicle number decreased and that of spikelet number per panicle increased in higher-yielding conditions. In the combined analysis of the higher- and lower-yielding conditions, spikelet number per area was strongly associated with grain yield (Fig. 5.2e)

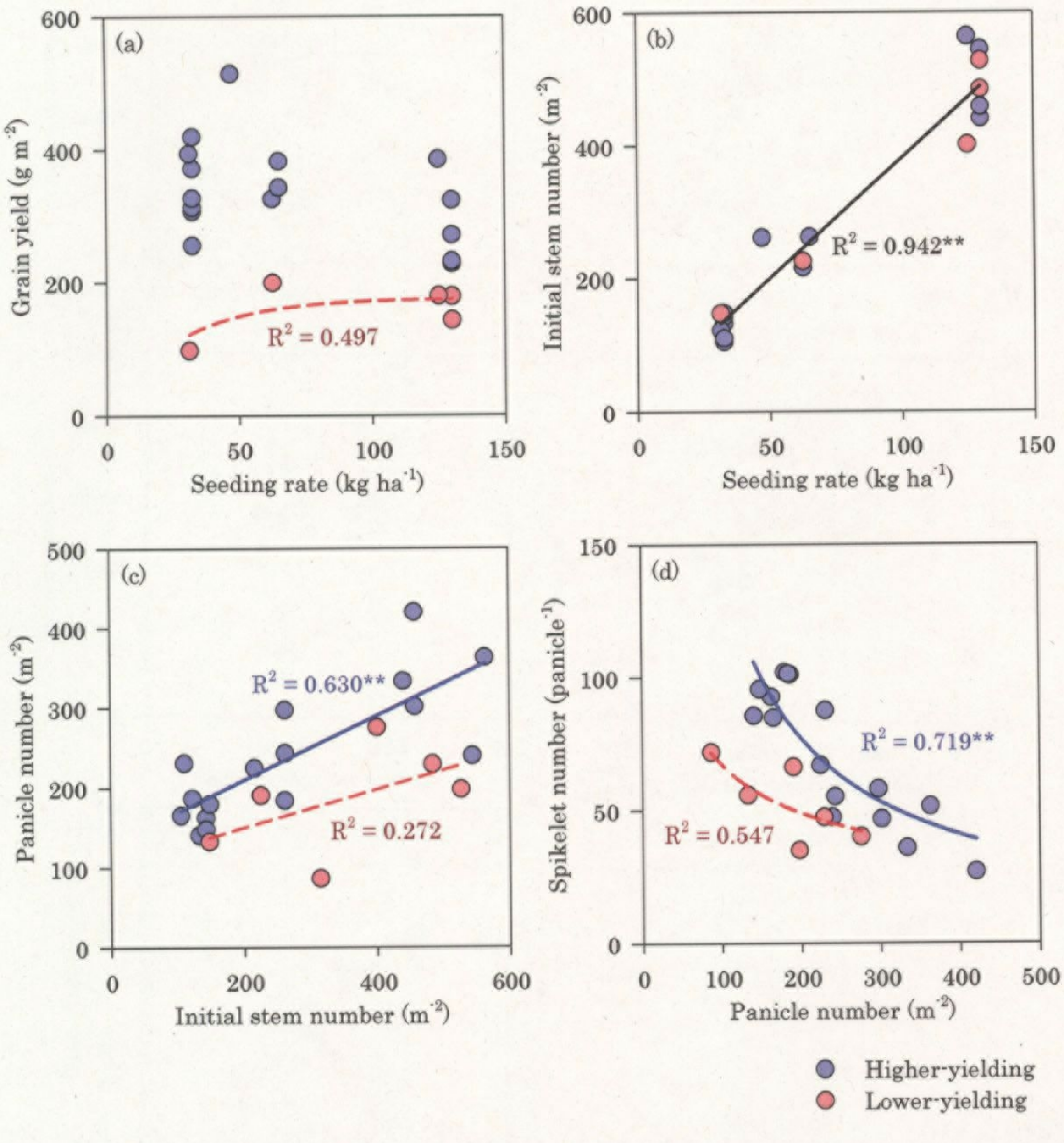

Fig. 5.1. Relationship between seeding rate and grain yield (a), seeding rate and initial stem number (b), initial stem number and panicle number (c) and panicle number and spikelet number per panicle (d). Linear or logistic regression was drawn for (b), (c) and (d). Black, blue and red regression line indicates regression for the combined, higher- and lower-yielding group, respectively. ** indicates significant regression at 1% level.

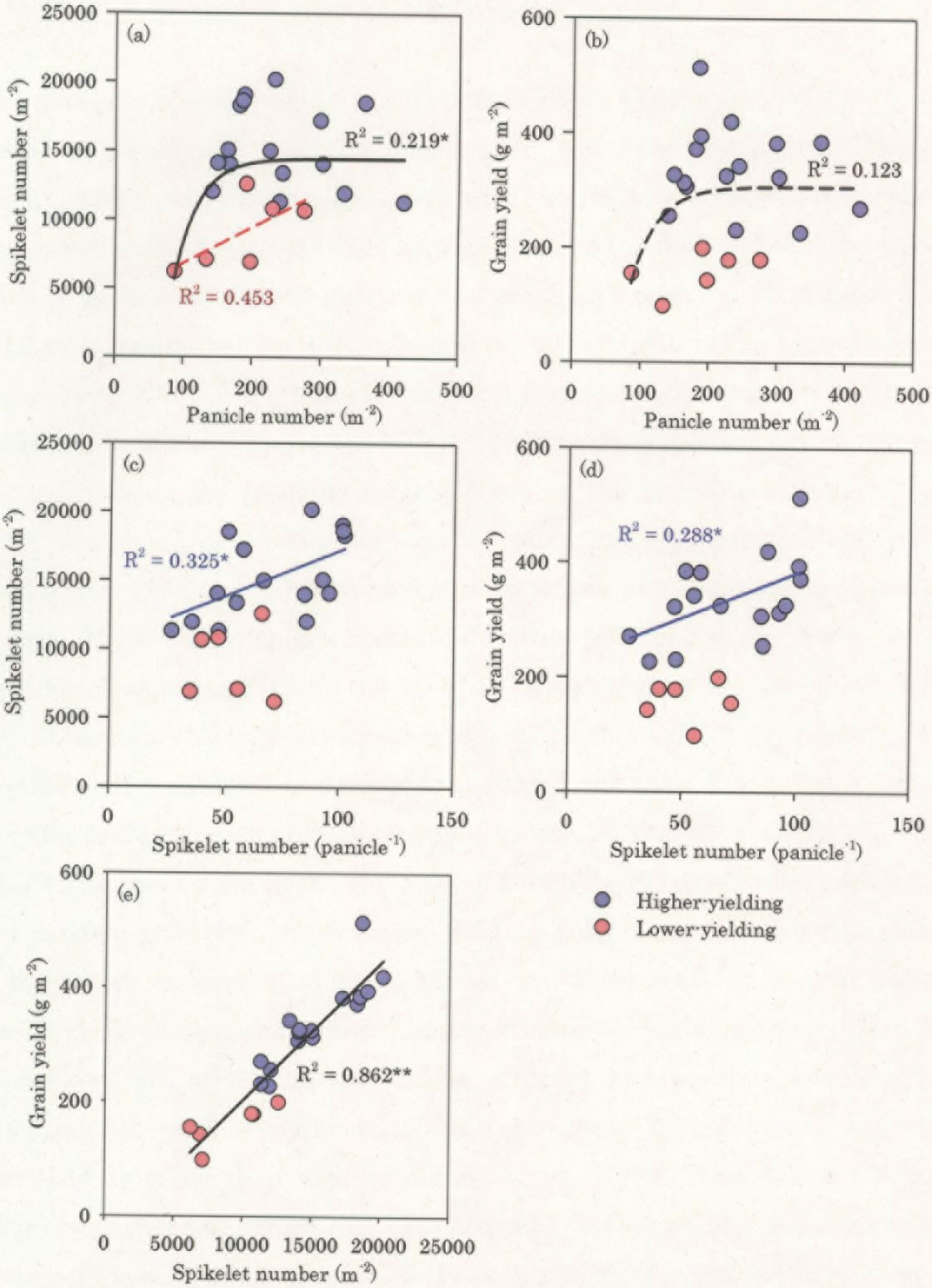

Fig. 5.2. Relationship between panicle number and spikelet number per area (a), panicle number and grain yield (b), spikelet number per panicle and spikelet number per area (c) and spikelet number per panicle and grain yield (d). Linear or exponential regression was drawn for (a), (b), (c) and (d). Black, blue and red regression line indicates regression for the combined, higher- and lower-yielding group, respectively. * indicates significant regression at 5% level.

1.2. Analysis of 210 data sets from Chapter 4

The data sets obtained from 210 grid cells in 3 broadcasting plots in 2005 in Chapter 4 were separated into 2 groups (the higher- and lower-yielding) by discriminant analysis (SPSS, 2000), using mean soil water content on 8 measurement dates and visual weed score on 14 November as predictors and panicle number, dry matter per panicle or panicle dry matter per area as a grouping variable. The optimum threshold values were determined by testing from 0 to 100 m^{-2} in 10 m^{-2} increments for panicle number, from 0.0 to 1.0 g $panicle^{-1}$ in 0.1 g $panicle^{-1}$ increments for dry matter per panicle and from 0 to 100 g m^{-2} in 10 g m^{-2} increments for panicle dry matter per area. After determining the optimum threshold values, the data sets with panicle number larger than 30 m^{-2}, dry matter per panicle higher than 0.7 g $panicle^{-1}$ and panicle dry matter higher than 40 g m^{-2} with higher mean soil water content (mean of grouped grid cells was 35.7% v v^{-1} with the standard deviation (SD) of 2.4) and lower visual weed score (mean value was 3.7 with the SD of 2.1) were grouped into the higher-yielding (n = 58). Other data sets with panicle number smaller than 30 m^{-2}, dry matter per panicle lower than 0.7 g $panicle^{-1}$ or panicle dry matter lower than 40 g m^{-2} with lower mean soil water content (mean of grouped grid cells was 30.8% v v^{-1} with the SD of 2.9) and higher visual weed score (mean value was 5.8 with the SD of 1.5) were grouped into the lower-yielding (n = 152). In the higher-yielding group, panicle number increased with the increasing number of emerged plants, but there was not a clear relationship between plant number and panicle number in the lower-yielding group (Fig. 5.3a). This was because death of plants or stems occurred and percentage of fertile stems (proportion of panicle number to emerged plant number) was lower in the lower-yielding group than higher-yielding (25 vs. 110%). There was a tendency that higher dry matter per panicle was obtained with smaller panicle number, especially in the higher-yielding group (Fig. 5.3b). In both the higher- and lower-yielding groups, panicle number was positively correlated with panicle dry matter per area, and R^2 was larger in the lower-yielding group than in the higher-yielding group (Fig. 5.3c). This indicated contribution of panicle number to grain yield was larger in the lower-yielding group than in the higher-yielding. Two regression lines indicated the increase of panicle dry matter by panicle number was smaller in the lower-yielding group than in the higher-yielding group. In the higher-yielding group, dry matter per panicle was also positively correlated with panicle dry matter per area, but not in the lower-yielding (Fig. 5.3d). Comparing the regressions and R^2 values between the higher- and lower-yielding groups, it was indicated that the importance of panicle number for grain yield decreased and that of panicle size (larger spikelet or ripened grain number per panicle) increased in higher-yielding conditions.

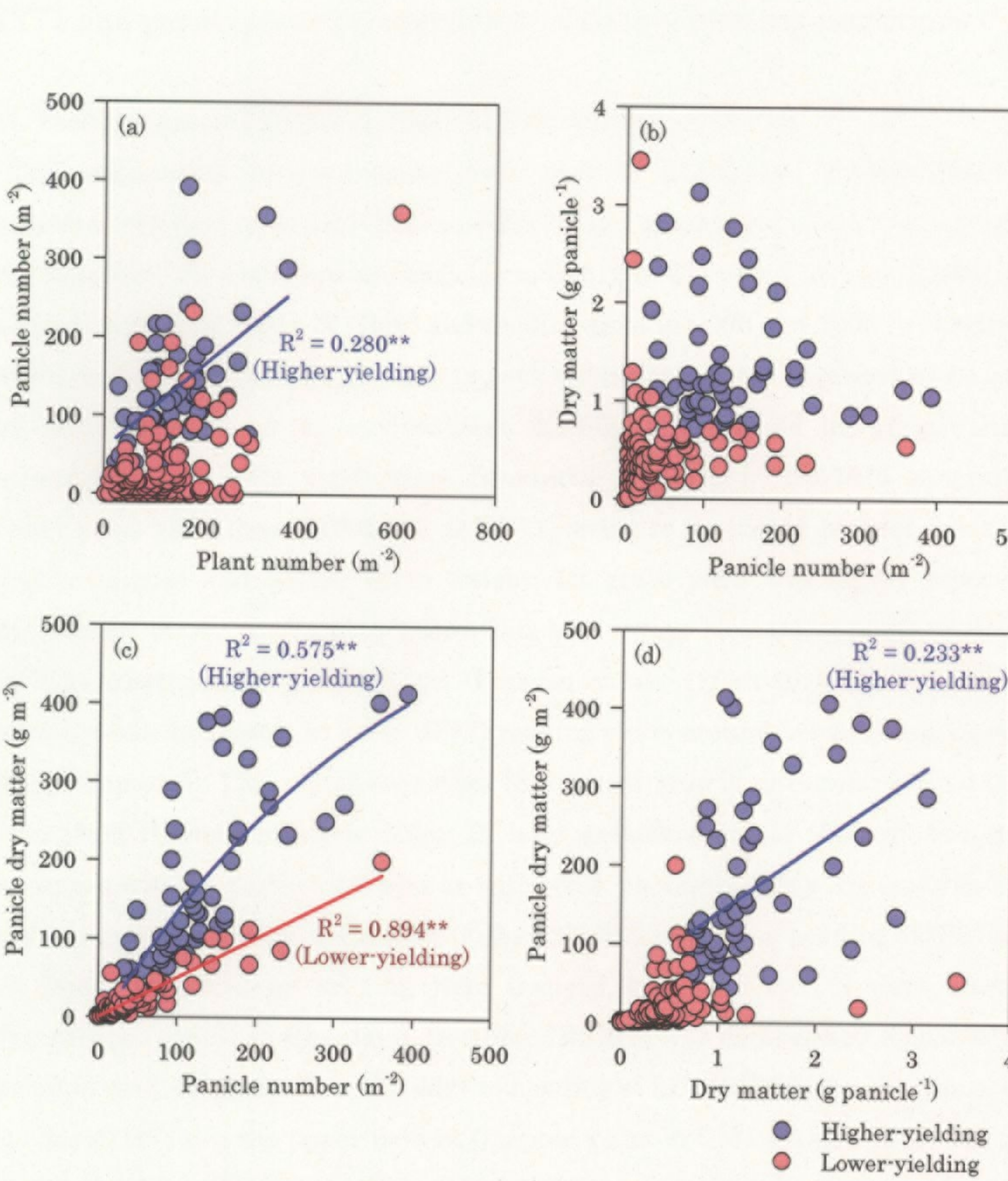

Fig. 5.3. Relationship between plant number and panicle number (a), panicle number and dry matter per panicle (b), panicle number and panicle dry matter per area (c) and dry matter per panicle and panicle dry matter per area (d). Linear or exponential regression was drawn for (a), (c) and (d). Blue and red regression line indicates regression for the higher- and lower-yielding group, respectively. ** indicates significant regression at 1% level.

2. Performance of 3 genotypes, KDML105, IR57514-PMI-5-B-1-2 and HY71 and genotypic requirements for different growing conditions

2.1. Performance of KDML105, IR57514-PMI-5-B-1-2 and HY71

The relationship between mean grain yield of KDML105, IR57514-PMI-5-B-1-2 (hereafter referred to as IR57514) and HY71 and grain yield of each genotype in 10 environments (the lower and upper fields in Exp. 2 in Chapter 2 and the combination of cultivation method (CM1 or CM2) and seeding time in 2005 and 2006 in Chapter 3) is shown in Fig. 5.4. Mean grain yield in each environment was regarded as an index of the favourableness of the environment. KDML105 increased its grain yield with increasing mean grain yield (more favourable conditions). IR57514 generally had higher grain yield than KDML105 or HY71, owing to its higher harvest index, larger panicle number and higher grain weight. Its grain yield was higher especially in May-sowing (early seeding) in 2006. This was owing to weaker photosensitivity of IR57514 compared with KDML105 (Romyen et al., 1998). In CM1, longer days to heading tended to result in lower SPAD reading value around heading and lower grain yield (Chapter 3). This result suggested that longer growth duration resulted in lower grain yield through nitrogen deficit in later growth stage. If seeding time is early, genotypes without photosensitivity or with weak photosensitivity are suitable because they can avoid long growth duration (Fukai, 2002). The days to heading of IR57514 was not largely affected by seeding time (ranged from 104 to 117 days, except for May-sowing in 2005 in Chapter 3, in which IR57514 was damaged by long non-flooded period in early season), while the days to heading of KDML105 had wider range (127 to 169 days). HY71 in the upper field in Chapter 2 and in CM1 with June-sowing in both 2005 and 2006 had the shortest days to heading and the highest grain yield among the 3 genotypes, owing to its higher biomass increase from heading to maturity and larger spikelet number per area. In the upper field in Chapter 2, HY71 headed before the onset of late season drought, and the percentage of ripened grains and grain weight was also higher than KDML105 and IR57514. In contrast, HY71 in CM2 with May-sowing in 2006 reduced its biomass from heading to maturity, owing to overgrowth until heading (its shoot dry matter at heading was 949 g m^{-2} with the SPAD reading value lower than IR57514), and low harvest index, percentage of ripened grains and grain weight resulted in low grain yield.

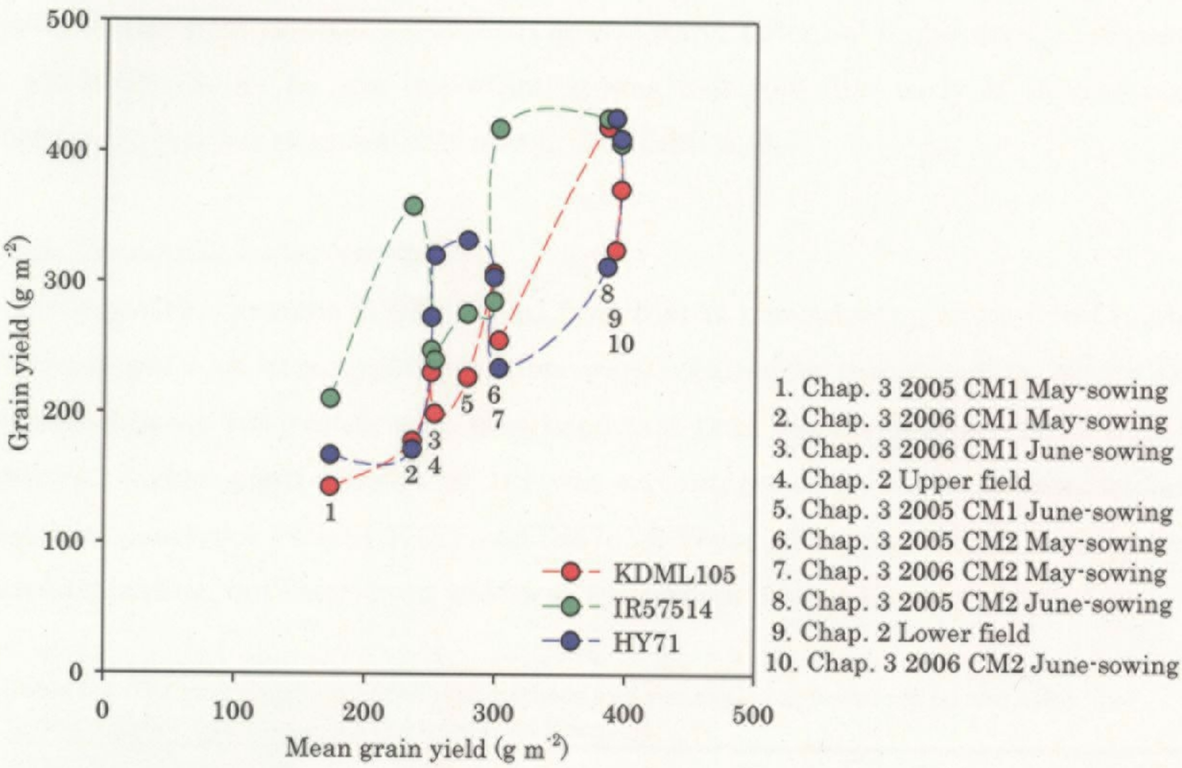

Fig. 5.4. Relationship between mean grain yield of KDML105, IR57514 and HY71 and grain yield of each genotype in 10 environments (the lower and upper fields in Exp. 2 in Chapter 2 and the combination of cultivation method (CM1 or CM2) and seeding time in 2005 and 2006 in Chapter 3). Numbers below the symbols indicate the environments listed on the right side of the figure.

2.2. Genotypic requirements

2.2.1. Late season drought conditions

In transplanting under late season drought conditions, earlier maturing genotypes are suitable because they can flower before the onset of drought (Exp. 2 in Chapter 2; Fukai and Cooper, 1995; Fukai, 1999; Pantuwan et al., 2002). Early or intermediate genotypes had higher grain yield than late genotypes also in DS (Exp. 2 in Chapter 2). Although other drought-resistance-related characters such as delay in flowering, leaf death, deeper root, osmotic adjustment or leaf water potential under drought (Fischer et al., 2003) should be also important, it was indicated that early or intermediate maturing genotypes were suitable also in DS (Table 5.2).

2.2.2. Favourable water conditions

Genotypic requirement in DS differed from that in transplanting (Exp. 2 in Chapter 2). Genotypes with larger panicle number were required for transplanting, but for DS, spikelet number per panicle was more important than panicle number (Table 5.2). In addition, higher plant density in DS was advantageous for early or intermediate maturing genotypes such as HY71 and IR57514. These genotypes did not perform well in transplanting, but their grain yield was the highest among 14 genotypes in DS.

Table 5.2. The recommended cultivation methods and genotypic requirements for the lower- and higher-yielding conditions and the weedy condition.

Lower-yielding condition
Higher seeding rate
Seeding rate of approx. 62.5 kg ha^{-1} should be suitable under the late season drought condition.
Optimum seeding rate to suppress weeds depends on the intensity of weed infestation.
Avoiding early seeding
If early seeding is inevitable, genotypes with weaker photosensitivity like IR57514 should be chosen. The combination of low seeding rate (about 31.3 kg ha^{-1}) and higher rate of fertilizer is also effective.
More precise land levelling
It is effective to reduce the uneven distribution of standing water and weedy spots.
Row seeding combined with inter-row weeding
It makes it easy to control weeds and reduces the within-field variation in rice growth.
Under late season drought conditions, early or intermediate maturing genotypes (drought escape) with higher biomass production are suitable.
Higher-yielding condition
The combination of low seeding rate (about 31.3 kg ha^{-1}) and higher rate of fertilizer with June-sowing
Genotypes with larger spikelet number per panicle and higher biomass production

3. Recommendation of cultivation managements

3.1. Lower-yielding conditions

In the analysis in section 1.1, it was indicated that higher seeding rate was effective to achieve higher grain yield through larger panicle number (Table 5.2). Under the late season drought condition, the middle seeding rate (62.5 kg ha^{-1}) should be adopted to have enough panicle number for high grain yield. Grain yield in the low seeding rate was almost half of that in the high or middle seeding rates, owing to its smaller panicle number. Higher seeding rate is an effective management also for weed control (Naklang, 1997; Romyen et al., 2002; Phuong et al., 2005). In the data sets in Chapter 4, grid cells with plant number larger than 200 m^{-2} had lower visual weed score, larger panicle number and higher shoot and panicle dry matter on average, compared with the grid cells with plant number less than 200 m^{-2}. The optimum seeding rate to suppress weeds should depend on the intensity of weed infestation.

Early seeding should better be avoided to have larger panicle number because obtained panicle number was not large even with high seeding rate (e.g. May-sowing in CM1 in Chapter 3 and Koei 1 in 2005 in Chapter 1), owing to the low percentage of fertile stems caused by nutrient deficit. If early seeding is inevitable, one way to achieve higher grain yield is to choose the genotypes with non- or weak photosensitivity, because they can avoid nutrient deficit derived from long growth duration (Table 5.2).

From the result in Chapter 4, it was suggested that more precise land levelling technique was required to have more uniform rice growth through uniform distribution of standing water and soil water content (Table 5.2). As the spatial variability of soil water content was negatively correlated with the weed infestation (visual weed score or shoot dry matter of weeds), careful land levelling should be also effective to reduce weedy spots. Lantican et al. (1999) and Rickman et al. (2001) reported that more precise land levelling improved grain yield by reducing water deficit or weed infestation. In the investigation in Chapter 1, several farmers omitted harrowing to save time and cost. Even if they conducted harrowing, it was sometimes not enough to have uniform soil surface. The importance of careful land preparation should be well explained to farmers. Rotary tilling should help level the land more precisely (Kabaki et al., 2003), and this could be adopted in a large-scale field. Another way to more precise land levelling is to divide a large plot into a number of small fields (Lantican et al., 1999). This method is effective if a farmer can not afford to adopt rotary tillage because of its higher cost.

Row seeding combined with inter-row weeding is effective to control weeds (Table 5.2). In Chapter 4, inter-row weeding suppressed weeds significantly and shoot and panicle dry matter per area of rice was higher compared with broadcasting. Row seeding with tractor-mounted mechanical seeder requires 4 to 12 hours ha^{-1} for seeding (broadcasting requires 4 hours ha^{-1}) (Bakker et al., 2002). Kabaki et al. (2003) examined row seeder mounted on a 4-wheeled tractor in Northeast Thailand, but a 4-wheeled tractor is not common in this region and this method could not be accepted by farmers. Row seeder mounted on a 2-wheeled hand tractor should be an alternative of broadcasting as labour-saving technology.

3.2. Higher-yielding conditions

Under the higher-yielding conditions, the combination of low seeding rate and high fertilizer application rate (i.e. CM2 in Chapter 3) was effective for high grain yield (Table 5.2). CM2 achieved higher grain yield also in May-sowing, and it was indicated that low seeding rate and high fertilizer application rate was effective also in early seeding. However, farmers in Northeast Thailand generally apply lower rate of chemical fertilizer than that in CM2 (Lefroy and Konboon, 1998; Pandey et al., 2002). Hence the method using less chemical fertilizer and more organic matter such as farmyard manure (Wade et al., 1999a; Haefele et al., 2006), green manure (Herrera et al., 1997) and leaf litters (Naklang et al., 1999; Whitbread et al., 1999) should also be investigated.

Summary

Northeast Thailand is one of the major rainfed lowland rice producing areas. Average grain yield in Northeast Thailand is low, mainly due to late season drought starting around flowering time and low soil fertility. Recently, transplanting (TP) has been rapidly replaced by direct seeding (DS) with less labour-requirement, owing to the shortage of labour for TP. The percentage of DS in Northeast Thailand was about 25% in 1996, and DS should be widely adopted in future. However, cultivation methods for DS have not been established in this region. The objectives of this thesis were to clarify the relationships between seeding rate or plant number and grain yield and the effect of growing conditions on those relationships and to propose suitable cultivation managements for DS in rainfed lowlands in Northeast Thailand.

Chapter 1. Variation in grain yield of direct seeded rice among farmers' fields in Ubon Ratchathani Province

The investigation of DS rice growth was conducted in farmers' fields together with the interview to the owners of the fields. There was a wide range of variation in their cultivation managements, and it was suggested that suitable cultivation methods have not been established yet. The variation in grain yield among fields and years was also large. Grain yield was correlated with panicle number, and it was suggested that cultivation method to achieve larger panicle number was required for higher grain yield.

Chapter 2. Comparison between direct seeding and transplanting, using different plant densities or genotypes

The effect of plant density on grain yield (Exp. 1) and the genotypic differences in grain yield (Exp. 2) of rainfed lowland rice grown with TP and DS was evaluated. These experiments were conducted in two fields with different water availability. In Exp. 1, KDML105 was grown in both TP and DS, and IR24 (semi-dwarf and early maturing genotype for irrigated lowland) was grown only in TP. Three levels of plant density in TP (16, 25, and 44 hills m^{-2}) and DS (31.3, 62.5, and 125 kg seeds ha^{-1}) were tested. In

Exp. 2, 14 genotypes with different maturity were examined. Water limitation was not observed in the lower field, but drought with leaf rolling, leaf death and delay of heading occurred in the upper field after mid October. In the upper field, grain yield tended to be lower in DS than in TP. In the lower field, however, grain yield was higher in DS than in TP because of higher biomass production and a larger panicle number. In Exp. 1, the low seeding rate in DS in the lower field showed equally high grain yield as higher seeding rates. In contrast, the low seeding rate in the upper field tended to have lower yield than higher seeding rates. In both the lower and upper fields, grain yield of TP tended to be lower at the low plant density than at higher plant densities. In Exp. 2, genotypic difference in grain yield was significant in a combined analysis of all 4 growing conditions. In the lower field, the interaction between cultivation method and genotype was also significant. In DS in the lower field, some early- to intermediate-maturing genotypes produced high shoot dry matter at maturity comparable to those of the late-maturing genotypes. High shoot dry matter production and large spikelet number per panicle were associated with high grain yield in DS in the lower field, whereas in TP genotypes with large panicle number were required for high grain yield. Regression analysis showed that late-maturing genotypes yielded less than earlier maturing genotypes in the upper field but not in the lower field.

Chapter 3. Cultivation method for higher grain yield under favourable water conditions

In DS, nitrogen deficit in later growth stage derived from high plant density could be a problem, especially under favourable growing conditions. In this chapter, the effects of seeding rate and fertilizer application on grain yield were evaluated under favourable water conditions, to propose the management to achieve higher grain yield under favourable water conditions. In 2004, seeding rates of 500, 250 and 125 seeds m^{-2} were examined under topdressed (+TD) and non-topdressed (–TD) conditions, using 2 genotypes, KDML105 and IR57514-PMI-5-B-1-2 (IR57514). In 2005 and 2006, 2 cultivation methods (seeding rate of 500 seeds m^{-2} and nitrogen application of 50 kg ha^{-1}; CM1 and seeding rate of 125 seeds m^{-2} and nitrogen application of 90-100 kg ha^{-1}; CM2) were compared with 2 seeding time (May and June) and 3 genotypes (KDML105, IR57514 and HY71). In 2004, spikelet number per area tended to be higher in +TD than –TD, and the analysis of panicle structure revealed that spikelets on tertiary pedicel in low seeding rate of KDML105 greatly increased by topdressing. These results suggested that the combination of lower seeding rate and continuous application of nitrogen was necessary for larger spikelet number per area and higher grain yield. In 2005 and 2006, CM2 had higher grain yield than CM1 owing to its larger spikelet number per panicle. Grain yield of KDML105 in June-sowing in CM2 was as high as the highest yield reported in TP, and this study showed DS had as high yielding performance as TP under favourable water conditions. Correlation between biomass production from heading to maturity and grain yield indicated the importance of the biomass production in later growth stage. Under favourable water conditions, cultivation method avoiding nutrient deficit should be adopted and higher biomass production in later growth stage should be achieved by appropriate seeding rate, seeding time and nutrient management.

Chapter 4. Spatial variability in growth of direct seeded rice

Large within-field variation in rice growth is often a problem in DS. In this chapter, field experiment was conducted in 2004 and 2005 to evaluate the spatial relationships among the variations in soil water content, rice growth (cv. KDML105), and weed infestation, by using geostatistics (semivariogram) in three broadcasting (BC) plots (only in 2005), and to compare the within-field variation in BC rice growth with a row-sown (RS; inter-row spacing of 30 cm) rice. BC plots were not weeded, but inter-row weeding was conducted in the RS plots for both years. Size of each plot was 14 by 20 m in both years, and data was collected from the centre of 70 grid cells (2 m × 2 m) in 3 BC plots in 2005 or 9 grid cells (4.7 m × 6.7 m) in BC and RS plots in 2004 and RS plot in 2005. In BC plots, large within-field variation was observed in emerged plant number (seedling number), shoot and panicle dry matter and weed infestation in both years. Within-field variation in soil water content in 2005 was relatively small, but flooded and non-flooded cells existed simultaneously in the plots. Analysis of correlations and cross-semivariograms in the BC plots revealed a positive correlation between soil water content and shoot and panicle dry matter. Weed infestation at rice maturity was negatively correlated with soil water content and rice growth. Within-field variation in rice growth in RS was smaller than that in BC in both years due to its smaller variation, as well as the reduced weed infestation. These results suggested that reducing the spatial variability in rice growth requires careful land levelling to reduce the uneven distribution of standing water and the variability in soil water content, combined with effective weed management. RS with inter-row weeding should be an effective management to reduce the within-field variation through smaller variation in seedling number and less weed infestation compared with BC.

Chapter 5. General discussion and conclusions

From the results in Chapters 1 to 4, it was indicated that higher seeding rate (approx. 60 kg ha^{-1}) was effective for higher grain yield under the lower-yielding conditions (i.e. late season drought or weedy conditions). In contrast, lower seeding rate also achieved high grain yield under the higher-yielding conditions, and spikelet number per panicle affected grain yield rather than panicle number. Early seeding (seeding in May) resulted in longer growth duration, and this caused nitrogen deficit in later growth stage and lower grain yield. However, growth duration was not largely affected by seeding time in weakly photosensitive genotype (i.e. IR57514), and the difference in grain yield between May-sowing and June-sowing was small. Weakly (or non-) photosensitive genotypes should be suitable for early seeding.

These results indicated that achieving larger panicle number by higher seeding rate (approx. 60 kg ha^{-1} for the late season drought, but required seeding rate under weedy conditions should depend on the intensity of weed infestation) was effective for higher grain yield under late season drought or weedy conditions. In addition, more uniform land levelling should be required to have uniform distribution of standing water and reduce weedy spots. Early or intermediate maturing genotypes are suitable under late season drought condition. Under favourable growing conditions, the combination of low seeding rate and high fertilizer application rate (topdressing) was effective to achieve higher grain yield through larger spikelet number per panicle. This combination of low seeding rate and high fertilizer application rate was also effective in early seeding. Genotypes with larger spikelet number per panicle were suitable under favourable growing conditions.

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