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Opportunities to increasing dry season rice productivity in low temperature affected areas

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Abstract

Rice is a major source of food for more than 2.7 billion people and planted on nearly 130 million hectares in which 10% is subjected to low temperature problems. Dry season (DS) rice cropping has been expanding in the high altitude lands in Asia and the low temperature is one of constraints to rice production. This study aims to quantify the potential for growing irrigated rice in DS, particularly in high altitude areas in northern Lao PDR where temperatures are low and pose problems for seedling establishment. Research focused on identifying sowing times to avoid the detrimental effects of low temperature, the optimal seedling age for transplanting, the potential of plastic covers and half burnt paddy husk layer to protect nursery seedbeds from low temperature and varieties suitable for this environment. Studies were conducted over 5 years and were examined at six locations. In two locations, where temperature was favorable for rice production throughout the DS, time of sowing was not critical. In higher altitude areas in northern Lao PDR, however, low temperature caused establishment problems in nurseries. In these areas, mid-November sowing before the onset of winter reduced the low temperature effects on seedling establishment while sowing in mid winter (December and January) increased the risk of failure. There were no significant effects of seedling age (25-, 35- and 45-day old) for transplanting on yield for DS rice. Using clear plastic to cover the nursery increased minimum temperatures on average by about 4 °C, which improved seedling growth and resulted in higher grain yield. The mean minimum temperature of 12 °C for 30 days after seeding is critical and temperature below 12 °C resulted in high risk of crop failure due to poor germination, poor seedling growth or insufficient seedlings. Rice needs to be sown at times where the mean minimum temperature exceeds 12 °C or plastic covers are required to protect seedlings. The current popular varieties did not show significant tolerance to extreme cold temperature.

Keywords: Cold temperature; Rice cropping; Nursery management; Seedlings; Sowing time

1. Introduction

Rice is a major source of food for more than 2.7 billion people and planted on nearly one-tenth of earth's arable land. Of 130 million hectares of rice land about 30% is subjected to salinity problems, 20% drought and 10% low temperature (Wu and Garg, 2003). Yield loss due to low temperature at high latitude and altitude areas were well documented in Japan (Shimono et al., 2007), Korea, Northeast and southern China, Bangladesh, India, Nepal and other countries (Lee, 2001; Kaneda and Beachell, 1974). In similar low temperature conditions severe yield loses were reported in Australia (Farrell et al., 2001), Italy and United States (Board et al., 1980).

Dry season rice cultivation is a common practice in Asia. Rice–rice double cropping involves mostly early wet season or dry season cultivation. These lands are often located in higher altitudes (>500 masl) and frequent crop failures occurs due to low temperature problem (Dingyuan and Liqun, 1989; Tran, 2004). For example, in Lao PDR a number of irrigation schemes were developed in the 1990s, and as a result the dry season (DS) irrigated rice became a common practice providing 20% of the total rice production. The DS irrigated rice area increased from 12,000 ha in 1990 to 102,000 ha in 2001. Most of the DS rice cultivation is double cropped with wet season (WS) rice cultivation, including northern areas at high altitude ranging from 300 m to over 1000 m. DS rice is normally sown in winter

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and low temperature is a common problem in most locations in the region. Low temperature can reduce germination (Basnayake et al., 2003; Ali et al., 2006), cause poor establishment (Sasaki, 1979, 1981; Shimono et al., 2002, 2004, 2007; Lewin and Maccaffery, 1985), delay phenological development and increase spikelet sterility (Farrell et al., 2001; Lee, 2001; Gunawardena et al., 2003a,b) resulting in low yield. Similarly, the effects of cold-water on nutrient uptake during seedling development in nurseries at higher altitudes have been reported in Pakistan (Zia et al., 2004). Ali et al. (2006) reported the effects of genotypes and physiological age of rice seeds on seed germination under low temperature conditions in Bangladesh.

In low temperature areas where germination and seedling growth may be slowed and older seedlings may be used for transplanting, understanding the effects of transplanting seedlings of various ages on plant growth and grain yield can provide flexibility for crop establishment. Previous investigations on the effects of seedling age on grain yield showed that transplanting young seedlings produced higher yields in the WS (Sipaseuth et al., 2001). Early maturing varieties are required for DS irrigated conditions to ensure that WS rice can be sown at an appropriate date. However, information on the effects of different times of sowing in winter and effect of seedling age at transplanting on grain yield and harvesting date in irrigated DS rice are not available in Lao PDR. There is currently no information or strategies available.

One technology that could increase the success of rice cropping in low temperature areas is to protect young seedlings from low temperature by covering the nursery with plastic. This technique was established for WS crops in Japan in 1942 and quickly spread through the country in the mid 1950s (Hayashi, 1961; Hoshikawa et al., 1995). The development of seedling protection methods can be important to improve crop establishment for DS crops in areas where low winter temperature affects germination.

Studies were conducted to (1) identify the most appropriate time of sowing within winter and critical temperature for germination in the nursery for low temperature affected areas in dry season, (2) investigate the effects of seedling age at transplanting on grain yield under low temperature condition, and (3) investigate the effectiveness of seedbed protection methods for securing seedlings during extremely cold period in the DS. Experiments were conducted in six provinces in both southern (where low temperature problems are not normally a concern) and northern Lao PDR.

2. Materials and methods

A series of field experiments in DS irrigated rice were conducted in six locations during a 5-year period beginning in the 1999/2000 DS. The six locations were all in the Lao PDR and covering a range of altitudes from 120 masl to 560 masl representing varying degrees of early DS low temperature stress (Inthavong et al., 2001). The locations were Luang Namtha (560 masl), Xieng Khoung (560 masl), Sayabouli (290 masl), and Luang Prabang (350 masl) in northern Lao PDR, Vientiane Municipality (170 masl) in central Lao PDR, and Champassak (120 masl) in southern Lao PDR.

2.1. Experiments

2.1.1. Experiment 1: sowing date and variety

The objective of Experiment 1 was to investigate the effects of sowing date and variety on DS cold stress to rice seedlings and ultimately rice productivity. The experiment was conducted at four locations (Vientiane, Champassak, Luang Namtha and Xieng Khoung) in both 1999/2000 and 2000/2001 DS (Table 1).

Four rice varieties from three phenological groups were evaluated: early maturing (SK12), medium maturing (RD10) and late maturing (TDK1) and a local check. Check varieties were different for each location and were TSN1 (Vientiane), PN1 (Champassak), TDK3 (Luang Namtha) and Tiane (Xieng Khoung).

In this experiment sowing date was the main-treatment while variety was a sub-treatment. There were four sowing times at each location (Table 1). In the 1999/2000 DS sowing occurred on 15 November, 6 December, 30 December and 10 January and in 2000/2001 DS sowing was on 18 November, 8 December, 27 December and 18 January. The lowest temperature occurs in late December and January, and hence these sowing days represent prior to winter (November), early winter (early December) and mid winter (late December–January).

2.1.2. Experiment 2: sowing date and variety

Experiment 2 was similar to Experiment 1 except that two more locations were included (Luang Prabang and Sayabouli) and only two varieties (TDK1 and TDK 5) were used. TDK5 is a short duration variety. There were three sowing dates at each location in the 2001/2002 DS: 16 November, 4 December and 29 December.

Table 1
The elevation and total number of sowing at six locations in five dry seasons in Lao PDR

Season	Experiment	Luang Namtha 560[a]	Xieng Khoung 560[a]	Vientiane 171[a]	Champassak 120[a]	Luang Prabang 350[a]	Sayabouli 290[a]
1999/2000 DS	Experiment 1	4 (2)	4 (1)	4	4		
2000/2001 DS	Experiment 1	4	4	4	4		
2001/2002 DS	Experiment 2	3	3 (2)	3	3	3	3
2002/2003 DS	Experiment 3	3	3			3	3 (1)
2003/2004 DS	Experiment 4	3	3				

The number of sowings that failed due to low temperature is presented in brackets.
[a] Elevation in m.

2.1.3. Experiment 3: nursery protection, sowing date and seedling age

The objective of Experiment 3 was to evaluate nursery seedling protection methods at different sowing times and seedling age on seedling growth and rice yield. Experiments were conducted at four locations (Luang Namtha, Xieng Khoung, Luang Prabang and Sayabouli) in the 2002/2003 DS. In all cases the short duration TDK5 variety was used. Three different sowing times were evaluated with different seedling protection treatments: (1) a control with no protection, (2) a plastic cover over the surface of the nursery seed bed for 5–11 days after sowing when seedlings were 5 cm in length, and (3) a plastic dome covering the nursery seedbed. The plastic dome frame was made of bamboo and had a transparent plastic sheet covering it. The height of the dome at the centre was 50 cm. The plastic cover treatment, had a plastic sheet covering the seedbed. The sheet was placed so that it was about 2–5 cm above the soil surface, accomplished by placing bamboo poles across the nursery to elevate the sheet. For both the plastic dome and plastic sheet experiments a 30 cm deep water furrow was prepared around the nursery seedbed. The edges of the plastic sheet and dome were below the water surface. After sowing seeds, a two to three cm thick layer of charcoaled paddy husks (specific heat = 0.38 J g^{-1} °C^{-1}) was placed over the seedbed. The furrow was kept full of water and after seedling emergence the water level was raised to 1–2 cm above the seedbed level. The purpose of the charcoaled husks layer and water in furrows was to absorb radiation during the day to maintain a higher temperature during the night.

Sowing times were 15 November, 13 December and 10 January. In the 15 November sowing time only the control treatment was used. In the latter sowing times, seedlings were transplanted at 25, 35 and 45 days after sowing (DAS). When the seedlings were too small (because of low temperature) for transplanting at a given seedling age, it was considered as a failure for planting at the particular seedling age. There were no replications of the nursery treatments. Each nursery plot was 1.2 m $\times$ 6.0 m in size.

The main field was arranged in split-split-plot design with sowing date as the main-treatment, nursery protection method as the sub-treatment and age of seedlings as sub-sub-treatment. There were four replications and the plot size was 3 m $\times$ 4 m. The "Student *t*" statistics were used to compare the mean height of seedlings grown under plastic dome/cover and unprotected control. The grain yield data was analyzed as a split-split-plot design.

2.1.4. Experiment 4: nursery protection, sowing date and seedling age

In the 2003/2004 DS, two experiments were conducted at Luang Namtha and Xieng Khoung to further investigate the effects of seedling protection methods, sowing date and seedling age on dry season rice establishment and productivity. The experiment was similar to Experiment 3 except that there were only two transplanting times (30 and 45 DAS). TDK5 was the only variety used and sowing times were 15 November, 5 December and 26 December.

2.2. Cultural practices

The land preparation for the experiments started each year in mid-October. Cultivation practices typically used by farmers were adapted to make nursery seedbeds. Traditional methods of seedbed preparation were used for Experiments 1 and 2, where the experiments were conducted to investigate the effects of sowing date on grain yield without seedbed protection. Experiments 3 and 4 had specific nursery preparations for those two nursery management treatments as described above. Seeds were sown at the rate of 450 g per nursery bed. Seeds were soaked for 2 days and sown to the nursery when the emerging epicotyls were one to two mm long. Germination count was taken from the seedling population of four random squares of 100 cm^2 area. Adequate nutrients (N, P and K) were applied uniformly to nursery beds to avoid the effect of nutrient deficiency on seedling growth and to the main field for uniform growth.

2.3. Measurements

Thermometers, which recorded minimum and maximum temperatures, were installed around each experiment to measure ambient air temperature, inside the plastic domes/covers, and in the water inside the plastic domes/covers. Daily maximum and minimum temperatures for the experiment's duration were collected from meteorological stations, which were each located within 2–8 km of the trial site and at similar altitudes. Seed germination was determined 5 days after sowing by counting total number of seeds and germinated seeds in four random squares of 100 cm^2 area in the nursery. Seedling height and seedling weight (dry) at transplanting were recorded in all experiments. In addition, in Experiment 3, seedling height (a sample of 50 seedlings) was measured five times from 5 to 45 DAS. Tiller number at 45 days after transplanting, flowering date and grain yield (adjusted to 14% moisture) were determined.

2.4. On-farm trial

In the 2004/2005 DS, on-farm trials were conducted to compare the plastic dome with farmers' conventional practices of no protection. Ten farmers were selected from three provinces in northern Lao PDR where cold temperatures were a problem for seedling growth. Altitudes in these locations ranged from 350 masl to 650 masl. The farmers were trained to use the plastic dome before the on-farm trial. The minimum and maximum temperature during seedbed period and grain yield were recorded in each farm.

3. Results

3.1. Temperature effects on germination and seedling growth

The temperature during nursery period varied across experiments, with higher elevation locations, such as Luang Namtha and Xieng Khoung, having the lowest temperatures and subsequently nursery seedling problems and crop failure

Table 2
Mean minimum temperature (°C) for 30 days after sowing and crop establishment for rice sown at four different times in 5 years in Xieng Khoung province

Season		Mid November	Early December	Late December	Mid January
1999/2000 (Experiment 1)	Temperature (°C)	12.0	10.8	12.5	14.3
	Establishment (%)	100	0	100	67
2000/2001 (Experiment 1)	Temperature (°C)	14.5	12.2	13.1	12.9
	Establishment (%)	100	100	100	100
2001/2002 (Experiment 2)	Temperature (°C)	13.9	11.9	10.4	–
	Establishment (%)	100	0	0	–
2002/2003[a] (Experiment 3)	Temperature (°C)	13.9		10.4	14.3
	Establishment (%)	100		100	100
2003/2004[a] (Experiment 4)	Temperature (°C)	13.9		9.4	10.3
	Establishment (%)	100		80	100

Crop establishment is indicated as percentage of viable seedlings available for transplanting.
[a] Data from control experiment (without nursery protections).

(Table 1). Specifically, Xieng Khoung, had the lowest temperatures resulting in poor germination and seedling growth and thus a reduced number of seedlings available for transplanting (Table 2). On three occasions, mean minimum temperatures over a 30-day period were below 12 °C and no seedlings were available.

In 2002/2003, seedling growth was slower in Xieng Khoung than Luang Namtha due to cooler temperatures (10.4 °C versus 11.6 °C, respectively). As a result, the seedlings were too small (less than 20 cm) for transplanting at 30 days after sowing (Fig. 1). When 30-day mean minimum temperatures were favorable in November and December at Luang Namtha seedling growth was fast and seedlings could be transplanted 20 DAS. However, at Luang Namtha, January mean monthly minimum temperature (30 days) was lower than 12 °C and had poor seedling growth during nursery period. In 2002/2003 there were no failures during the crop establishment phase as there were sufficient seedlings for transplanting.

To quantify the low temperature effect on the amount of seedlings available for transplanting, seedling growth was compared to the mean minimum temperature for 30 DAS for the different locations and sowing times. The relationship between 30-day mean minimum temperature and both seedling height and weight was similar. When mean minimum temperatures were below 12 °C, seedling height (Fig. 2a) and dry weight (Fig. 2b) were reduced and in several occasions there was complete failure in germination. Mean minimum temperatures between 12 °C and 16 °C for 30 days were considered to be risky for establishment in the nursery and above 16 °C were considered safe from low temperature damage (Fig. 2).

3.2. Optimum sowing time and grain yield

Sowing time had a significant effect on grain yield in 11 of the 20 experiments conducted during the 5-year period (Table 3). At the low altitude sites (Vientiane and Champassak) these differences were not related to cold temperature but rather to pest problems at the very early and late sowing times. Therefore, these sites will not be discussed further.

At the high elevation sites (Luang Namtha and Xieng Khouang), and to a lesser degree Luang Prabang and Sayabouli, some of the sowing time effects on yield were due to temperature variations at different sowing times within an experiment. At Luang Namtha and Xieng Khoung weekly mean minimum temperature was often around 12 °C in December and January for the 1999/2000 DS (Fig. 3). In this season, the crop failed completely when sown in early December (7 December) at Xieng Khoung and when sown on 28 December and 20 January at Luang Namtha (Fig. 4). Yield was substantially reduced in 7 December sowing at Luang Namtha and 20 January sowing at Xieng Khoung, respectively, in 1999/2000 DS. These sowing dates coincided with low mean minimum temperature <12 °C for a 30-day period during the seedbed contributing to insufficient seedlings for transplanting. In 2001/2002 and 2002/2003 DSs yield varied greatly in Xieng Khoung and Sayabouli, respectively, due to temperature variation among sowing times. Time of sowing experiments at high altitudes over 5 years showed that December and January sowing had lower mean yield than November sowing because of the low temperature problems in nursery establishment. However, in low altitude areas low temperature was not a

Table 3
Effects of sowing time on grain yield in 20 experiments conducted in dry season at six locations during 1999/2000 to 2003/2004 DS

Season	Experiments	Luang Namtha	Xieng Khoung	Vientiane	Champassak	Luang Prabang	Sayabouli
1999/2000	Experiment 1	**	**	*	*		
2000/2001	Experiment 1	ns	ns	ns	*		
2001/2002	Experiment 2	ns	**	ns	*	**	ns
2002/2003	Experiment 3	ns	*			ns	**
2003/2004	Experiment 4	*	ns				

*$p < 0.05$; **$p < 0.01$; ns, not significant.

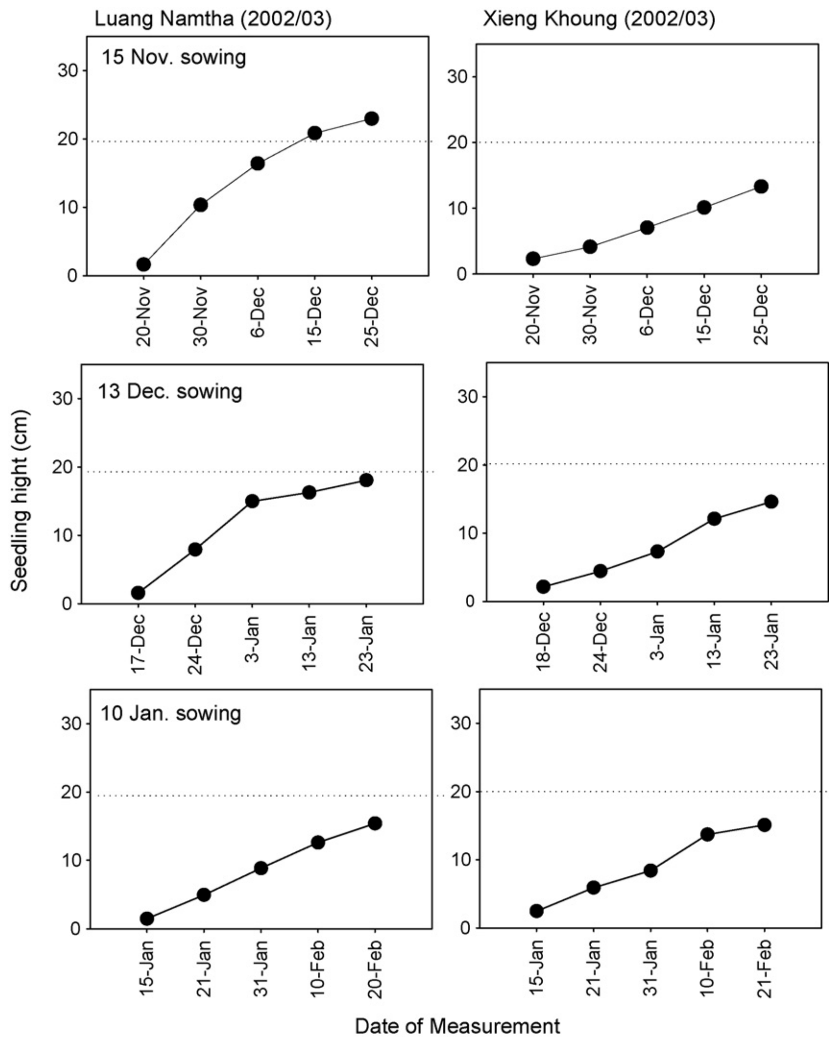

Fig. 1. Mean seedling height at three sowing times (November, December and January) under normal conditions during nursery establishment at Xieng Khoung and Luang Namtha in 2002/2003 dry season.

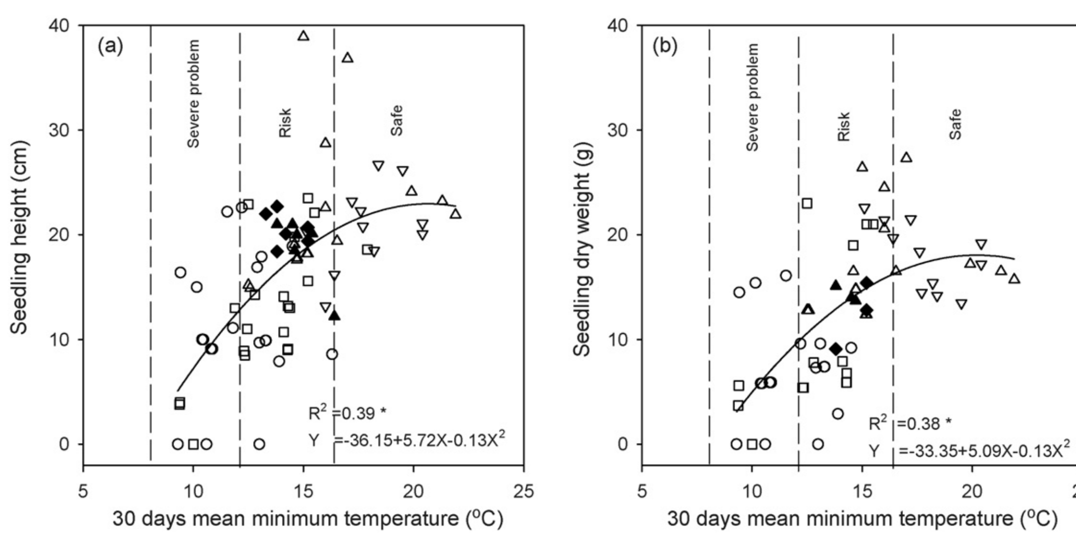

Fig. 2. The relationship between the 30-day mean minimum temperature and (a) seedling height and (b) seedling dry weight at 30 days after sowing. Data is from all experiments from 1999/2000 DS to 2003/2004 DS at Xieng Khoung (○), Luang Namtha (□), Vientiane (△), Champassak (▽), Luang Prabang (▲) and Sayabouli (◆). Crop failure was indicated by zero seedling height and weight. Data from unprotected control treatment were taken where nursery protection treatments were tested in Experiments 3 and 4.

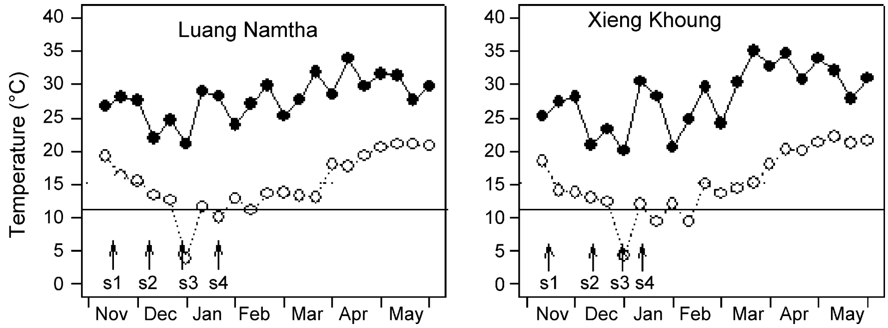

Fig. 3. Average weekly maximum and minimum air temperature at Luang Namtha and Xieng Khoung, from November 1999 to May 2000 in the 1999/2000 DS experiment (s1–s4: sowing times 1–4).

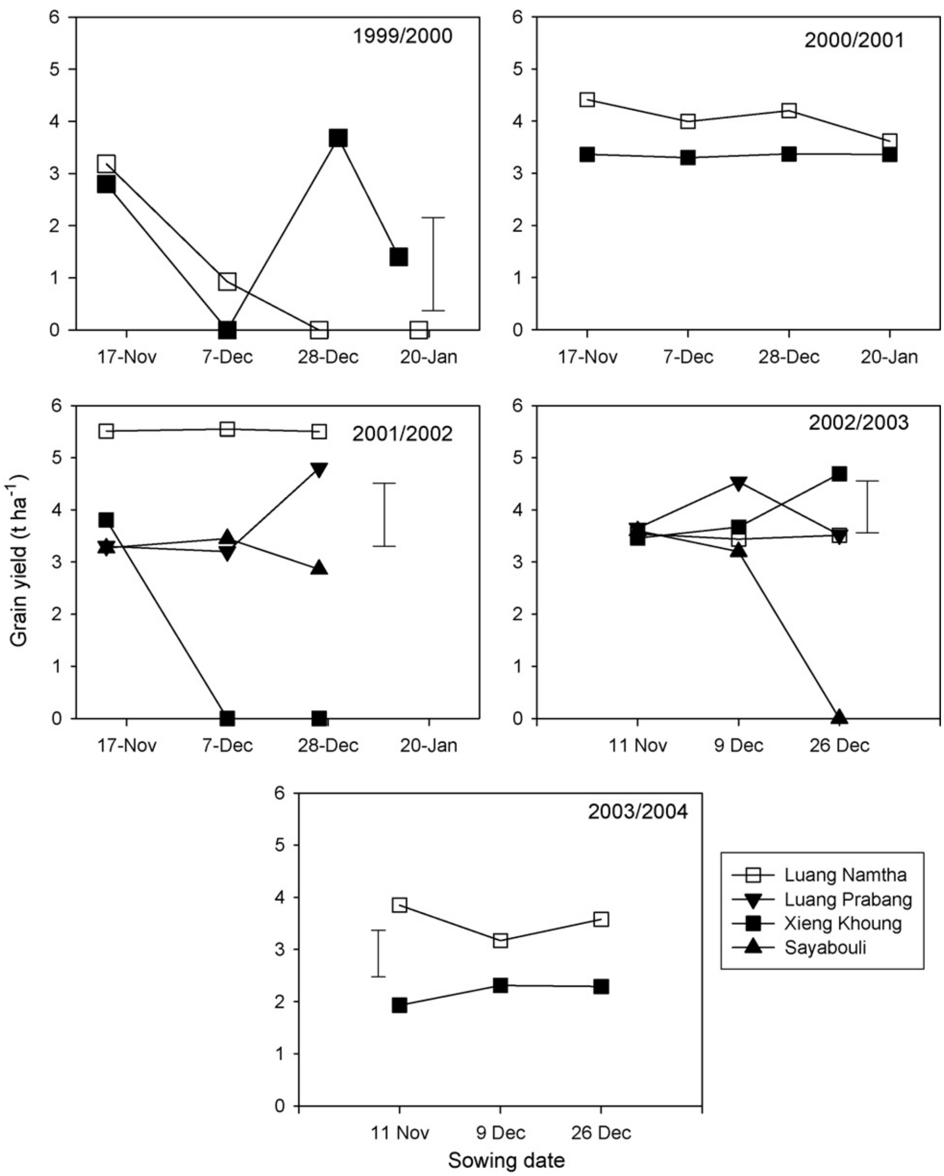

Fig. 4. Grain yield variation at four locations (Luang Namtha, Xieng Khoung, Sayabouli and Luang Prabang) in four times of sowings in 1999/2000 and 2000/2001 dry seasons and three times of sowings in 2001/2002 to 2003/2004 dry season. Vertical lines represent the LSD 5% values for the comparison of yield variation among sowing dates in each location. The grain yield of 2002/2003 and 2003/2004 were obtained from controlled treatments (without nursery protection) of the respective experiments.

Table 4
Mean yield of three sowing times of crops transplanted with seedling age of 25, 35 and 45 days for each location in 2002/2003 and 2003/2004 DS (a) and the reduction in growth duration to harvest when transplanted with 35- and 45-day-old seedlings instead of 25-day-old seedlings for three sowing times at four locations in 2002/2003 (b)

Location	2002/2003				2003/2004		
	Seedling age			Difference	Seedling age		Difference
	25 days	35 days	45 days		30 days	45 days	
(a) Grain yield (t ha^{-1})							
Luang Namtha	3.54	3.57	3.41	ns	3.59	3.73	ns
Xieng Khoung	3.79	3.91	3.84	ns	2.50	2.63	ns
Luang Prabang	3.98	3.49	4.26	ns	–	–	
Sayabouli	3.27	3.42	3.57	ns	–	–	

Location	Seedling age					
	Mid-November		Mid-December		Mid-January	
	35 days	45 days	35 days	45 days	35 days	45 days
(b) Reduction in growth duration (days)						
Luang Namtha	6	12	6	20	8	11
Xieng Khoung	6	9	8	16	5	13
Luang Prabang	10	20	10	18	10	20
Sayabouli	10	20	9	15	–	–
Mean	8.0	15.3	8.3	17.3	7.6	14.1

major problem and often December sowing produced a higher grain yield.

3.3. Effect of seedling age at transplanting

In 2002/2003 and 2003/2004 experiments (Experiments 3 and 4), there was no effect of seedling age at transplanting on grain yield at any location in northern Lao PDR (Table 4a). However, there was an effect of seedling age on growth duration in all locations in 2002/2003 (Table 4b). The growth duration (under control unprotected treatment) from transplanting to maturity could be reduced by 8 and 15 days when 35- and 45-day-old seedlings were used for transplanting, respectively, compared to 25-day-old seedlings.

3.4. Variety differences

Low temperatures affected germination in December sowing in Luang Namtha and Xieng Khoung, resulting in either no germination or seedling death for all varieties in Experiment 1. Because of the low temperatures, TDK3 did not germinate, and the number of seedlings for the other varieties was greatly reduced in December sowings. Generally, none of the other three varieties (TDK1, SK12 and RD6) grown at these two locations in 1999/2000 dry season showed any tolerance to low temperature. In Experiment 2, harvest was delayed due to low temperature in Luang Namtha and Xieng Khoung compared to Luang Prabang, and Sayabouli (Table 5). At low altitudes TDK1 and TDK5 normally flower at 107–108 and 97–101 DAS, respectively, however, these two varieties flowered 40 and 24 days later at higher altitude areas of Xieng Khoung and Luang Namtha, respectively. In these areas TDK 5 matured 7–18 days earlier than TDK 1, and produced a similar yield ($p < 0.05$, Table 5), providing more flexibility for double cropping in these areas.

3.5. Seedling protection methods on temperature and seedling growth

The minimum ambient temperature variation inside the plastic dome, outside the dome and in the water furrow around the nursery bed (inside the dome) at Xieng Khoung is presented in Fig. 5. The minimum air temperature under the plastic dome averaged 3–4 °C higher than outside the dome and never fell below 15 °C, even when the outside air temperature was below 10 °C. The minimum water temperature was slightly higher than the air temperature inside the dome (2–3 °C).

Seedling height and weight was higher in the plastic dome and cover compared to the control (Fig. 6). In Xieng Khoung, air temperature was low during the nursery period and the seedling height in the unprotected control was below 20 cm

Table 5
Mean duration (days) from transplanting to harvest for variety TDK1 and TDK5 in the 2001/2002 DS at each location

Location	Altitude (m)	Mean duration (days)		Grain yield (t ha^{-1})	
		TDK1	TDK5	TDK1	TDK5
Luang Namtha	560	131	124	5.58	5.53
Xieng Khoung	560	147	129	3.81	3.93
Luang Prabang	350	134	129	3.57	3.32
Sayabouli	290	107	97	3.48	2.91
Vientiane	171	108	101	4.08	4.01
Mean		125	116	4.10	3.94
LSD 5%[a]		24		1.02	

The mean duration is calculated from three sowing dates in each season.
[a] LSD for mean comparison among locations of each variety.

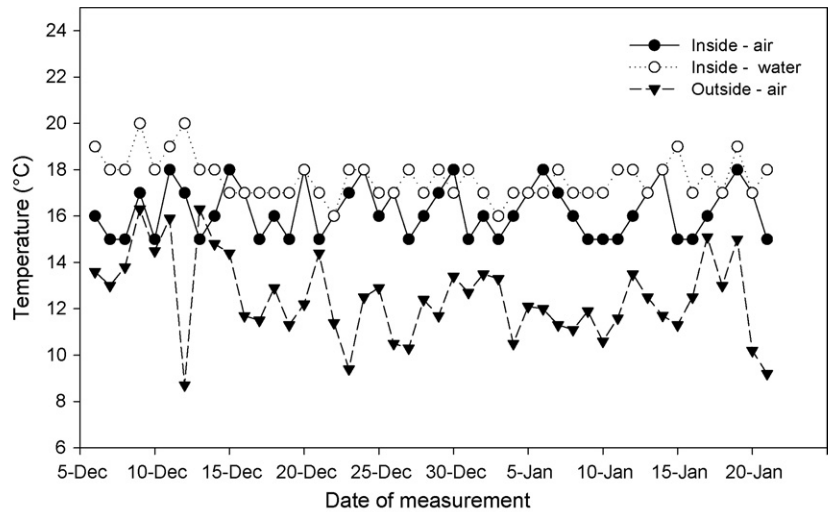

Fig. 5. Air and water minimum temperature inside and outside the plastic dome, measured at 8.00 a.m. during the nursery period in December and January 2002/2003 at Xieng Khoung.

(average size of the seedling at pulling for transplanting) and hence unable to be used for transplanting. However, under plastic cover or plastic dome, the seedlings reached 20 cm height within 15 days and reduced the risk of losing seedlings for transplanting. At 10 days after sowing, the benefits of plastics protection in increasing seedling height were identified at all locations and this difference was further increased until 40 DAS.

There was no effect of transplanting seedlings at different ages on grain yield in Experiment 3 and Experiment 4 and the interaction between sowing date and protection methods was not significant. Hence the grain yields (December sowings) of seedling age treatments were calculated for each nursery protection treatment. At Xieng Khoung in the Experiment 3 and Experiment 4 the grain yield was significantly higher when plants were established under the plastic dome compared to the unprotected control (Table 6). At Sayabouli in Experiment 3 and Xieng Khoung in Experiment 4, the grain yield was significantly higher in the plastic cover than the control. In these experiments, there was no failure to transplant in all treatments. The mean yield advantage of plastic cover and dome over control was 10 and 5%, respectively.

3.6. On-farm demonstration trials for seedbed protection

In the on-farm trials, the grain yield in the plastic dome treatment was significantly higher than the unprotected control (Table 7). The mean yield across all districts was increased by 23% by using plastic dome compared with the control for nursery establishment. The main limitation for grain yield in DS with the unprotected control was the use of small seedlings for transplanting and slow recovery after transplanting. In some cases reduced seedling number for transplanting resulted in poor crop establishment in the control.

The farmers were interviewed to record their thoughts on the use of plastic domes. They all liked the plastic domes and felt that it reduced the cold temperature stress. In addition, they also added that the use of plastic domes reduced damage by rats and birds to the young seedlings.

4. Discussion

The problem of low temperature during rice seed germination and seedling development has been reported in many countries, particularly at higher altitude in Asia (Kaneda and Beachell, 1974), southern rice growing regions in China (Hunan, Jiangxi and Yunnan) and in Australia (Lewin and Maccaffery, 1985). The result presented in this paper has wide application to overcome low temperature problems in dry season rice cultivations in many countries.

The four experiments in six locations had contrasting minimum temperatures during crop establishment across 5 years. In southern and central Lao PDR, monthly mean minimum temperatures during DS were higher than 16 °C and the rice crop was not affected by low temperature. In contrast, high altitude locations such as Luang Namtha and Xieng Khoung experienced temperatures below 12 °C during crop establishment that affected germination and seedling growth and the problems are considered severe. The probability of receiving minimum temperature below 12 °C was higher in this location during December and January (in mid winter). These results are consistent with others who reported that temperatures below 10 °C caused germination failure in most Asian rice growing areas (Matsushima et al., 1968; Tajima et al., 1983; Lee, 2001; Ali et al., 2006). In a detailed laboratory test, Ali et al. (2006) found that under 11 °C, the rate of germination could be reduced by 10–22% when fresh seeds of four varieties were used while aged seeds (48 days stored under 24% grain moisture content and 45 °C) had almost 0% germination under the same temperature.

Temperatures between 12 °C and 16 °C during establishment are considered risky. Low temperature problems such as those in Xieng Khoung (560 m) resulted in poor crop establishment as the main cause of crop failure and in some

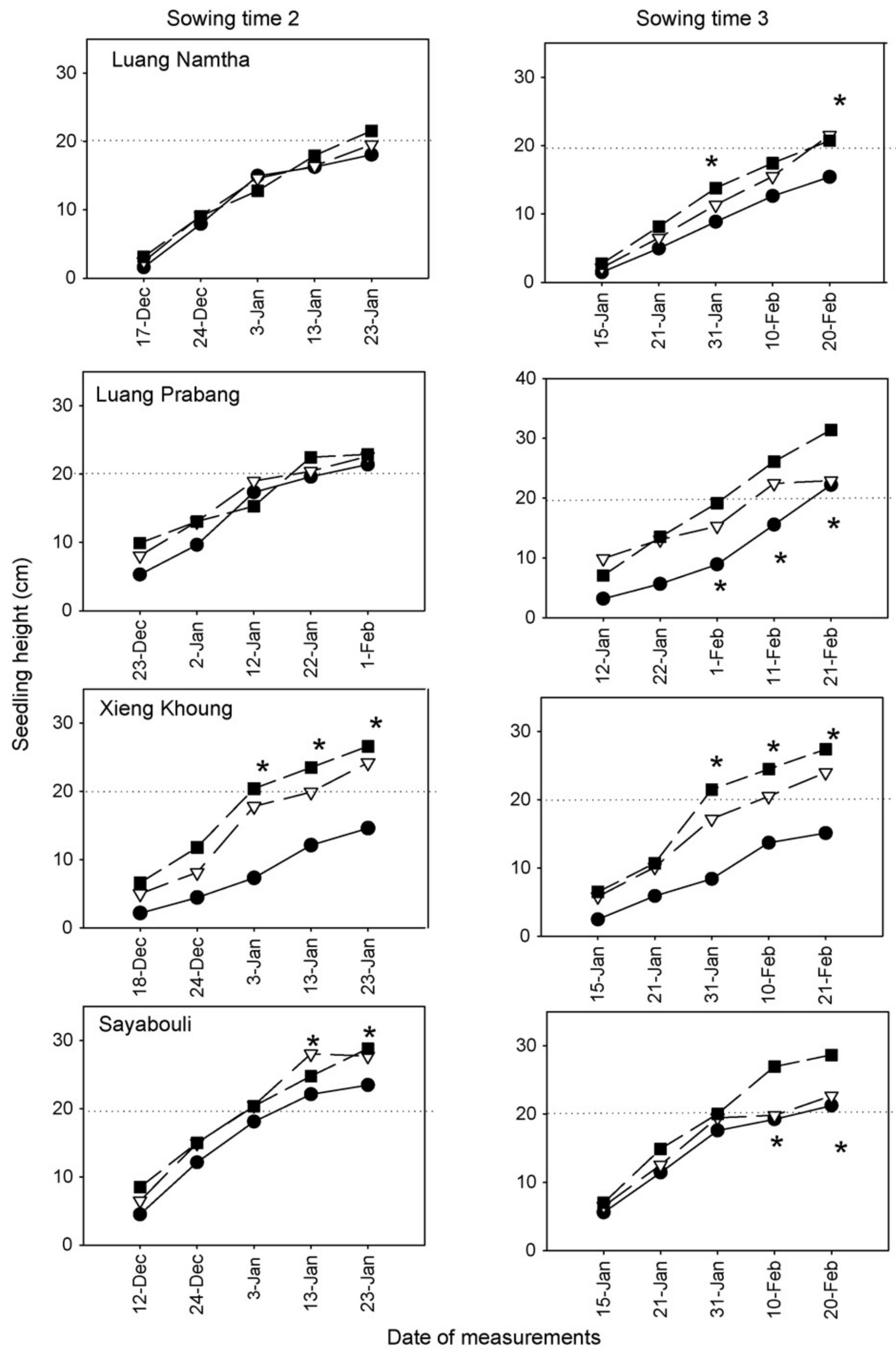

Fig. 6. Mean seedling height at two sowing times (sowing 2, late December; sowing 3, mid January) in dry season under unprotected control (●), with a plastic dome (■) and plastic cover until seedlings grow 5 cm height (▽) during nursery establishment at four different locations in the 2002/2003 DS. *Significance of $t_{(0.05,\ 48,\ \mathrm{d.f.})}$ values calculated for the mean height comparison between plastic treatment and control at each time of measurement.

cases resulted in lower grain yields because there were fewer seedlings available for transplanting. In these areas rice should be sown in November when the minimum temperature is still relatively high before the arrival of mid winter. However, irrigation water may not be sufficiently available in some of the rice growing areas in north, to allow this strategy to be adopted.

Nishiyama (1985, 1995, 1997) reported varietal differences for germination and survival under low temperature conditions. In a recent study Ali et al. (2006) demonstrated varietal differences for germination under 11 °C. However, in the current study, the seedlings of all four varieties in Experiment 1 were affected similarly by low temperatures (between 10 °C and 16 °C) and did not show high tolerance to low temperatures. These findings demonstrated that the current available varieties do not have low temperature tolerance, and systematic screening may be required to identify varieties suitable for low temperature conditions for northern Lao PDR. Further, Ali et al. (2006) showed the importance of seed physiological age for screening genotypes for low temperature tolerance and concluded that there is a strong correlation

Table 6
The mean grain yield (t ha^{-1}) for nursery establishment in the unprotected control, plastic cover and plastic dome at several locations in the 2002/2003 and 2003/2004 dry season

Location	Experiment	Control	Cover	Dome	LSD 5%
Luang Namtha	Experiment 3	3.48	3.62	3.56	ns
Luang Namtha	Experiment 4	3.60	3.72	3.68	ns
Xieng Khoung	Experiment 3	4.04	4.21	4.24	0.17
Xieng Khoung	Experiment 4	2.18	2.58	2.32	0.12
Luang Prabang	Experiment 3	4.03	4.29	3.84	ns
Sayabouli	Experiment 3	3.22	4.21	3.69	0.56
Mean		3.43	3.77	3.56	
±S.E.		0.69	0.65	0.65	

Table 7
On-farm evaluation to compare the grain yield (t ha^{-1}) achieved with the control and with the plastic dome in Nam Bak, La, Namtha and Sing districts

Province	District	Altitude (m)	Number of farmers tested	Control	Dome
Luang Prabang	Nam Bak	350	3	2.02	2.42
Oudomxay	La	620	3	2.56	3.35
Luang Namtha	Namtha	550	2	2.95	3.48
Luang Namtha	Sing	650	2	2.46	2.97
Mean				2.46	3.02
±S.E.				0.23	0.21

The grain yield is the mean of two to three farmers in each district.

between rate of germination under room temperature and low temperature at 11 °C.

Early maturing varieties are required for successful rice–rice double cropping at high altitudes. Dingyuan and Liqun (1989) suggested that early maturing varieties could reduce some detrimental effects of low temperature in spring (February–April) sowings in some parts of Southern China. The use of short duration varieties are recommended for sowing in the DS in Laos because low temperatures retards crop development, in this case by up to 40 days leaving little time available between the harvest of one rice crop and the planting of the next.

Seedling age at transplanting is important for better establishment and grain yield during the wet season (Sipaseuth et al., 2001), however, in the dry season there was no effect of seedling age (between 25 and 45 DAS) on yield. Since seedling age has no effect, farmers have more flexibility during the crop establishment period.

Increased flexibility and higher yields in high altitude regions can also be achieved by using protective covers over the nursery seedbeds for DS rice. Plastic covers and domes increase seedling height, size and availability. Assuming 20 cm tall seedlings (generally practiced by farmers) are used for transplanting, the mean duration of the nursery period was 42 days in the control compared to 25 and 30 days in the plastic dome and plastic cover, respectively. The use of plastic domes had a greater reduction in the time seedlings needed to stay in the nursery in high altitude areas such as Xieng Khoung (16-day reduction) compared to lower altitude areas like Sayabouli (7-day reduction). This reduced duration in the nursery with the use of plastic protection provides farmers with further flexibility in managing their crops. In addition, charcoal husk has some added value to increase the available potassium in the paddy fields. The results of this finding could be used for other crop nurseries management in high elevations. The technology has been defused to the rural communities in Northern Laos and they are using it for vegetable and horticultural crop nursery managements.

The experiments have successfully demonstrated critical temperatures for seed germination and a simple method for nursery protection using locally available plastics and paddy husk for DS rice. Several farmers showed that the technique to be a practical solution to the low temperature problem areas in DS. Participating farmers achieved a 23% yield increase compared with the yield of the crop that was established from the conventional unprotected nursery in mid-winter. Therefore the technique could be used elsewhere to overcome germination problems during nursery establishment in cold dry seasons. The cost effectiveness and extension strategy for this technology needs to be further evaluated.

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