Improving drought tolerance in rainfed lowland rice: an example from Thailand

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Abstract
A large portion of the world's poor farm in rainfed systems where the water supply is unpredictable and droughts are common. In Thailand there are approximately 6.2 million ha of rain fed lowland rice which account for 67% of the country's total rice-growing area. This rice system is often characterised by too much and too little water in the same season. Farmers' estimates of their annual losses to drought are as high as 45% in the upper parts of the toposequence. In contrast to irrigated rice systems, gains from crop improvement of rainfed rice have been modest, in part because there has been little effort to breed and select for drought tolerance for the target rainfed environments.

The crop improvement strategy being used in Thailand considers three mechanisms that influence yield in the drought prone targets: yield potential as an important mechanism for mild drought (where yield loss is less than 50%), drought escape (appropriate phenology) and drought tolerance traits of leaf water potential, sterility, flower delay and drought response index for more severe drought conditions. Genotypes are exposed to managed drought environments for selection of drought tolerant genotypes. A marker assisted selection (MAS) scheme has been developed and applied for selection of progenies in the backcrossing program.

The plant breeding program uses rapid generation advance techniques that enable early yield testing in the target population of environments (TPE) through inter-station (multi-location yield testing) and on-farm trials. A farmer participatory approach has been used to identify the TPE for the breeding program. Four terrace paddy levels have been identified, upper (drought), middle (drought prone to favorable) and lower (flooded). This paper reports the change in the breeding program for the drought prone rainfed lowland rice environments of North and Northeast Thailand by incorporating our knowledge on adaptation and on response of rice to drought.

Media summary
Rice is the main food staple in Asia. Many rural poor rely on rice farming under rainfed conditions where farmers estimates of losses to drought can be as high as 45% annually. In Thailand new breeding approaches are being developed to produce varieties that yield well in good years and are tolerant to drought.

Key words
Rainfed lowland rice, drought tolerance, genotype-by-environment interaction, breeding, marker assisted selection, farmer participation.

Rainfed lowland rice environments in Thailand
Approximately 76% of the total 9.2 million ha of rice growing areas in Thailand are under rainfed conditions. Of the three rainfed rice ecosystems, upland, lowland and deep water, rainfed lowland occupies 6.8 million ha (OAE 2001), covering 75% of the total rice growing areas. The majority of the rainfed lowland areas are found in the Northeast (4.8 million ha) and North (1.4 million ha) of Thailand. Rice yield in these regions is low and fluctuates from year to year, ranging between 1.5 and 2.2 t ha^{-1}. There has been little improvement in yield from plant breeding.

Most areas of rainfed lowland rice in Northeast (NE) and North (N) Thailand are classified as shallow favourable and shallow drought-prone (IRRI 1984). Several constraints limiting production of rainfed lowland rice in NE and N have been recognised. Seasonal rainfall is bimodal, usually beginning in May and ending around mid October, but is highly variable. Drought may develop at any time during the growing season. Early-season drought occurs in most areas, affecting timely transplanting of seedlings and the growth of direct seeded rice. Late season drought develops in most years at the end of the rainy season before crop maturation, particularly in paddy rice in a high toposequence position (Jongdee 2001). Farmers estimate their yield loss due to drought as high as 45 % in the upper position of the toposequence (Jongdee 2003), while Jongdee et al. (1997) have simulated losses between 13 and 35% Most paddy soils are light in texture hence permitting high percolation and losses of water and nutrients. Inland saline soil is found throughout the NE covering 2.8 million ha (Somrith 1997). Leaf and neck blast are the most important diseases in both the NE and N of Thailand.

2. Strategies for improving drought tolerance for the rainfed lowland rice systems in Thailand

2.1 Defining target population of environments (TPE)

The target population of environments (TPE) is the set of all environments, fields and season in which an improved variety is targeted to perform well (Nyquest , 1991); Cooper et al., 1997). It is important to understand the characteristics of the TPE, which play a dominant role in determining plant performance. Several approaches have been suggested for identifying TPE(s). Muchow et al. (1996) demonstrated the use of crop models to identify environments in terms of incident water stress, whereas Cooper and Fox (1996) suggested the use of probe and reference genotypes in multi-environment trials. The first approach requires historical weather data while the second requires reference genotypes, which are known for their adaptation to each target environment. In some cases where environmental information may not be available, information can be directly obtained from farmers. Two methods recommended are rapid rural appraisal (RRA) and agroecosystems analysis (Mackill et al., 1996).

In N & NE Thailand, the time and duration of standing water in the paddy dominates in the determination of the TPE for rainfed lowland rice production. An analysis of the probability of standing water in the paddy was conducted in order to determine whether there were any time differences at the beginning and end of the growing season and possibility of drought occurrence across different rainfall regimes. A water balance model was used to estimate level of standing water in paddy using weekly rainfall data from 1987 to 2001 for Nong Khai and Nakhon Ratchasima provinces. Nong Khai is a province in the upper NE, which has high rainfall of 2000 mm/year whereas Nakhon Ratchasima province, located in the lower NE, has low rainfall of 1000 mm/year. The probabilities of having standing water in the paddies required for potential growth of rainfed rice for a 15-year period for Nong Khai and Nakhon Ratchasima provinces are shown in Figure 1. The beginning and ending of growing season for Nong Khai was slightly earlier than Nakhon Ratchasima but there was a high chance of early drought at Nakhon Ratchasima. The probability for Nong Khai was consistently high from week 18 (30 April to 6 May), whereas there was variation for Nakhon Ratchasima during early season until week 31 (30 July to 5 August). At the end of the growing season, the probability declined sharply after week 41 (8 to 14 October) in both provinces, but the decline was earlier in Nong Khai than Nakhon Ratchasima indicating late season drought was a common problem for both the upper and lower NE. Thus, in upper NE environments late season drought tolerant cultivars are required, whereas both early and late season drought tolerant cultivars are required for the lower NE.

In our earlier work, the target domain for rainfed lowland rice in the N and NE Thailand was classified by using genotype and environment (G x E) interaction and cluster analysis of grain yield from multi-location trials. It was however difficult to define G x L (location) groupings because of year to year variation (genotype by location by year interaction, G x L x Y) in grain yield which was generally high in rainfed lowland rice (Wade et al., 1999). The groups of environments and therefore the TPE changed from year to year.

Recently, information obtained from farmer workshops and subsequent surveys at the village and household level have been used to define the TPE. This classification uses the hydrology of rice paddies even at the local level in farmers' fields. Four terrace paddy levels are identified, upper (drought), middle (drought prone), middle (favourable) and lower (flooded) (Table 1). The upper level can be defined as an unfavourable environment where drought can develop at any growth stage and the middle, where rainfall is variable and soils are light in texture, as drought-prone. The lower flooded level can be classified as less favourable because drought can develop in the early season followed by a sudden flood. Among four paddy levels, the upper and middle (drought prone) paddies account for 65% where drought is considered to be a major problem (Farmer Survey 2002). Occurrence of drought is more frequent in the early rather than the late part of the growing season but yield loss is more severe in the latter. Farmers' estimates of yield reduction from late-season drought were 45–50% and 15–20% for the upper and middle terraces, respectively. Thus, the target of our breeding program is the development of cultivars with tolerance of late-season drought.

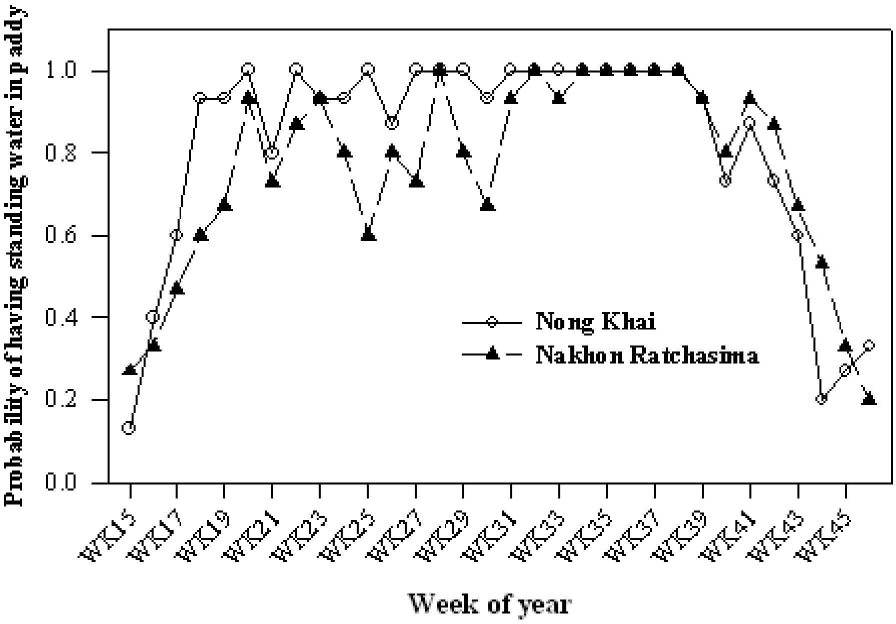

Figure 1. The probability of standing water in rice paddies each week as estimated by water balance using rainfall data from 1987 to 2001, for Nong Khai (○) and Nakhon Ratchasima (▲), Thailand

Table 1. Use of the position on the toposequence to define the type of drought and thus the target population of environments (TPE) for the breeding program, and the yield losses in them for rainfed lowland rice in Thailand.

Position on toposequence	Type of drought	Yield loss in the TPE
Upper (drought)	Early, intermittent, and late drought	Late drought causes 45–50% yield loss
Middle (drought-prone)	Early and late drought	Late drought causes 15–20% yield loss
Middle (favorable)	Early drought	Minimal yield loss
Lower (flooded)	Early drought and sudden flood	

2.2 Developing methods to select for drought tolerance in rainfed lowland rice

There is growing evidence that varieties can be developed for improved yield under drought stress and respond well to favorably-watered conditions (i.e. the good years) if there is early selection for yield under both drought and well-watered conditions. Plant breeders rely on direct selection for grain yield as the main criterion for selection. That process might be made more efficient by the use of indirect traits associated with drought. A number of studies have examined the complex processes, mechanisms and traits that provide drought tolerance and better adaptation of rainfed lowland rice. Fukai and Cooper (2001) have summarized this complexity and focused on three broad mechanisms that influence yield depending on the severity and predictability of the drought. The relationship among these three components in different types of drought is shown in Figure 2. The figure shows that at mild to moderate levels of drought stress (yield is reduced by less than 50%), the yield potential of a genotype is an important mechanism for determination of yield of the genotype in the target environment. At more severe stress, a mechanism for drought escape or tolerance is required. If the drought is severe, predictable, and terminal, then yield is maintained by escaping the drought through the use of earlier maturing varieties. If the drought is severe, mid season and unpredictable, a mechanism for drought tolerance is required. Thus Fukai et al. (1999a) indicated that appropriate phenology, high potential yield and ability to maintain high LWP were associated directly with higher grain yield under drought conditions.

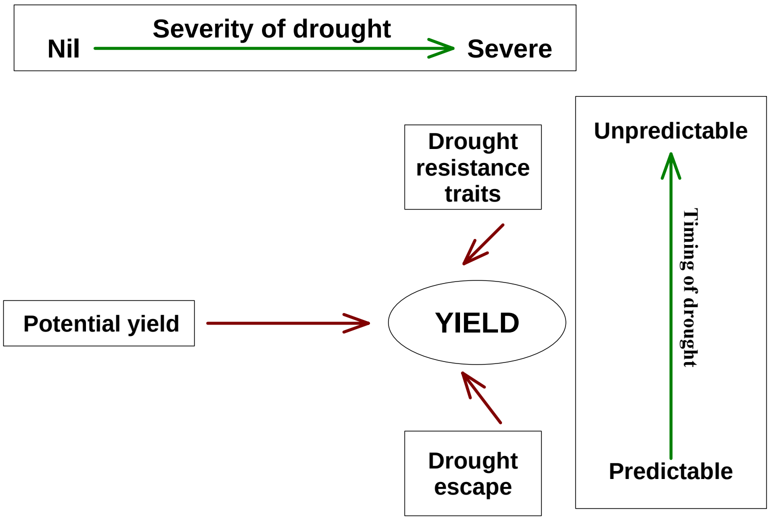

Figure 2. Schematic presentation of three components of yield: potential yield, drought escape and drought tolerance. These components play different roles, depending on predictability and severity of drought in the target environment.

While many traits have been studied for their use in breeding for drought tolerance in rice, only a few show evidence of their contribution to improved yield under drought (Lafitte et al. 2003). Studies in Thailand have focused on the use of high leaf water potential (LWP), low spikelet sterility, reduced delay in flowering, drought response index (DRI) (Bidinger, 1982; Pantuwan, 2002) and drought score (IRRI, 1996) for assessing drought tolerance.

Jongdee et al. (2002) found significant genetic variation in LWP among rice lines under drought stress around flowering. Lines that maintained higher LWP had less spikelet sterility under drought stress, with significant phenotypic (r_p) and genetic correlation (r_g) between LWP and percentage of spikelet sterility after 7 ($r_p = -0.48 \pm 0.19$ and $r_g = -0.58 \pm 0.30$) and 14 days from withholding water ($r_p = -0.91 \pm 0.06$ and $r_g = -1.38 \pm 0.29$) (Figure 3). They also showed that genotypic ranking in LWP tended to be consistent across developmental stages, vegetative, booting and flowering stages, providing an opportunity to assess lines for this trait in either the vegetative or reproductive stage.

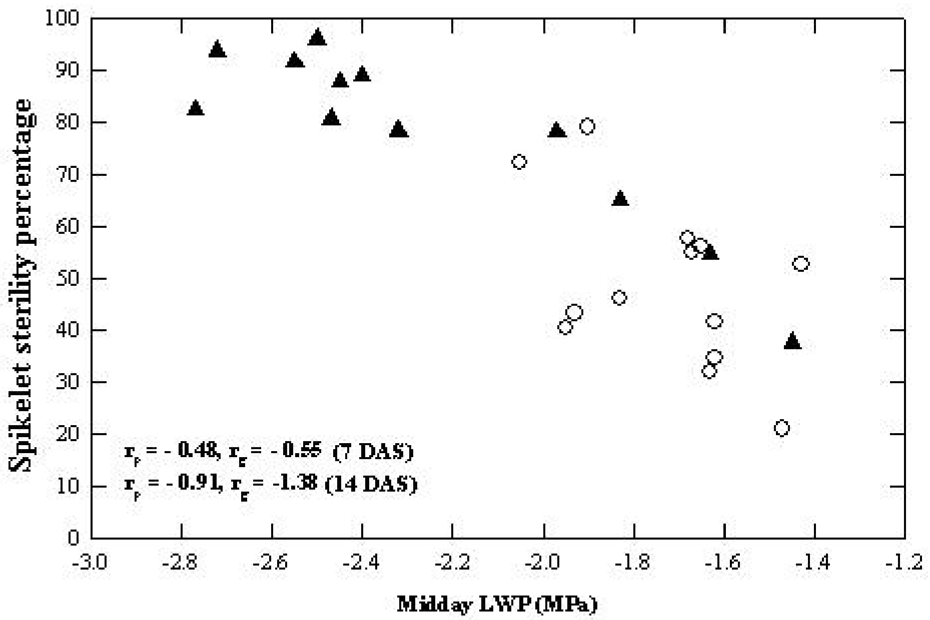

Figure 3. The relationship between percentage of spikelet sterility and leaf water potential of lowland rice plants after 7 (○) and 14 (▲) days from the commencement of drought stress (DAS).

In rice, drought stressed plants delay flowering (relative to well-watered plants). Pantuwan et al (2002b) found significant variation in the delay in flowering among drought stressed genotypes in which flowering time was similar under irrigated condition. The delay was negatively associated with grain yield (r = -0.43**), harvest index (r = -0.34**), fertile panicle (r = -0.40**), and filled grain percentage (r = -0.35**) and positively associated with yield reduction percentage (r = 0.42**). Thus variation in the delay in flowering among genotypes that have been exposed to the same drought conditions can be used as an index of drought tolerance.

Pantuwan et al. (2002) also examined the use of a drought response index (DRI) as a selection index. The DRI was calculated based on the formulae of Bidinger et al. (1982, 1987) after normalising for the effects of yield potential and flowering time under non-stress conditions. The variation in DRI among and within four rice populations was measured when plants were exposed to drought around the grain filling period. The DRI was found to be highly correlated with grain yield under drought stress and explained about half of the total variation in grain yield (r = 0.69**). The DRI of 1.3 was identified as tolerance while –1.3 was identified as susceptible. More recent work by Makara et al (2004) has shown significant variation in DRI among rainfed lowland rice cultivars in Cambodia and that the measure of DRI showed high habitability over drought prone environments (Table 2).

Table 2. The drought response index (DRI) of 15 rice genotypes, the LSD 5% values, the genotype mean heritability (h^2) and the genotype-by-environment/genotype ratio of the estimated components of variance ($\sigma^2_{GEI}/\sigma^2_g$) when grown at two locations (PV and CA) and for a number of years (1998- 2001) in rainfed lowlands in Cambodia. (After Makara et al. 2004)

Gen.No.	Genotype	PV 98	PV 99	PV 00	PV 01	CA 00	CA 99	CA 01	Mean
2	IR57514-PMI-5-B-1-2	0.76	-0.33	**1.35**	-0.20	0.94	0.39	0.39	0.47
26	CAR3	0.32	0.14	0.43	-0.14	-0.48	0.14	**1.71**	0.30
3	IR66327-KKN-10-P1-3R-0	0.01	-0.58	0.41	0.63	**1.34**	0.04	0.05	0.27
17	CAR6	-0.68	-0.04	0.89	0.14	0.46	0.79	0.32	0.27
5	IR66327-KKN-25-P1-3R-0	0.30	**1.24**	0.98	-0.16	-0.39	-0.53	0.41	0.27
10	IR66327-KKN-8-P1-3R-0	0.66	-0.36	-0.77	**1.09**	0.42	-0.03	-0.09	0.13
22	Khpor Daung	0.25	**1.25**	-0.93	-0.62	0.14	0.21	-0.17	0.02
24	Somaly	-0.06	-0.20	-0.21	0.57	-0.43	0.38	0.00	0.01
18	CIR158-B-B-SB-8-3-2	-0.39	-0.07	0.16	0.41	0.34	0.12	-0.70	-0.02
8	IR66327-KKN-54-P1-3R-0	-0.55	0.52	0.02	-0.41	0.59	-0.17	-0.45	-0.06
25	KDML105	-0.35	0.51	-0.86	0.47	-0.49	0.10	0.15	-0.07
13	IR66368-CPA-84-P1-3R-0	0.02	-0.42	-0.81	0.45	-0.32	0.41	-0.31	-0.14
15	Bang Kuy (acc. 2865)	-0.21	0.15	-0.13	0.26	-0.87	0.76	-1.27	-0.18
1	IR46331-PMI-32-2-1-1	-0.29	-0.70	0.19	-2.12	-0.03	-1.05	-0.03	-0.58
16	CAR4	0.21	-1.07	-0.74	-0.37	-1.21	-1.54	-0.01	-0.68
	LSD5%	*ns*	*0.94*	*0.95*	*0.95*	*0.98*	*0.90*	*ns*	*0.40*
	Heritability (h^2)	*0.23*	*0.58*	*0.72*	*0.74*	*0.60*	*0.57*	*0.50*	*0.44*
	$\sigma^2_{GxE}/\sigma^2_g$	*4.24*							

Ns=not significant, Bold and shading indicates higher than 1.0 and lower than –1.0, respectively.

2.3 Development of the drought screening facilities

Facilities for field screening for drought resistance at the vegetative and reproductive stages has been developed at three stations with financial support of the Rockefeller Foundation. The vegetative drought screening (Sarkarung and Pantuwan, 1999) is planted out-of-season at the end of the monsoon rains. It is currently used as routine drought screening for advanced breeding lines from the N and NE rainfed lowland rice breeding program. This strategy is particularly useful to evaluate larger number of genotypes for drought score in the dry season and selected ones are then evaluated for grain yield in the wet season.

Two systems are being developed for the reproductive drought screening: water management simulated late-season drought (WMS) and the line source sprinkler (LSS). The WMS is currently used as a routine drought screening for advanced breeding lines (inter-station yield testing) in the N and NE rainfed lowland rice breeding program. The drought stress is affected by a) planting the nursery approximately three weeks after the optimum date to increase the chance of drought at the end of the rainy season, and b) by draining the water from the bunded fields before flowering. This method is described elsewhere (Fukai et al. 1999) and can provide a reasonably high likelihood of exposing the lines to a drought.

In the LSS system, gradients of moisture regimes can be developed to provide estimates of performance under full irrigation and at four levels of water deficit. This system is appropriate for detailed studies of drought tolerant traits because different severities of drought can be developed. However the LSS requires a large plot size for each entry and thus only a small number of lines (commonly 100) can be tested. The LSS is used mainly for the identification of parental materials as described in the next section (Section 2.4).

2.4 Selection of parental materials to increase drought tolerance

The cultivar KDML105 and RD 6 are the most widely-grown cultivars in the rainfed lowland systems of Thailand. These cultivars have superior eating quality demanded by the market (jasmine rice). However these cultivars also lack yield potential and are susceptible to drought. Thus the progress in improvement of cultivars for the TPE could be enhanced by the judicious choice of parents that provide the genetic materials for the three components of yield under drought viz yield potential, appropriate phenology and drought tolerance, while maintaining the quality characters of the popular cultivars. In practice, breeders often use parents from exotic material to improve yield potential and phenology and local materials to maintain or enhance drought tolerance.

A large effort is currently under way to identify putative drought tolerant lines for use in the breeding program. In the 2002/03 dry seasons, a total of 800 traditional cultivars that had been collected across the rainfed lowlands in Thailand and 600 advanced breeding lines were subjected to drought screening at the vegetative stage. Selection was based on LWP and drought score. The top 50 lines of traditional cultivars which had an ability to maintain higher LWP than the commercial cultivars, KDML105 and RD6, were selected. Crosses of these lines were made to the two commercial cultivars. In the 2003 wet season, these 50 cultivars were screened again against late season drought and selection based on LWP, delay in flowering, spikelet sterility, DRI and grain yield. Because there was variation in flowering time among these 50 cultivars, those with similar flowering time under well-watered condition will be grouped and screened separately. Some of 50 crosses will be discarded, and only 7-10 crosses will be retained for future work. The objectives of this work are to develop near iso-genic and recombinant inbred lines for future molecular study and for selection in the conventional breeding program.

3. The breeding program

3.1 Change in selection process

The original selection process for developing improved rainfed lowland rice varieties consisted of three major selection phases: intra-station, inter-station and on-farm selections. Intra-station selection involves selection within a research station, whereas inter-station selection uses results conducted at many stations (i.e. selection across multi-environments). The original selection process had a strong emphasis on intense intra-station selection of genotypes and limited inter-station testing (Figure 4). Often the early generation lines were grown under irrigation. Most lines were discarded in this phase based on visual selection and results from yield testing at a single location (i.e. selected for local adaptation). Only a small number of lines (e.g. 50-70 lines) relative to the total number of materials (400-500 lines) generated from the crossing program were selected for subsequent multi-location yield testing (inter-station) and on-farm. This approach was somewhat successful, although it took 14 to 18 years to identify the improved cultivars for release. Because of quality and market requirements the newly released cultivars were less acceptable to farmers than the old cultivars such as KDML105 and RD6.

This original selection and testing process was evaluated under the Australian Centre for International Agricultural Research (ACIAR) project on Plant Breeding Strategies for Rainfed Lowland Rice in Northeast Thailand and Laos during 1995 to 1997. The presence of large genotype-by-environment (G x E) interactions in combination with limited yield evaluation of lines in multi-location environments were identified by Cooper et al (1999b) as major factors contributing to the slow progress in developing new cultivars. They reported a large genotype-by-site-by-year (G x S x Y) interaction for grain yield (Table 3). A major factor contributing to this G x S x Y interaction was the genotypic variation for days to flowering in combination with environmental variation for the timing and intensity of drought (Cooper et al. 1999a).

Based on these findings Cooper et al (1999a) concluded that the intense intra-station selection of genotypes and limited inter-station testing of the original selection process would be unlikely to select genotypes with broad adaptation and high grain yield for the TPE(s) of N and NE Thailand.

Table 3 Estimates of components of variance (± standard errors) for grain yield (t ha^{-1}), based on 1116 rainfed lowland rice lines (checks and random progeny derived from seven crosses) evaluated in a multi-environment trial with a site-year cross classification structure for combined analysis of six Northeast and two North sites.

Source of variance	Components of variance
G	0.060 ± 0.006
G x S	0.003 ± 0.006
G x Y	0.049 ± 0.006
G x S x Y	0.259 ± 0.009
Residual	0.440 ± 0.005

Cooper et al. (1999b) recommended a new selection process using rapid generation advance (RGA) of early generations of the breeding materials (F_3-F_5) and the replacement of the yield testing in the intra-station phase by early generation inter-station yield testing with large number of F_6-F_7 lines (Figure 5). The new strategy began in 2000. To improve farmer adoption of new cultivars, farmer participatory selection is being integrated into this breeding program.

The different selection criteria used to develop cultivars for each of the TPE defined by the upper, middle (drought prone), middle (favourable) and lower flooded are shown in Table 4. Phenology, particularly flowering time, is the most important trait for avoiding late-season drought in each of the different parts of the toposequence. Flowering should occur before the standing water in the paddy disappears. Thus, the breeding program targets three flowering groups for the different parts of the toposequence, (1) early maturing: flowering around mid-September to the beginning of October, (2) intermediate maturing: flowering around mid to late October, and (3) late maturing: flowering around early November.

The details of the new breeding program that incorporates the strategies for the improvement of rainfed rice is described in the next sections. Yield is selected directly in the multi-locations yield testing program (described in Section 3.2); the lines are evaluated for the drought-tolerance trait of spikelet sterility as determined under water managed trials which are conducted at a few sites (Section 3.2); more lines are tested in the TPE in the farmer fields and the farmers participate in the selection (Section 3.3); and molecular markers are being used to aid selection for some traits (Section 3.4).

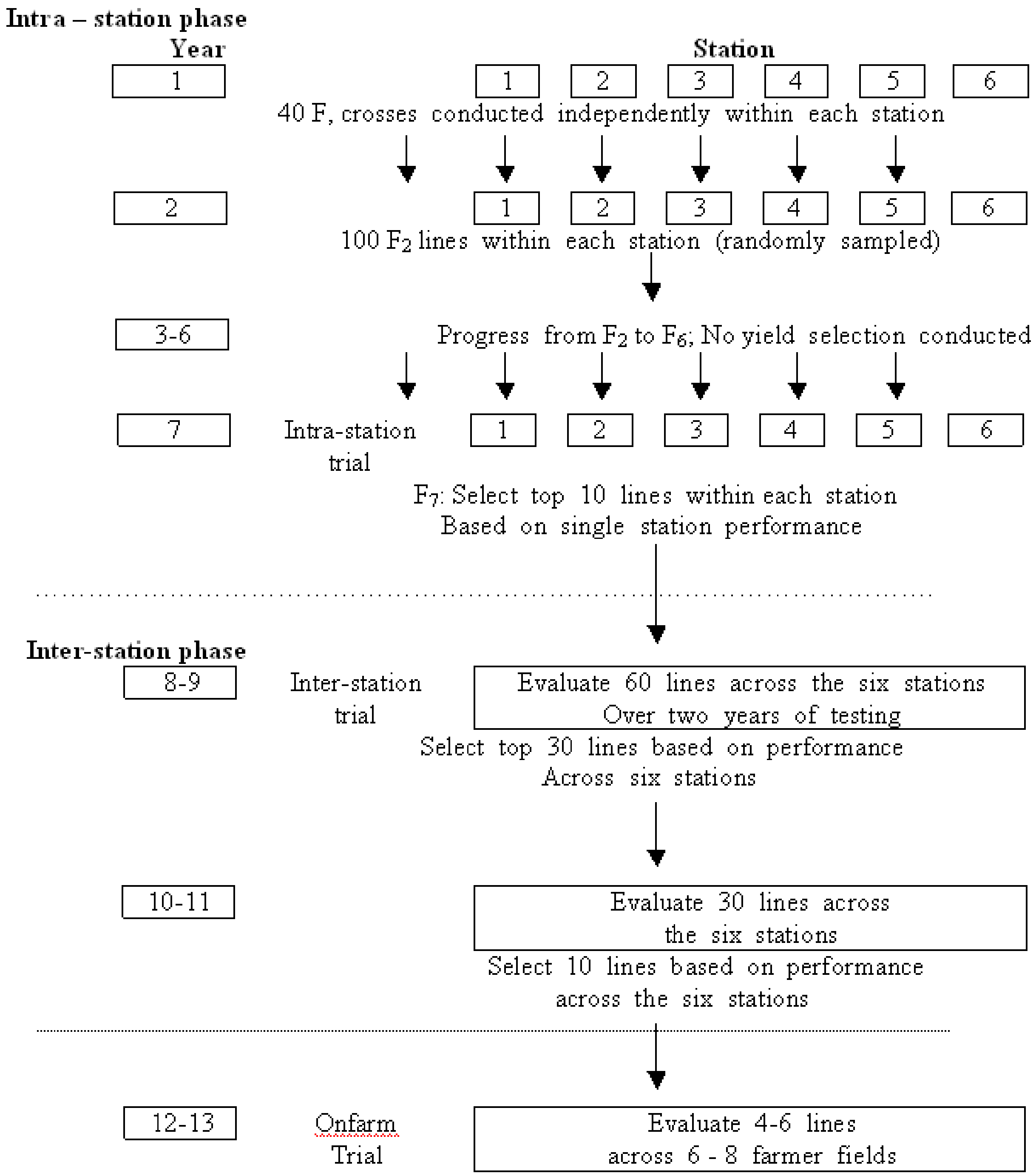

Figure 4. The original selection process for rainfed lowland rice breeding program for Northeast and North, Thailand (Cooper et al., 1999).

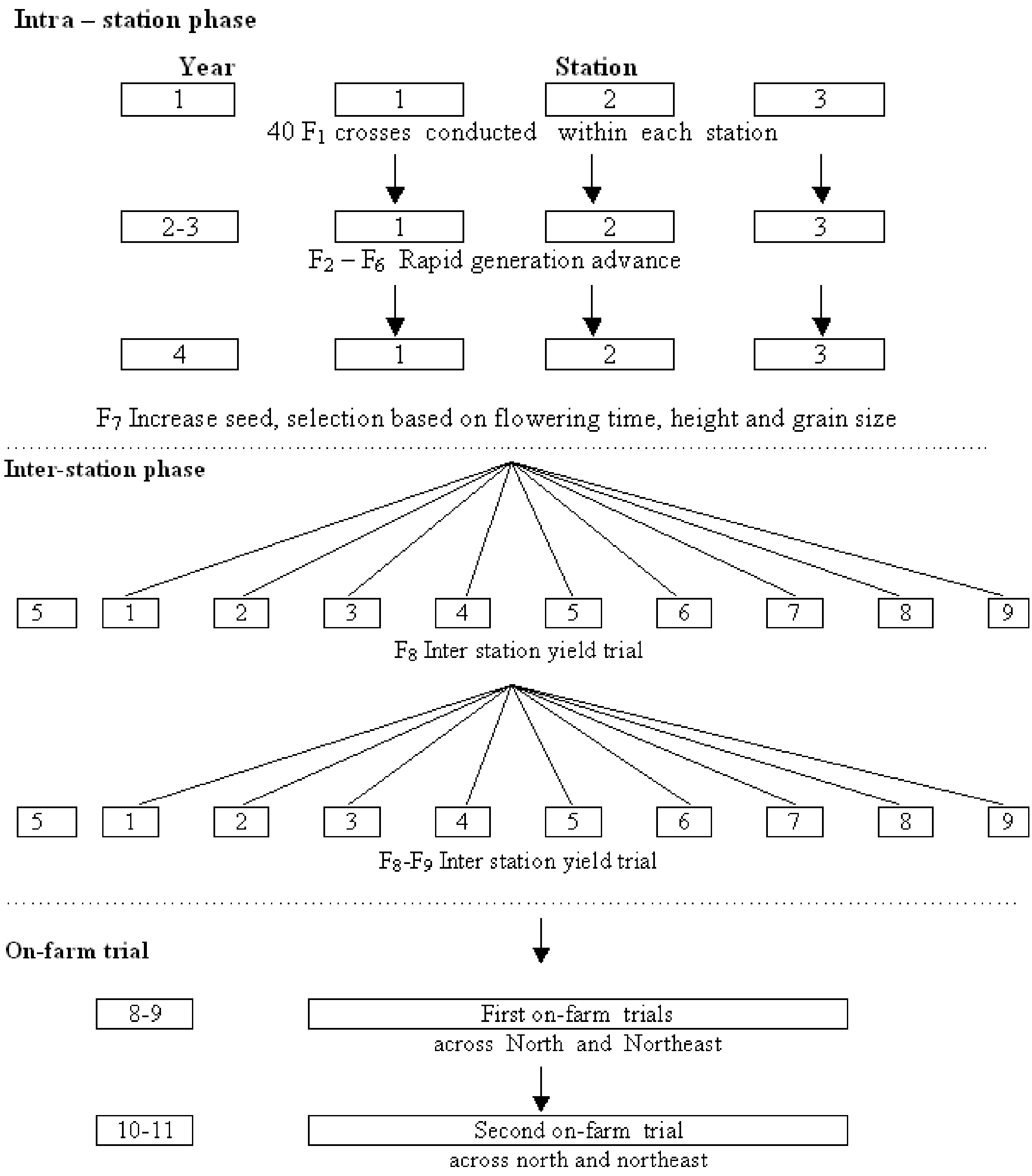

Figure 5. A new selection process which have been modified based on recommendation of Cooper et al. (1999)

Table 4. Selection criteria to develop cultivars for each target population of environments (TEPs) in the rainfed lowland rice breeding program in Thailand.

Target domain	Cultivar requirement	Selection strategy
Upper (drought)	Early maturity Weakly photoperiod sensitivity Drought tolerance Less delay in flowering Low spikelet sterility Maintenance of LWP[a]	Select for yield under the test location
Middle (drought-prone)	Intermediate maturity Photoperiod sensitivity Intermediate height Drought tolerance Less delay in flowering Low spikelet sterility Maintenance of LWP	Select for yield under the test location
Middle (favorable)	High grain yield Intermediate height	Select for potential grain yield
Lower (flooded)	Late maturity Photoperiod sensitivity Submergence tolerance	Select for yield under the test location

[a]LWP = leaf water potential.

3.2 Selection on-station

Intra-station selection phase: A few research stations are involved in developing lines for yield testing (see Figure 5). Selection of F_2 plants is based on characters with high heritability such as flowering time, plant height, and grain size. Selected materials are advanced to F_6-F_7 by single seed descent method. Rapid generation advance (RGA) by the dark room technique is used for photoperiod sensitive materials and 2-3 generations can be advanced in one year thus reducing time during the intra-station phase. By using the dark room technique, photoperiod sensitive lines can be identified. There is no selection during the RGA.

Inter-station selection phase: All lines, which have been selected from intra-station selection, are evaluated for grain yield. The inter-station yield nursery is conducted in twelve research stations across the N (four stations), upper and lower NE (five and three stations, respectively) for two years. The trials are conducted under two conditions of water availability: the water regime of the normal rainfed lowlands at nine of the stations and a water managed simulated late-season drought (WMS) at one station in each region (three stations). The objective of the inter-station selection is to evaluate families for grain yield under normal rainfed conditions and identify drought tolerant lines under simulated drought conditions.

The first inter-station yield nursery contains a large number of lines (200–300) grown in two replications. In the second inter-station yield nursery, lines that have been selected under the first yield nursery are evaluated again. The lines are grouped by flowering time and each group forms a separate trial to reduce effect of flowering on the estimate of the G x E interaction. Each trial contains a set of reference or probe genotypes that have been selected for their known responses to different water environments (Cooper and Fox 1999, Wade et al. 1999) and commercial check cultivars. The level of standing water and level of the water table at each site are measured in order to identify type and severity of drought.

The selection in the inter-station yield trial is based on grain yield under normal rainfed lowland and manipulated late season drought. The data are analyzed by station first and then a combined analysis across the stations is performed. The lines are grouped based on the results from combined analysis for grain yield into different patterns by cluster analysis. The groups of lines that perform well at most environmental sites are selected and the groups that have low grain yield in most environments are discarded. Individual lines in each group are selected based on resistance to major diseases and insect pests and also appropriate grain quality. Drought tolerant lines are identified based on the drought tolerant traits discussed earlier (Section 2.2).

The selected lines from this process were grouped based on phenology into early and medium groups, and evaluated at the farm level in the upper and middle parts of the toposequence for the early and medium group, respectively.

3.3 Selection at the farm level

The objectives of on-farm testing are to ensure that selection has been effective and that progress made on-station can be transferred to the on-farm trials (Atlin 2000). Our previous selection program mainly focused on research stations where growing conditions were more favourable than farmers' fields and only a small number of lines (4-6 lines) remained for the on-farm trials. While new cultivars have been released recently from the old selection process, the efficiency of selection was considered to be low because too few lines were tested in the target environments of the farmers' fields (Cooper et al. 1999a, Atlin 2000). In addition the newly released cultivars have been poorly adopted by farmers. Courtios et al. (1999) noted that poor adoption of new cultivars can be due to many factors, including their lack of traits of importance to farmers.

The present on-farm selection process includes two steps. In the first step, 20 lines in each of the three flowering groups which match the target domains (environments) are grown in small plots; in the second, a small number of lines are grown in larger plots. In both cases farmers are invited to participate in the selection of materials for agronomic characters, eating quality and other characters of importance to them. This on-farm testing with farmer-participatory selection has only been conducted for the last two years. Already one line, UBN92110 has been identified as promising, and will be released for the upper paddy levels. This line was developed in 1992 and evaluated in multi-location yield testing in 2000 and on-farm yield testing in 2002. It should be noted that it took 8 years in the intra-station phase because RGA was not used for generation advance at that time. The preference by farmers for this line as measured as the percent of farmers that favoured the agronomic and cooking qualities is shown in Table 5. Farmers favoured the earliness, high yield and good milling of this line even though the cooking qualities were poorer than the popular variety RD6.

Table 5. The evaluation in 2002 of experimental rice lines by farmers using the percentage of farmer's vote in preference analysis for agronomic characters, grain and eating quality for the rainfed lowland in Northeast and North Thailand.

	Agronomic			**Cooked rice**	
Cultivar/line	**Characters (%)**	**Paddy rice (%)**	**Milled rice (%)**	Warm (%)	Cool (%)
SKN	96	72	86	84	95
UBN92110	83	28	34	49	14
RD6	0	73	72	81	94

3.4 Marker assisted selection

A double haploid (DH) population developed from a cross between CT9993-5-10-1-M and IR62266-42-6-2 was used to identify quantitative trait loci (QTL) for drought tolerant traits, eg. LWP, drought score, spikelet sterility, grain yield, DRI and delay in flowering. Phenotypic evaluation was conducted at three sites under LSS in rainfed lowland field conditions. Markers to assist selection for these drought tolerance traits have been developed by BIOTEC, Thailand and used for the selection of progenies for backcrossing. Originally, fifteen donor lines were selected based on drought score under vegetative drought screening. Based on the phenotyping data, fifteen donors from the original vegetative screening were reduced to five lines (Table 6). These lines were selected based on LWP, drought score, delay in flowering, spikelet sterility and DRI. The populations are being developed to backcross 3 generation 1 (BC_3F_1). These materials will be advanced to BC_3F_5 and will be evaluated under field condition.

Table 6. Selected lines from a double haploid population derived from a single cross between CT9993-5-10-1-M and IR62266-42-6-2, which were used as drought tolerance donors for introgression experiment to commercial cultivars.

Pedigree	Grain yield (t/ha)		Days to flowering after drainage (days)		LWP (MPa)	Spikelet sterility (%)
	Irrigated	Stress	Irrigated	Stress		
IR68586-F2-CA-31	1.7	0.6	33	48	-1.9	15
IR68586-F2-CA-43	2.6	1.9	23	52	-1.7	49
IR68586-F2-CA-54	2.2	1.0	25	24	-1.9	45
IR68586-F2-CA-109	1.1	0.4	31	32	-1.4	69
IR68586-F2-CA-143	2.5	1.1	23	29	-1.5	50
KDML105	1.9	0.9	20	24	-2.3	85
RD6	1.7	0.2	22	47	-2.2	88
Range	0.7 to 4.2	0.1 to 2.2	3 to 43	3 to 62	-2.7 to -1.5	15 to 98
Mean	2.0	0.6	24	38	-2.2	56
Std.Err.	0.05	0.03	0.46	1.18	0.02	1.4

4. Conclusions

This paper has reported the progress of changes made over the past few years for improvement of drought tolerance in the rainfed lowland rice breeding program for N and NE Thailand. The original breeding program has been modified and new approaches have been developed to improve selection efficiency and shorten the time in developing new cultivars. The changes included improvement of selection process, better identification of target domains (environments), development of drought screening facilities, integration of marker assisted breeding and introducing farmer participatory plant breeding into conventional breeding.

Target domains (environments) and representative sites have been identified for evaluation of breeding lines. In the new selection process, the intra-station phase has been shortened and intra-station yield testing discarded. Grain yield is selected based on results from multi-location trials and more attention is given to testing under on-farm conditions. Drought screening methods and facilities have been developed and are being used in a routine screening of breeding materials. Farmer participatory plant breeding approaches have been integrated into the on-farm testing program to ensure that farmers will accept new cultivars. As a result of the new selection process, one line will be released after a shorter period of time in the selection process than that in the previous breeding program, and this line has already been evaluated for farmer acceptance.

A marker assisted selection scheme has also been developed and applied to the selection of materials in developing backcross drought tolerant populations. New parental materials and drought tolerant populations are continuously being developed with increasing emphasis on selection for drought tolerant characteristics in the parental lines. It t is not yet known how successful this new approach will be in developing more drought tolerant cultivars that are acceptable to farmers. The approach is however a considerable departure from the past and incorporates most of our current understanding on the adaptation of rice to the variable rainfed lowland environments.

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