Chapter 4

RESULTS

4.1 Field experiment

Some characters of NL 460 were not determined as emergence was poor.

4.1.1 Environment conditions

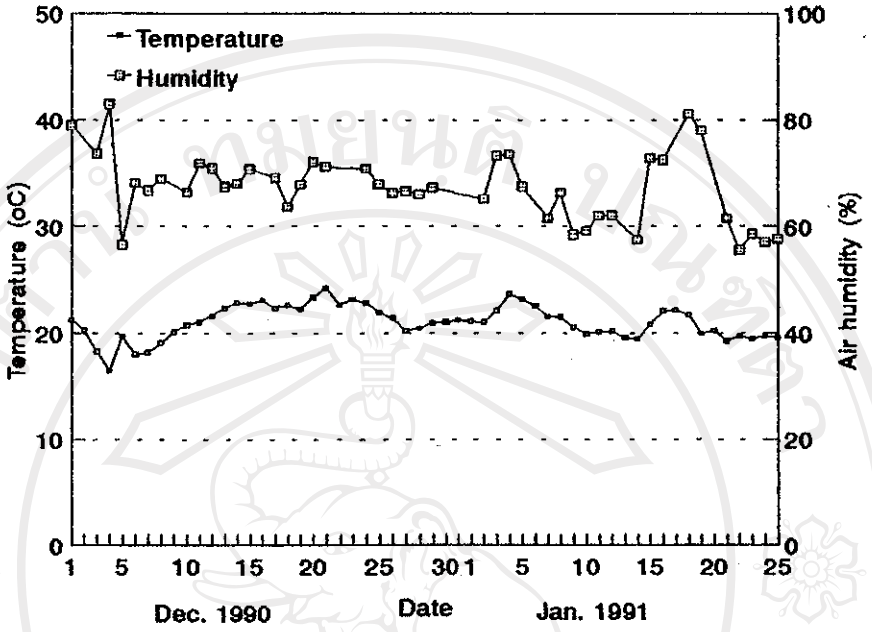
During the development of reproductive organs, *e.g.* from double ridge stage (Zadoks 3.0) (beginning reproductive growth) to flowering stage (Zadoks 6.1 - 6.9), daily mean temperature was stable around 20-25°C; and daily air humidity fluctuated slightly between 60% to 80% (Figure 4a).

Flowering period (Zadoks 6.1-6.9) of all genotypes (Figure 4b) lasted about one month. Anther extruded from the glumes (flowering) usually between 7:00 and 8:00 a.m.

4.1.2 Vegetative growth

No visual symptom of B deficiency had been observed during vegetative growth (Zadoks 1.0-4.9) in all 10 genotypes at any soil B supplies. Duration from emergence to double ridge stage (Zadoks 1.0-3.0) varied little among various soil B for all genotypes (Table 4).

a. Temperature and humidity



b. Duration of developing reproductive organs

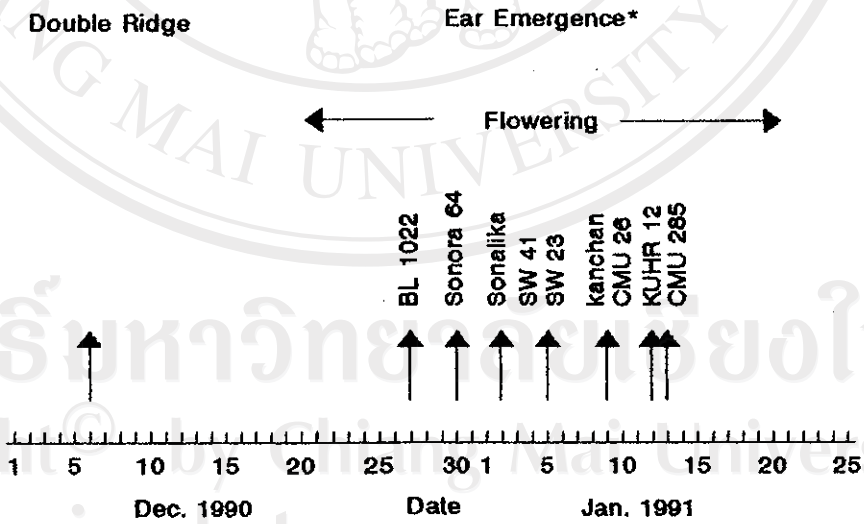


Figure 4. a) Daily mean temperature (°C) and air humidity (%) was recorded in the Station of Multiple Cropping Center during Dec. 1990 - Jan. 1991; and b) duration of developing reproductive organs.
* Arrows indicating date of 50% ear emergence.

Table 4. Effects of soil B treatments on days from emergence to double ridge stage of 9 wheat genotypes[1]

Soil B treatment	Genotype								
	Bds			Bdm			Bdt		
	SW 41	BL 1022	CMU 285	SW 23	Sonalika	Kanchan	Sonora 64[2]	KUHR 12	CMU 26
B0	21.4	16.5	24.3	20.0	20.7	22.5	18.0	22.0	23.7
B1	21.7	17.4	25.0	21.3	20.8	22.7	17.5	21.8	24.1
B2	21.2	16.0	25.0	20.7	20.5	22.5	17.5	21.5	23.8
B3	20.8	17.5	25.0	21.0	21.1	22.5	17.5	22.0	23.5

$LSD_{0.05}$ = 1.2 (Bs*G)
CV % = 2.54
1. Sowing date was Nov. 16, emergence was Nov. 20.
2. B1 and B3 of Sonora 64 were estimated.
Bs: Soil B treatments; G: genotypes.
B0, B1, B2 and B3: 0.09, 0.12, 0.16 and 0.24 mg Bkg^{-1} soil, respectively.

4.1.3 Development of anther and pollen

4.1.3.1 Anther length

The anther length responded to soil B in BL 1022, SW 23, Kanchan, Sonora 64 and KUHR 12 ($P<0.09$). In these genotypes, the shortest anther length was found in B0 plants (Table 5). There was also a strong effect ($P<0.01$) of genotypes on anther length.

4.1.3.2 Pollen reaction to iodine

Pollen staining with KI/I_2 solution designates starch deposit in pollen grain. Pollen positive reaction to iodine among genotypes significantly differed ($P<0.01$) at various soil B (Table 6). In B0 plants of SW 41, BL 1022 and Sonora 64, the percentage of pollen with positive reaction to iodine, which was 43.5% for SW 41, 74.0% for BL 1022 and 66.0% for Sonora 64, was markedly lower than that in B1, B2 and

B3 plants. In Kanchan and KUHR 12, there was a trend of the higher soil B to have the higher percentage of pollen positive reaction to iodine. CMU 285, SW 23, Sonalika and CMU 26 showed no responses to soil B supply.

Table 5. Effects of soil B treatments on anther length (cm) of 9 wheat genotypes

Soil B treatment	Genotype								
	Bds			Bdm			Bdt		
	SW 41	BL 1022	CMU 285	SW 23	Sonalika	Kanchan	Sonora 64	KUHR 12	CMU 26
B0	3.4	3.3	3.6	3.2	3.5	3.6	3.2	3.6	3.1
B1	3.6	3.6	3.7	3.4	3.3	3.9	3.5	3.8	3.2
B2	3.4	3.6	3.7	3.5	3.5	3.8	3.4	3.9	3.2
B3	3.4	3.6	3.8	3.4	3.4	3.8	3.6	3.7	3.2

$LSD_{0.05}$ = 0.3 (Bs*G)
CV % = 3.76

Table 6. Effects of soil B treatments on the percentage of positive pollen reaction to iodine of 9 genotypes

Soil B treatment	Genotype								
	Bds			Bdm			Bdt		
	SW 41	BL 1022	CMU 285	SW 23	Sonalika	Kanchan	Sonora 64	KUHR 12	CMU 26
B0	43.5	74.0	82.6	81.6	89.4	78.3	66.0	78.9	85.4
B1	87.9	90.0	91.2	82.4	95.3	84.2	90.0	89.3	88.9
B2	81.3	87.0	86.2	88.2	93.9	90.8	87.0	90.4	91.4
B3	89.2	90.0	89.7	89.4	93.9	86.6	97.0	92.5	90.9

$LSD_{0.05}$ = 10.8 (Bs*G)
CV % = 5.80

4.1.4 Grain set

4.1.4.1 Basal floret fertility

Basal floret fertility is the average number of grains in the two basal florets (F1+2) of 10 central spikelets of the wheat ears (Rerkasem *et al.*, 1991). The results showed the evident effects of soil B on basal floret fertility ($P<0.05$) (Figure 5). The lowest basal floret fertility was recorded in B0 plants for SW 41, BL 1022 and Kanchan, which was 1.26, 1.61 and 1.59, respectively; and the value of the basal floret fertility approached the maximum value of 2 with increasing soil B supply. By contrast, CMU 285, SW 23, Sonalika, Sonora 64, KUHR 12, CMU 26 and NL 460 showed no responses of basal floret fertility to soil B. The values of basal floret fertility ranged from 1.79 to 1.97.

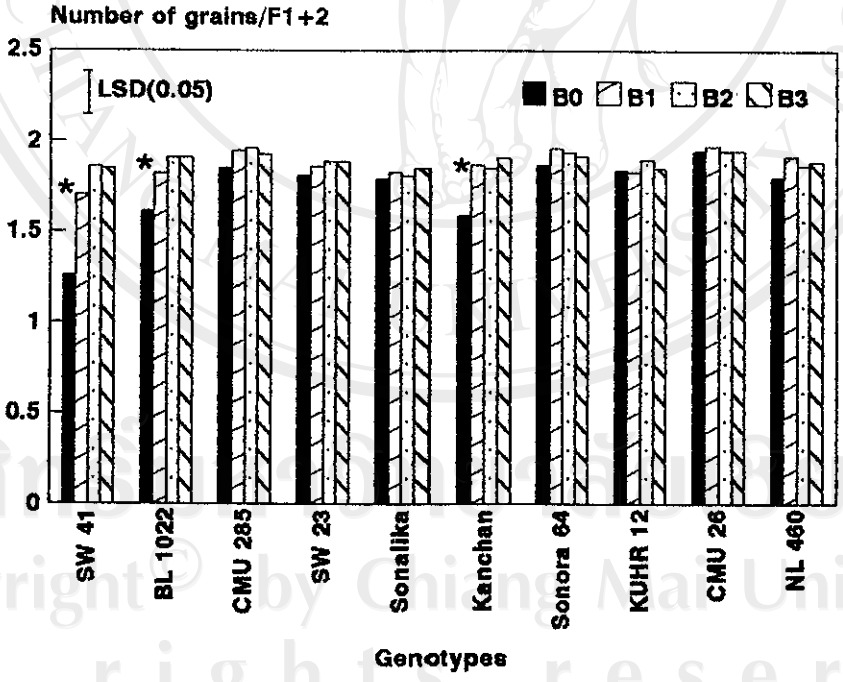


Figure 5. Effects of soil B on grains in the two basal florets (F1+2) of 10 central spikelets of ear for 10 wheat genotypes.
* Indicating significance ($P<0.05$) of probability.

4.1.4.2 Percentage of fertile florets

Percentage of fertile florets is calculated as the ratio of florets with developed grains to the total florets. A significant interaction ($P<0.01$) was detected between soil B and genotype. In some genotypes, such as Sonora 64, KUHR 12, CMU 26, NL 460, SW 23, Sonalika and CMU 285, the percentage of fertile florets was all 90% or higher, with no response to soil B (Table 7). The most sensitive genotype to B was SW 41; the percentage of fertile florets was only 51.4% in B0 plants, which was markedly lower than that in higher B levels (88.0-93.0%). In BL 1022 and Kanchan, there was a trend for the higher soil B to have the higher percentage of fertile florets.

Table 7. Effects of soil B treatments on fertile florets of 10 wheat genotypes (%)

Soil B treatment	Genotype									
	Bds			Bdm			Bdt			
	SW 41	BL 1022	CMU 285	SW 23	Sonalika	Kanchan	Sonora 64	KUHR 12	CMU 26	NL 460
B0	51.4	82.5	90.0	91.0	94.9	83.3	97.0	90.0	94.1	88.4
B1	88.0	91.1	96.5	93.2	87.4	93.5	96.6	92.2	95.5	91.9
B2	92.1	95.1	94.8	95.1	87.5	94.1	96.6	94.1	96.0	91.6
B3	93.0	94.2	93.6	94.0	91.5	92.4	96.7	91.5	95.3	91.0

$LSD_{0.05}$ = 12.5 (Bs*G)
CV % = 5.89

4.1.5 Yield components

4.1.5.1 Spikelets per ear

The spikelets per ear varied little among soil B treatments for all genotypes (Table 8). There were significant effects ($P<0.01$) of genotypes on spikelets.

Table 8. Effects of soil B treatments on spikelets per ear of 10 wheat genotypes

Soil B treatment	Genotype									
	Bds			Bdm			Bdt			
	SW 41	BL 1022	CMU 285	SW 23	Sonalika	Kanchan	Sonora 64	KUHR 12	CMU 26	NL 460
B0	14.7	12.9	15.1	15.6	12.3	15.0	15.9	15.7	14.4	16.2
B1	14.6	12.4	13.4	14.7	12.4	14.4	14.6	14.3	15.0	15.5
B2	14.3	13.4	14.1	14.2	12.2	13.5	14.9	14.9	13.4	15.2
B3	14.6	12.8	14.0	15.1	12.5	14.8	14.7	14.6	14.7	16.4

$LSD_{0.05}$ = 2.4 (Bs*G)
CV % = 5.9%

4.1.5.2 Grains per ear

Large effects of soil B on grains per ear were observed only in SW 41. In B0 plants, the lowest grains per ear were noticed (17.4) compared with other higher soil B plants (Table 9). There was a trend that grains per ear decreased with decreasing soil B supply in BL 1022 and NL 460. For other genotypes, grains per ear differed little among various soil B.

Table 9. Effects of soil B treatments on grains per ear of 10 wheat genotypes

Soil B treatment	Genotype									
	Bds			Bdm			Bdt			
	SW 41	BL 1022	CMU 285	SW 23	Sonalika	Kanchan	Sonora 64	KUHR 12	CMU 26	NL 460
B0	17.4	23.7	31.6	30.2	21.5	23.9	38.1	28.4	29.9	34.3
B1	31.9	28.9	32.7	29.4	23.1	27.6	34.0	25.7	30.9	40.2
B2	29.4	32.4	34.2	27.4	21.9	25.0	35.3	26.9	27.9	37.9
B3	30.3	34.3	32.9	28.9	23.2	24.3	34.2	27.2	31.2	45.2

$LSD_{0.05}$ = 10.4 (Bs*G)
CV % = 12.77

4.1.5.3 1000 grain weight

The 1000 grain weight varied little among various soil B supplies in 9 genotypes (Table 10).

Table 10. Effects of soil B treatments on 1000 grain weight of 9 wheat genotypes (g/1000 grains)

Soil B treatment	Genotype								
	Bds			Bdm			Bdt		
	SW 41	BL 1022	CMU 285	SW 23	Sonalika	Kanchan	Sonora 64	KUHR 12	CMU 26
B0	30.8	35.0	32.1	26.5	34.0	31.2	26.7	32.1	26.6
B1	29.2	34.9	29.3	24.7	33.9	34.0	26.3	35.3	27.4
B2	29.3	32.1	27.8	26.6	32.7	34.3	28.3	30.2	24.8
B3	28.4	32.8	26.0	25.1	32.8	33.8	26.2	33.4	27.4

$LSD_{0.05}$ = 8.0 (Bs*G)
CV % = 8.17

4.1.6 Grain yield

A marked response to soil B was found only in SW 41, the grain yield was depressed by 52.4% in B0 plants. There was a trend for the higher soil B to have the higher grain yield in BL 1022, and SW 23 (Table 11). In other genotypes, no differences in grain yield were found among various soil B.

Table 11. Effects of soil B treatments on grains yield of 1 m^2 field of 9 wheat genotypes (gm^{-2})

Soil B treatment	Genotype								
	Bds			Bdm			Bdt		
	SW 41	BL 1022	CMU 285	SW 23	Sonalika	Kanchan	Sonora 64	KUHR 12	CMU 26
B0	116.6	185.6	182.6	173.0	240.5	168.2	188.3	190.8	190.2
B1	241.5	267.4	238.7	197.7	222.4	146.1	195.4	191.6	182.2
B2	245.4	228.2	193.5	272.1	230.7	210.7	257.8	207.4	161.3
B3	248.7	242.9	248.9	223.4	187.3	180.7	219.9	206.4	201.0

$LSD_{0.05}$ = 94.9 (Bs*G)
CV % = 19.39

4.1.7 Boron concentration ([B]) in tissue

4.1.7.1 Whole tops at double ridge stage (Zadoks 3.0)

In general, [B] in whole tops at double ridge stage increased as soil B increased ($P<0.09$) (Table 12). In B0 plants, for BL 1022 and Sonora 64, [B] in whole tops was slightly lower than that in higher soil B supply plants and it was also lower than that in other genotypes, which was 7.6 mg Bkg^{-1} dry wt for BL 1022 and 7.4 mg Bkg^{-1} dry wt for Sonora 64. [B] in SW 41, for all plants from various soil B, were relatively higher than that in other genotypes.

Table 12. Effects of soil B treatments on [B] in whole tops at double ridge of 9 wheat genotypes (mg Bkg^{-1} dry wt)

Soil B treatment	Genotype								
	Bds			Bdm			Bdt		
	SW 41	BL 1022	CMU 285	SW 23	Sonalika	Kanchan	Sonora 64	KUHR 12	CMU 26
B0	12.1	7.6	11.5	8.6	10.1	11.5	7.4	11.5	11.6
B1	12.0	11.5	10.5	10.6	13.4	10.0	10.2	12.2	12.3
B2	14.6	9.4	9.7	11.4	11.6	13.0	10.9	10.3	14.2
B3	16.2	12.0	14.2	11.7	13.5	12.8	13.0	13.8	14.3

$LSD_{0.05}$ = 4.2 (B*G)
CV % = 15.85

4.1.7.2 Flag leaf at booting stage (Zadoks 4.5)

A significant interaction ($P<0.01$) between soil B and genotype was found (Table 13). In BL 1022, the highest [B] in flag leaf at booting stage was recorded in B3 plants, which was 7.9 mg Bkg^{-1} dry wt. In Sonora 64 and CMU 26, [B] markedly higher in B3 plants than that in B0, B1 and B2 plants as well as than that in other genotypes. The amount of [B] in Sonora 64 and CMU 26 was 8.9 mg Bkg^{-1} dry wt and 10.2 mg Bkg^{-1} dry wt, respectively. There was a trend that [B] in flag leaf responded positively to soil B in SW 23, Kanchan and KUHR 12. In other genotypes, *e.g.* SW 41, CMU 285, Sonalika and NL 460, effects of soil B on [B] in flag leaf were inconsistent, which ranged from 4.2 to 6.2 mg Bkg^{-1} dry wt.

4.1.7.3 Developing ear at booting stage (Zadoks 4.5)

There was a significant interaction ($P<0.05$) between soil B and genotype. In B0 plants for BL 1022, [B] in developing ear at booting

stage (3.2 mg Bkg^{-1} dry wt) was much lower than that in other higher soil B supply plants (Table 14), and was also the lowest among genotypes. In KUHR 12, the highest [B] (7.3 mg Bkg^{-1} dry wt) was found in B3 plants. A trend was also observed for the higher soil B to have the higher [B] in SW 41, Kanchan, Sonora 64 and NL 460. In other genotypes, *e.g.* CMU 285, SW 23, Sonalika and CMU 26, [B] in developing ear at booting stage showed no response to soil B.

Table 13. Effects of soil B treatments on [B] in flag leaf at booting stage of 10 wheat genotypes (mg Bkg^{-1} dry wt)

Soil B treatment	Genotype									
	Bds			Bdm			Bdt			
	SW 41	BL 1022	CMU 285	SW 23	Sonalika	Kanchan	Sonora 64	KUHR 12	CMU 26	NL 460
B0	4.2	5.0	4.6	4.7	5.2	4.7	4.9	4.1	5.4	4.6
B1	5.8	5.8	5.8	6.6	6.2	7.0	5.6	6.6	6.8	6.1
B2	4.4	5.7	5.1	4.7	4.7	4.8	5.0	5.7	5.1	5.5
B3	4.9	7.9	5.7	5.9	5.2	5.8	8.9	8.2	10.2	5.1

$LSD_{0.05}$ = 1.7 (Bs*G)
CV % = 12.18

Table 14. Effects of soil B treatments on [B] in developing ear at booting of 10 wheat genotypes (mg Bkg^{-1} dry wt)

Soil B treatment	Genotype									
	Bds			Bdm			Bdt			
	SW 41	BL 1022	CMU 285	SW 23	Sonalika	Kanchan	Sonora 64	KUHR 12	CMU 26	NL 460
B0	4.1	3.2	4.2	5.0	5.0	3.7	3.9	3.8	4.2	5.9
B1	4.5	5.8	5.4	5.2	6.4	5.3	5.9	4.0	4.6	5.6
B2	6.9	5.7	5.2	5.9	6.2	5.6	6.1	5.3	5.3	7.5
B3	5.7	5.3	5.8	5.3	5.8	5.5	5.7	7.3	4.6	6.6

$LSD_{0.05}$ = 1.9 (Bs*G)
CV % = 12.83

4.1.8 Correlations among various characters

Table 15 shows correlations among various characters in B0 plants of 9 wheat genotypes (excluding NL 460). The percentage of positive pollen reaction to iodine had high correlations with grain set (Table 13), ie. basal florets fertility (r=0.8486) and percentage of fertile florets per ear (r=0.9139), and with grain yield (r=0.8525). There was a weak correlation (r=0.5648) between the percentage of positive pollen reaction to iodine and [B] in flag leaf at booting.

Two indexes of grain set, basal floret fertility and percentage of fertile florets, were consistent (r= 0.9453). The grain yield evidently related to grain set, basal floret fertility (r=0.7153) and percentage of fertile florets (r=0.8281).

A weak correlation (r=0.5931) between grain yield and [B] in flag leaf at booting stage was found.

Table 15. Matrix of correlations (Pearson) among various characters in B0 plants for 9 wheat genotypes.

	A	B	C	D	E	F	G	H
A	1.0000							
B	0.0281	1.0000						
C	-0.2221	*0.8486	1.0000					
D	-0.1526	*0.9139	*0.9453	1.0000				
E	0.0531	*0.8525	*0.7153	*0.8281	1.0000			
F	0.5088	-0.1506	-0.2157	-0.3775	-0.2873	1.0000		
G	-0.5423	*0.5648	0.4594	0.5429	*0.5931	-0.3569	1.0000	
H	-0.1172	0.3083	0.2652	0.2241	0.2934	0.0834	0.1844	1.0000

* r>0.5500 (Rejection level: 0.5500)
A: anther length;
B: percentage of positive pollen reaction to iodine;
C: number of grains per two basal florets (F1+2);
D: percentage of fertile florets per ear;
E: grain yield;
F: [B] in whole tops at double ridge stage;
G: [B] in flag leaf at booting stage;
H: [B] in developing ear at booting stage.

4.2 Pot experiment

Results from two sowing dates, for the most part, were combined for analysis considering that the results were similar, when errors from two sowing dates were homogeneous after statistical examination. However, errors of two sowing dates for mature and late ears per pot were not homogeneous ($P<0.05$). Therefore, effects of sowing dates on ears per pot were analyzed with One Way ANOVA.

No visual symptoms of two genotypes (SW 41 and Sonora 64) were detected in various plant B treatments during vegetative growth.

4.2.1 Environmental conditions

During pot study for two sowing dates (from October 24, 1991 to April 24, 1992), monthly maximum, minimum and mean temperatures are shown in Table 16. Generally, temperature was stable during the period of plant growth at sowing date 1 (October, 1991 - February, 1992). However, temperature increased drastically, especially the maximum temperature, during the period of plant growth at sowing date 2 (January-April, 1992) .

Table 16. Monthly maximum, minimum and mean air temperature (°C) recorded in the experimental station of the Multiple Cropping Center during October, 1991 - April, 1992.

Month (1991-1992)	Air temperature (°C)		
	Maximum	Minimum	Mean
Oct.	32.0	22.1	26.3
Nov.	30.2	18.0	23.2
Dec.	29.0	15.2	21.1
Jan.	28.7	12.7	19.6
Feb.	30.6	13.3	20.7
March	35.7	17.6	25.3
Apr.	38.3	22.2	29.1

During the development of reproductive organs, *e.g.* from double ridge stage (Zadoks 3.0) to flowering stage (Zadoks 6.1-6.9), daily mean temperature and daily mean air humidity are shown in Figure 6a for sowing date 1 and in Figure 7a for sowing date 2. Daily mean temperature was stable, which was 20±2°C for sowing date 1 and 25±1°C for sowing date 2. Daily mean air humidity fluctuated slightly and ranged from 60% to 80% for sowing date 1 and from 50% to 60% for sowing date 2.

Flowering period of both genotypes is shown in Figure 6b for sowing date 1 and in Figure 7b for sowing date 2. The flowering period of each genotype lasted about 7 days. The anthers extruding from the glumes was usually between 7:00 and 8:00 a.m.

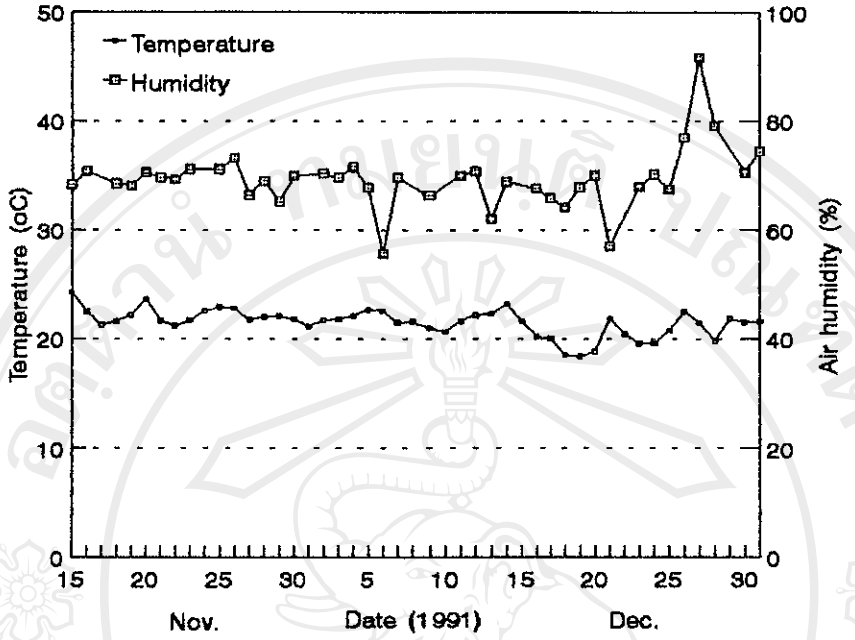
4.2.2 Development of anther and pollen

4.2.2.1 Anther Length

Anther lengths ranged from 2.9 to 4.1 cm for Sonora 64 and SW 41 at both sowing dates (Table 17). There were no effects of plant B treatments on anther lengths.

Anther lengths were significantly different ($P<0.01$) among top, middle and bottom parts of ear. The longest anther was recorded in middle part.

a. Temperature and air humidity



b. Duration of developing reproductive organs

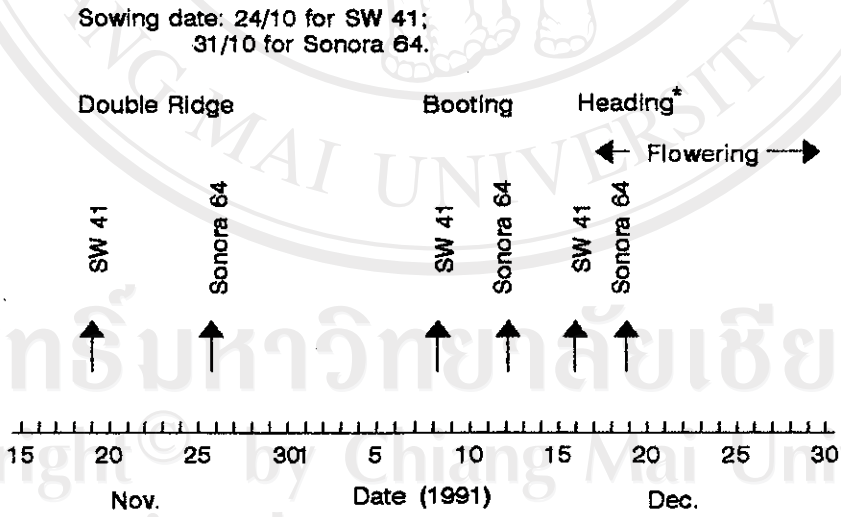
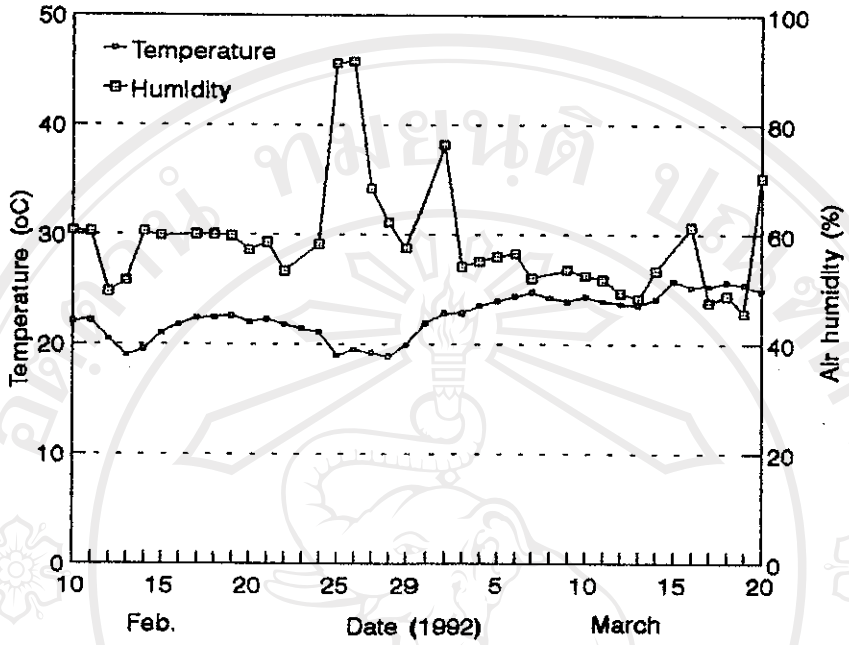


Figure 6. a) Daily mean temperature (°C) and air humidity (%) was recorded in the Station of Multiple Cropping Center during Nov.-Dec., 1991 (sowing date 1); and b) duration of developing reproductive organs.
* Arrows indicating date of ear emergence.

a. Temperature and humidity



b. Duration of developing reproductive organs

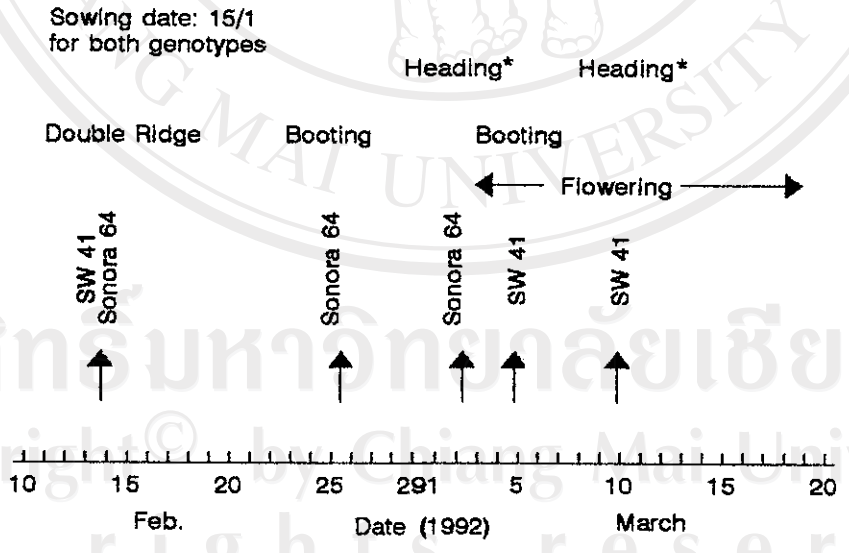


Figure 7. a) Daily mean temperature (°C) and air humidity (%) was recorded in the Station of Multiple Cropping Center during Feb.-March, 1992 (sowing date 2); and b) duration of developing reproductive organs.
* Arrows indicating date of ear emergence.

Table 17. Effects of plant B treatments on anther lengths (cm) of two genotypes for both sowing dates

Genotype	Plant B* treatment	Location in ear					
		Sowing date 1			Sowing date 2		
		Top	Middle	Bottom	Top	Middle	Bottom
Sonora 64	B0	3.2	4.0	3.8	2.9	3.5	3.3
	B1	3.0	3.6	3.3	3.2	3.8	3.3
	B2	3.7	4.1	3.6	3.3	3.6	3.1
	B3	3.5	4.0	4.0	3.3	3.8	3.5
SW 41	B0	3.4	3.8	3.4	3.4	3.8	3.2
	B1	3.3	3.6	3.6	3.3	3.7	3.4
	B2	3.3	3.6	3.7	3.2	3.8	3.4
	B3	3.2	3.9	3.5	3.3	3.9	3.2

* Plant B treatment: 0, 0.001, 0.005 and 0.02 mg $B l^{-1}$.
$LSD_{0.05}$ = 0.5 (Bp*G*D*L)
CV % = 8.15
Bp:plant B treatment; G:genotype; D:sowing date; L:location in ear.

4.2.2.2 The number of pollen

The number of pollen per anther did not differ statistically among plant B treatments for both genotypes at two sowing dates (Table 18).

A marked interaction ($P<0.01$) was detected between genotype and sowing date. In top and bottom parts of ear, for Sonora 64, the number of pollen was considerably greater at sowing date 2 than that at sowing date 1. The range of values for the number of pollen per anther was 947-1361 at sowing date 1 and 1373-1935 at sowing date 2. For SW 41, no differences were found between both sowing dates.

In SW 41, a strong difference ($P<0.01$) in the number of pollen per anther was found among various locations in ear. The largest number of pollen was recorded in middle part of ear.

Table 18. Effects of plant B treatments on the number of pollen per anther of two genotypes for two sowing dates

Genotype	Plant B treatment	Location in ear					
		Sowing date 1			Sowing date 2		
		Top	Middle	Bottom	Top	Middle	Bottom
Sonora 64	B0	947	1363	965	1406	1804	1748
	B1	1170	1542	1319	1611	2072	1935
	B2	1095	1366	1191	1373	1682	1406
	B3	1177	1469	1361	1856	1903	1916
SW 41	B0	1338	1206	1323	1506	1722	1592
	B1	1160	1461	1937	1402	1695	1415
	B2	1476	1890	1487	1079	1584	1766
	B3	1119	1478	1311	1323	1980	1486

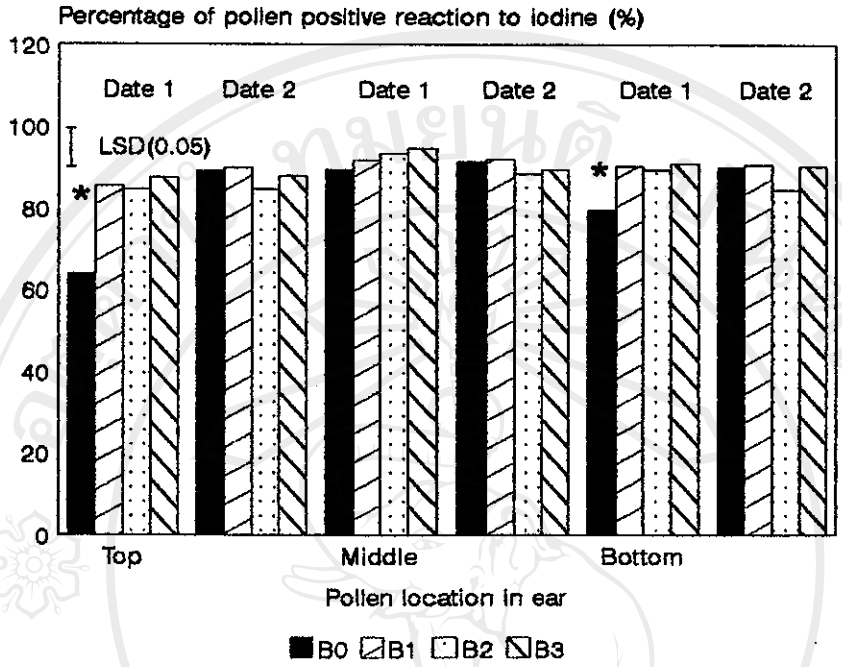
LSDo.os = 548 (Bp*G*D*L)
CV % = 22.69

4.2.2.3 Reaction of pollen to iodine

Significant differences ($P<0.05$) in percentage of pollen with positive reaction in KI/I_2 solution were observed among various plant B treatments only in top and bottom part of ear, for Sonora 64, at sowing date 1 (Figure 8). The lowest percentage occurred in B0 plant, which was 64.0% (top) and 79.7% (bottom), respectively. In SW 41, no effects of plant B treatments appeared at both sowing dates.

The effects ($P<0.01$) of pollen locations on the percentage of pollen with positive reaction in KI/I_2 were detected for both genotypes. Generally, the greatest percentage was in middle part of ear.

a. Sonora 64



b. SW 41

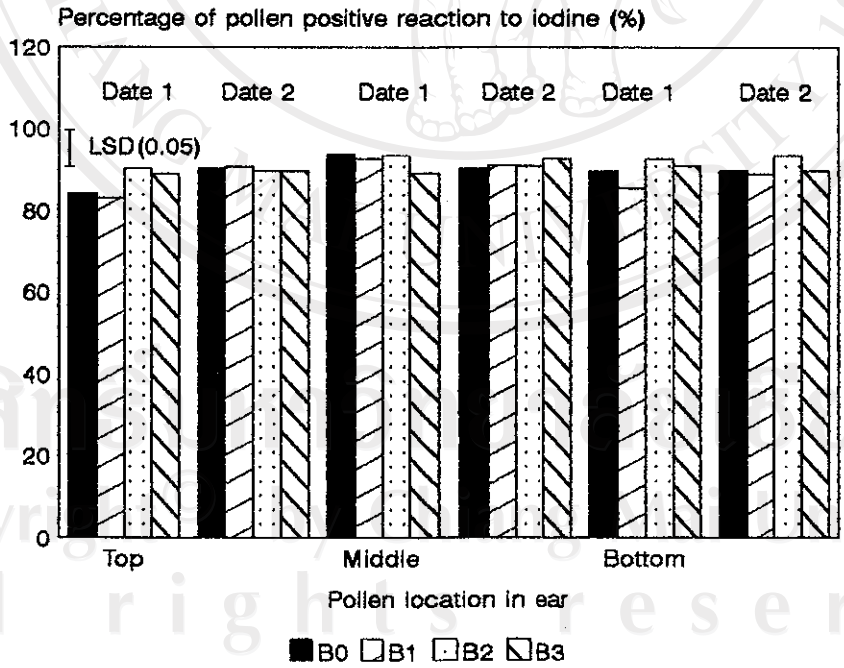


Figure 8. Effects of plant B treatments on positive reaction of pollen to iodine of two genotypes for both sowing dates.

4.2.3 Pollen germination *in vitro*

4.2.3.1 Effects of B treatments

1). Germinated pollen

a) At sowing date 1

At M0, pollen from all B supply plants gave low percentage of germinated pollen, ranging 2.2-5.6% for Sonora 64 and SW 41 (Figure 9). At M20 and M100, there was a strong trend ($P<0.01$) for pollen from higher B supply plants to have higher percentage of germinated pollen for both genotypes.

In Sonora 64, the percentage of germinated pollen was increased with increasing medium B ($P<0.01$) for all B supply plants. In SW 41, the lowest percentage of pollen was detected at M0; but no differences were found between M20 and M100, except that in B2 plants.

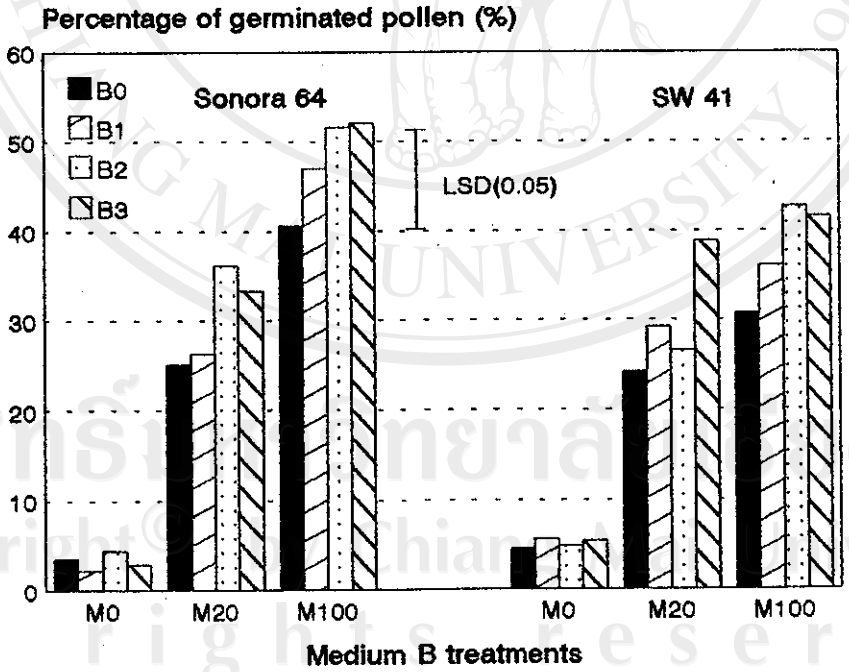


Figure 9. Effects of medium B treatments on the percentage of germinated pollen among various B supply plants for Sonora 64 and SW 41 at sowing date 1.

b) At sowing date 2

The percentage of germinated pollen consistently increased ($P<0.01$) as medium B increased from 0-20 mgl^{-1} H_3BO_3 in all B supply plants (Figure 10a). The percentage of germinated pollen at M100 was similar to that at M20 (Figure 10b). The line between medium B and the percentage of germinated pollen is linear so only 0-20 mgl^{-1} H_3BO_3 media were considered. The linear regression equation of two genotypes is well fitted ($P<0.01$) as shown following:

$Y = 4.7922 + 0.80153\ X$ $\qquad R^2=0.8060$

Y: The percentage of pollen germinated (%)

X: Medium B treatments (0-20 mgl^{-1} H_3BO_3)

The percentage of germinated pollen varied significantly ($P<0.05$) among plant B treatments only in high medium B supply (M20 and M100 for Sonora 64; M15, M20 and M100 for SW 41) (Table 19). It showed a trend that the percentage of germinated pollen increased as plant B supply increased, although the high percentage was observed at M100 in B0 plant for SW 41.

a. The percentage of germinated pollen at M0 - M20

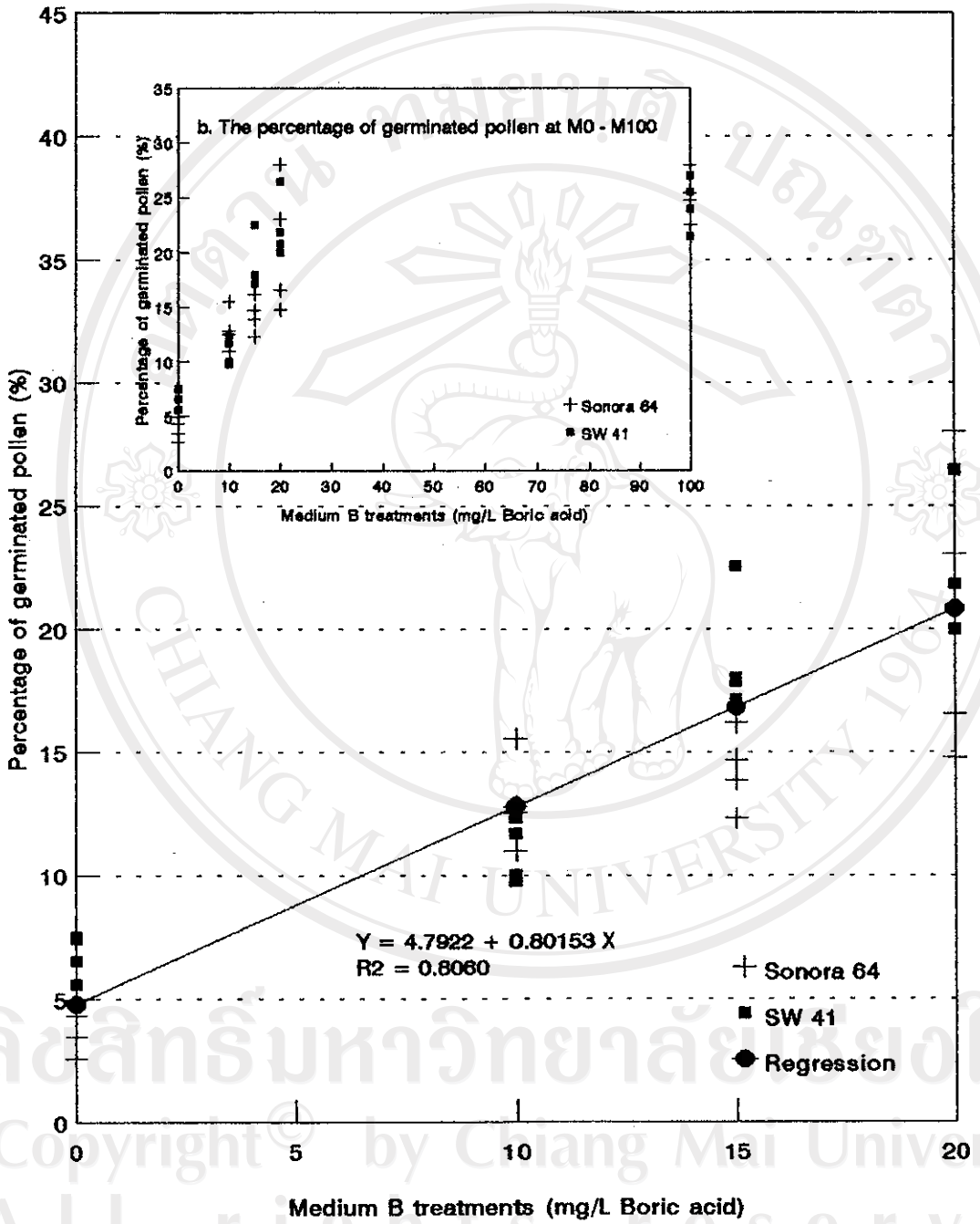


Figure 10. The relation between the percentage of germinated pollen and medium B treatment for all B supply plants of two genotypes at sowing date 2.

Table 19. Effects of media B on germinated pollen (%) among various B supply plants of two genotypes at sowing date 2

Genotype	Plant B treatment	Medium B treatment*				
		M0	M10	M15	M20	M100
Sonora 64	B0	5.0	15.5	12.3	14.8	22.5
	B1	2.6	12.5	13.9	23.0	27.9
	B2	4.3	11.0	14.7	16.5	25.4
	B3	3.5	12.8	16.2	28.0	24.8
SW 41	B0	5.6	9.8	17.2	20.8	25.5
	B1	7.5	12.3	17.9	21.8	21.4
	B2	6.6	10.0	18.0	20.0	27.0
	B3	7.5	11.7	22.5	26.5	23.9

* Medium B treatments: 0, 10, 15, 20 and 100 mgl^{-1} H_3BO_3.
LSD0.05 = 5.4 (Bp*Bm*G)
CV % = 20.3
Bm: medium B treatment.

2). Burst pollen

There were large effects ($P<0.01$) of medium B supply on the percentage of burst pollen among various B supply plants at sowing date 2 (Table 20). At M0, the percentage of burst pollen was markedly greater in B0 plants than that in B1, B2 and B3 plants for both genotypes. It was up to 60.6% for Sonora 64 and 61.3% for SW 41. At M10, for Sonora 64, the lowest percentage was recorded in B3 plants (19.7%). At other media, the percentage did not differ much among plant B treatments (actually, the low percentage was found in B2 plants at M20 for SW 41).

In the most plants, regardless of B supply to the plants for both genotypes, there was a slight trend ($P<0.08$) that the percentage of burst pollen depressed as medium B increased. In SW 41, however, the percentage of burst pollen varied little among medium B treatments in B2 and B3 plants.

Table 20. Effects of media B treatments on burst pollen (%) among various B supply plants of two genotypes at sowing date 2

Genotype	Plant B treatment	Medium B treatment				
		M0	M10	M15	M20	M100
Sonora 64	B0	60.5	53.3	29.5	42.6	37.4
	B1	34.3	48.1	23.9	34.7	23.1
	B2	45.2	48.5	20.4	43.6	33.7
	B3	41.4	19.7	22.3	42.8	23.6
SW 41	B0	61.3	33.9	42.1	45.9	37.1
	B1	37.4	38.7	28.3	40.6	23.8
	B2	28.0	34.8	38.3	28.5	30.7
	B3	38.0	36.5	37.6	45.0	36.2

$LSD_{0.05}$ = 16.3 (Bp*Bm*G)
CV % = 26.8

Table 21. Effects of media B treatments on ungerminated pollen (%) among various B supply plants of two genotypes at sowing date 2

Genotype	Plant B treatment	Medium B treatment				
		M0	M10	M15	M20	M100
Sonora 64	B0	34.5	31.2	58.2	42.7	40.0
	B1	63.1	39.4	62.3	42.3	49.0
	B2	50.4	40.5	64.9	39.9	40.9
	B3	55.1	67.5	61.5	29.1	51.6
SW 41	B0	33.1	56.3	40.7	33.3	37.4
	B1	55.1	49.0	53.8	37.6	54.7
	B2	65.4	55.2	43.7	51.5	42.3
	B3	54.4	51.8	39.9	28.6	39.8

$LSD_{0.05}$ = 18.6 (Bp*Bm*G)
CV % = 23.9

3). Ungerminated pollen

The relationship between the percentage of ungerminated pollen and plant B or medium B treatments was not evident at sowing date 2 (Table 21). At M0, for both genotypes, the percentage of ungerminated pollen was markedly lower in B0 plants than that in B1, B2 and B3 plants (34.5% for Sonora 64 and 33.1% for SW 41). In contrast, at M20 for SW 41, the lowest percentage (28.6%) was detected in B3 plants.

4.2.3.2 Effects of sowing dates

1). Germinated pollen

Percentage of germinated pollen was significantly affected ($P<0.01$) by sowing dates (Figure 11). At M100, in all plants of Sonora 64, the percentage of germinated pollen was pronouncedly greater at sowing date 1 than that at sowing date 2. For SW 41, the largest effects of sowing dates were observed in B1, B2 and B3 plants at M100. The higher percentage of germinated pollen was recorded at sowing date 1. At M20, marked effects of sowing date were found only in B2 plants of Sonora 64. The percentage was greater at sowing date 1 (36.2%) than that at sowing date 2 (16.5%). A considerable interaction ($P<0.01$) between medium B treatment and sowing date was detected.

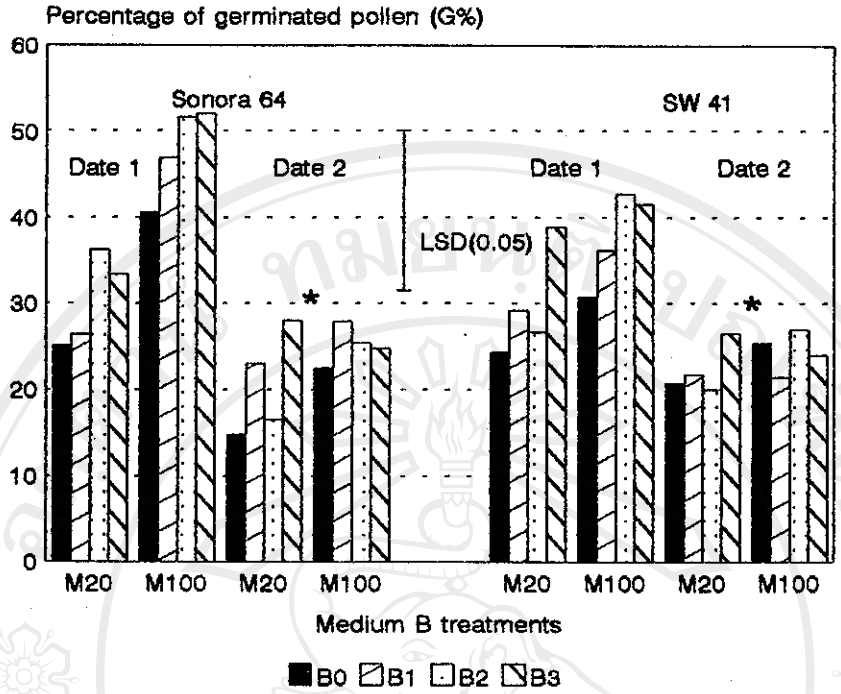


Figure 11. Effects of sowing dates on the percentage of germinated pollen of two genotypes

2). Burst pollen

Effects of sowing date on the percentage of burst pollen were significant ($P<0.01$) (Table 22). At sowing date 1, for Sonora 64, in B0 plants at M20 (62.3%) and in B1 plants at M100 (43.7%), the percentage of burst pollen was evidently higher than that at sowing date 2, 42.6% for B0 plants at M20 and 23.1% for B1 plants at M100. For SW 41, only in B2 plants at M20, the higher percentage of burst pollen (60.7%) was observed at sowing date 1.

3). Ungerminated pollen

Generally, the percentage of ungerminated pollen was consistently lower ($P<0.01$) at sowing date 1 than that at sowing date 2 (Table 23), since the higher percentage of germinated and burst pollen was recorded at sowing date 1.

Table 22. Effects of sowing dates on burst pollen (%) of two genotypes at M20 and M100

Genotype	Plant B treatment	Medium B treatment			
		M20		M100	
		Date* 1	Date 2	Date 1	Date 2
Sonora 64	B0	62.3	42.6	50.4	37.4
	B1	49.7	34.7	43.7	23.1
	B2	43.8	43.6	38.7	33.7
	B3	48.9	42.8	41.3	23.6
SW 41	B0	63.1	45.9	52.4	37.1
	B1	58.1	40.6	36.3	23.8
	B2	60.7	28.5	36.7	30.7
	B3	43.1	45.0	45.0	36.2

* Sowing date
LSD$_{0.05}$ = 18.8 (Bp*Bm*G*D)
CV % = 21.9
D: sowing date

Table 23. Effects of sowing dates on ungerminated pollen (%) of two genotypes at M20 and M100

Genotype	Plant B treatment	Medium B treatment			
		M20		M100	
		Date 1	Date 2	Date 1	Date 2
Sonora 64	B0	12.6	42.7	9.0	40.0
	B1	23.9	42.3	9.3	49.0
	B2	20.0	39.9	9.8	40.9
	B3	17.7	29.1	6.7	51.6
SW 41	B0	12.6	33.3	16.9	37.4
	B1	12.7	37.6	27.6	54.7
	B2	12.7	51.5	20.6	42.3
	B3	18.1	28.6	13.4	39.8

LSD$_{0.05}$ = 20.1 (Bp*Bm*G*D)
CV % = 35.9

4.2.3.3 Effects of temperature treatments

Effects of temperature on pollen germination were only examined at sowing date 2.

1). Germinated pollen

A strong interaction ($P<0.01$) was detected among plant B treatment, genotype, medium B treatment and temperature treatment. At M100, in the field temperature (25±1°C), the percentage of germinated pollen was 22.5% - 25.5% in both Sonora 64 and SW 41; increasing temperature to 30°C, markedly depressed the percentage of germinated pollen, but the effect varied with genotypes and plant B status (Figure 12). In SW 41, the effect of temperature on germinated pollen was the same in B0 (12.8%) and B3 (12.6%) plants. In Sonora 64, the effect of temperature at 30°C was much more severe in B0 plants than that in B3 plants, the percentage of germinated pollen was 10.9% in B0 plants and 19.8% in B3 plants.

At M20, the effects of temperature were the same between both genotypes. In B3 plants, the percentage of germinated pollen was significantly lower ($P<0.01$) at 30°C than that at field temperature, but no differences were found in B0 plants. The effects of high temperature did not differ between B0 and B3 plants.

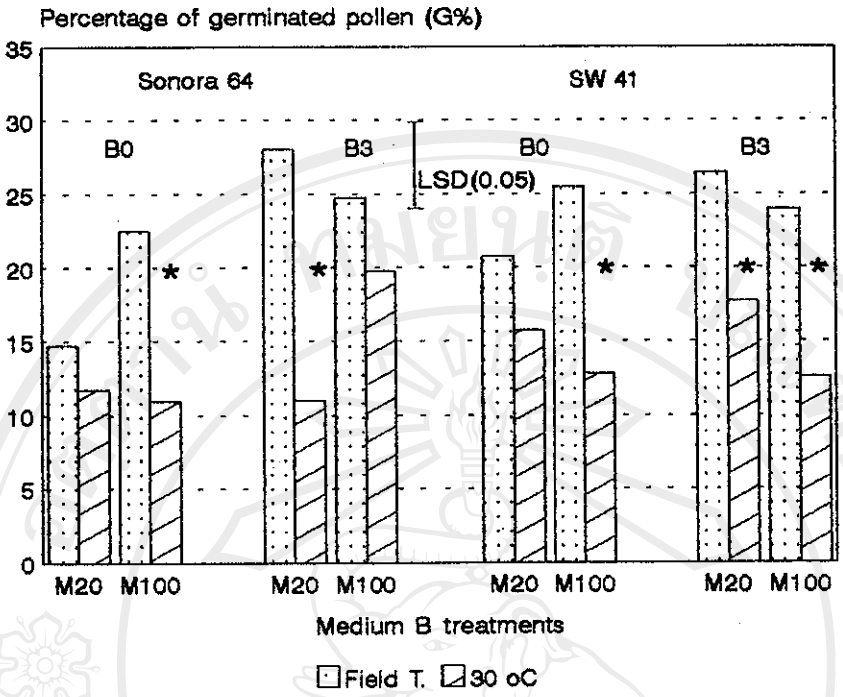


Figure 12. Effects of temperature treatments on the percentage of germinated pollen for both genotypes at M20 and M100.

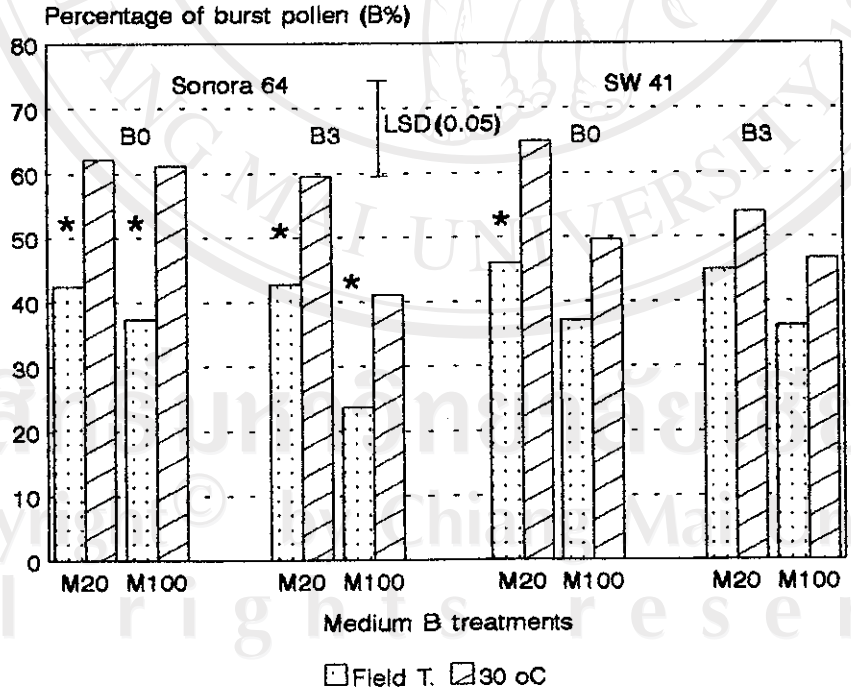


Figure 13. Effects of temperature treatments on the percentage of burst pollen for both genotypes at M20 and M100.

2). Burst pollen

The percentage of burst pollen was significantly affected ($P<0.01$) by temperature (Figure 13). At 30°C, for Sonora 64, the percentage was considerably higher than that in the field temperature in B0 and B3 plants at both media. The percentage, with this temperature, ranged from 41.1% to 62.2%. In SW 41, the largest effects of temperature occurred only in B0 plants at M20; the percentage of burst pollen was up to 65.0% at 30°C.

The responses to high temperature (30°C) between B0 and B3 plants were similar to that of the percentage of germinated pollen. Differences in the percentage of burst pollen were only detected in Sonora 64 at M100; the higher percentage of burst pollen was recorded in B0 plants.

3). Ungerminated pollen

The percentage of ungerminated pollen was insignificantly different between field temperature and 30°C (Table 24). The differences between B0 and B3 plants, at 30°C, were not observed at both B media for both genotypes.

Table 24. Effect of temperature on ungerminated pollen (UG%) of two genotypes at sowing date 2

Genotype	Plant B treatment	Temperature treatment			
		Field temperature		30°C	
		M20	M100	M20	M100
Sonora 64	B0	42.7	40.0	26.1	27.9
	B3	29.1	51.6	29.4	39.1
SW 41	B0	33.3	37.5	19.3	37.7
	B3	28.6	39.8	28.4	40.7

$LSD_{0.05}$ = 21.0 (Bp*Bm*G*T)
CV % = 32.0
T: temperature.

4.2.4 Pollen tube growth

4.2.4.1 Effects of B treatments

The pollen tube length strongly responded ($P<0.01$) to plant B treatments, but effects depended on genotypes and medium B at sowing date 1 (Figure 14). In Sonora 64, at M20, there were no effects of plant B treatments; at M100, the pollen tube length increased from 80 µm in B0 plants to over 120 µm in B3 plants. In SW 41, the pollen tube length increased as plant B supply increased at M20 and M100. The increase in the pollen tube length in B3 plants was almost twice as much as that in B0 plants.

Generally, the tube length was markedly longer ($P<0.05$) at M100 than that at M20. In SW 41, whereas, the longest tube was noticed at M20 in B1 plants.

4.2.4.2 Effects of sowing dates

Effects of sowing dates on pollen tube length were examined only at M100. There was a significant interaction ($P<0.01$) among plant B treatment, genotype and sowing date (Figure 15). For SW 41, the tube length was markedly longer in B0, B2 and B3 plants at sowing date 1 than that at sowing date 2; in B1 plants, no difference was found. In B3 plants, for Sonora 64, the longer tube length (122 µm) was recorded at sowing date 1; however, the tube length was longer at sowing date 2 in B0 and B2 plants than that at sowing date 1.

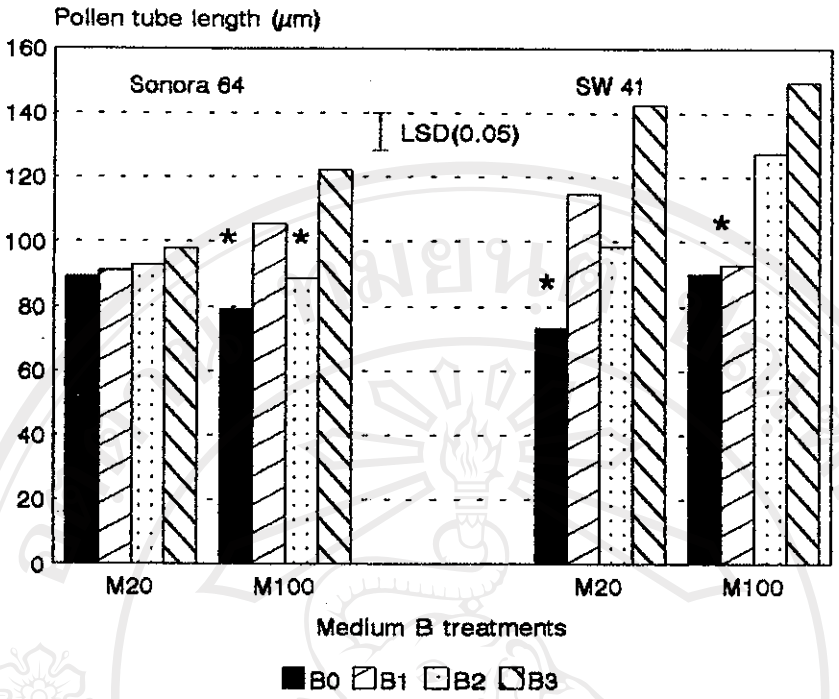


Figure 14. Effects of plant B treatments on pollen tube growth for two genotypes at M20 and M100 at sowing date 1.

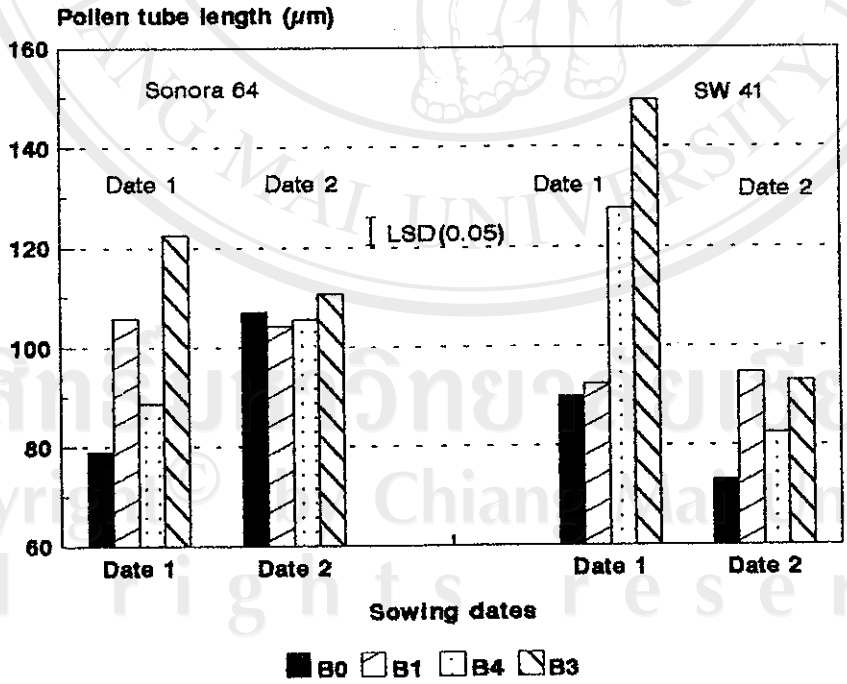


Figure 15. Effects of sowing dates on pollen tube growth for two genotypes at M100.

4.2.4.3 Effects of temperature treatments

The tube length was significantly shorter ($P<0.01$) at 30°C than that at the field temperature in B0 and B3 plants for both genotypes at M20 and M100 at sowing date 2 (Figure 16). At high temperature (30°C), the effects on pollen tube length varied with genotypes and plant B status. In Sonora 64, no differences were observed between B0 and B3 plants. In SW 41, the tube length was markedly shorter in B0 plants (61 µm) than that in B3 plants (76 µm).

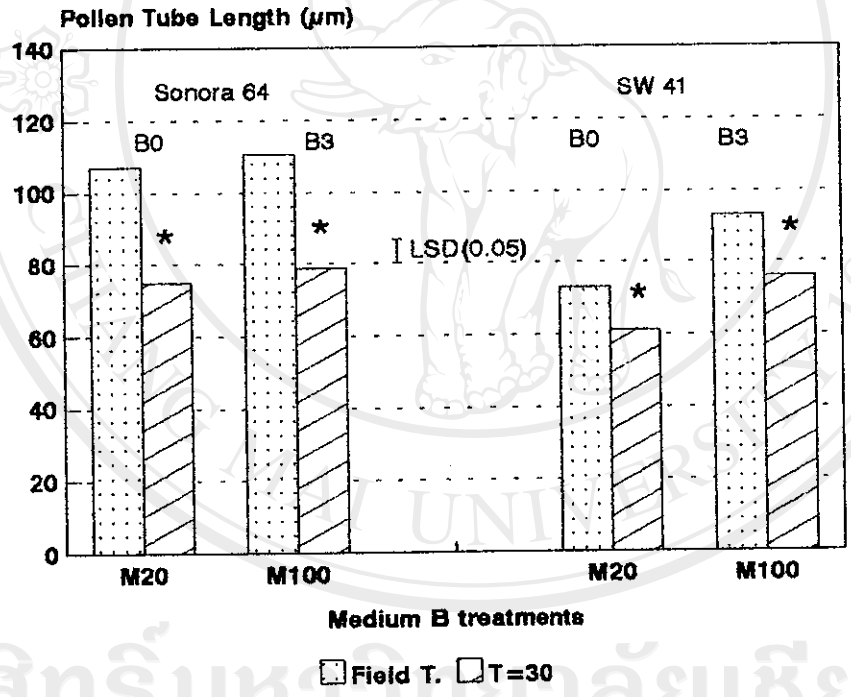


Figure 16. Effects of temperature on pollen tube growth for both genotypes at M20 and M100 at sowing date 2.

4.2.5 Grain set

4.2.5.1 Basal floret fertility

The differences between SW 41 and Sonora 64 in response to B were significant ($P<0.05$). For Sonora 64, the value of basal floret fertility, ranging from 1.87 to 1.99, did not differ significantly among plant B treatments at both sowing dates (Figure 17). In SW 41, the value of basal floret fertility was the lowest in B0 plants, which was 1.25 for sowing date 1 and 1.63 for sowing date 2, and increased with increasing plant B supply at both sowing dates.

4.2.5.2 Percentage of fertile florets

Effects of B on percentage of fertile florets for both genotypes at both sowing dates were similar to that of basal floret fertility (Figure 18). In SW 41, the percentage of fertile florets consistently increased as plant B supply increased at both sowing dates. For Sonora 64, the percentage of fertile florets varied little among plant B treatments at both sowing dates; they ranged from 85.3% to 91.9%. A significant interaction ($P<0.01$) between plant B treatment and genotype was detected.

Generally, the greater percentage of fertile florets was observed at sowing date 2 ($P<0.01$). In B0 plants, for SW 41, percentage of fertile florets was markedly higher at sowing date 2 (67.2%) than that at sowing date 1 (48.9%).

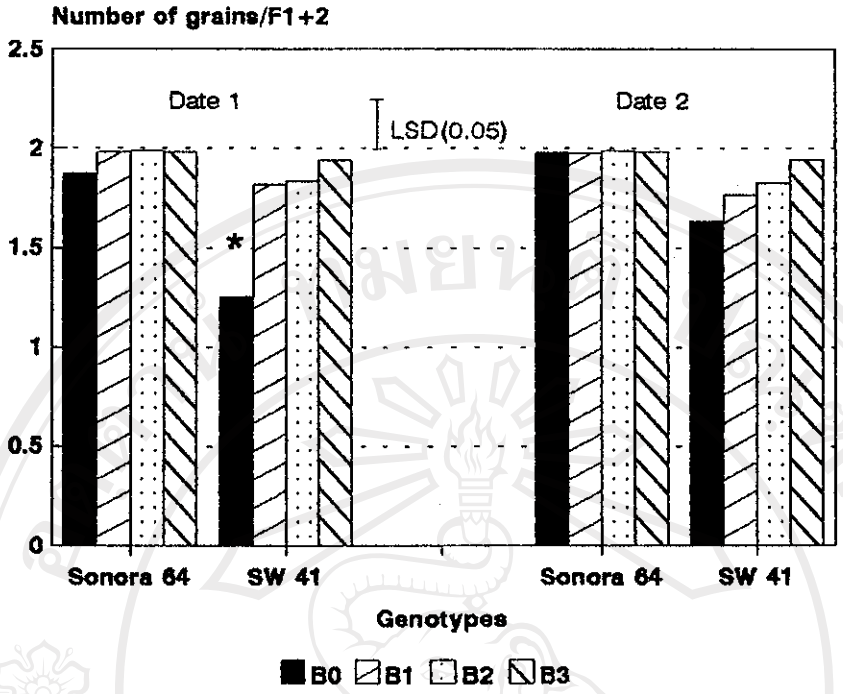


Figure 17. Effects of plant B treatments on two basal floret fertility for two genotypes at both sowing dates.

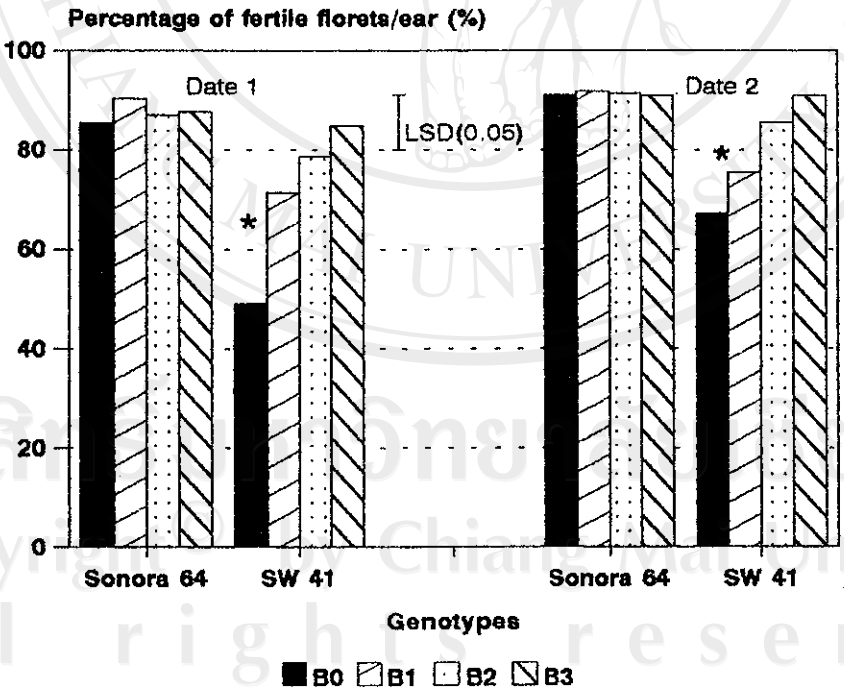


Figure 18. Effects of plant B treatments on percentage of fertile florets for two genotypes at both sowing dates.

4.2.6 Yield components

4.2.6.1 Spikelets per ear

Significant effects ($P<0.05$) of plant B treatments on spikelets (including superfluous spikelets) per ear were detected only at sowing date 1 for both genotypes (Table 25). There was a trend for the lower plant B supply to have the higher spikelets per ear in Sonora 64. For SW 41, spikelets was pronouncedly lower in B3 plants than those in other plants. At sowing date 2, spikelets per ear differed little among plants B treatments for both genotypes.

The spikelets per ear were consistently lower ($P<0.01$) at sowing date 2 than that at sowing date 1 for both genotypes. A high interaction ($P<0.05$) was observed among plant B treatment, sowing date and genotype.

Table 25. Effects of plant B treatments on spikelets per ear of two genotypes at both sowing dates

Plant B treatment	Genotype			
	Sonora 64		SW 41	
	Sowing date 1	Sowing date 2	Sowing date 1	Sowing date 2
B0	19.5	15.7	20.4	18.0
B1	17.6	16.2	19.7	17.7
B2	18.3	15.8	20.3	17.8
B3	18.5	16.1	17.5	18.2

$LSD_{0.05}$ = 1.2 (Bp*G*D)
CV % = 4.01

4.2.6.2 Grains per ear

Grains per ear is highly correlated with basal floret fertility and percentage of fertile florets. No differences were found in Sonora 64 at both sowing dates; the values ranged form 39.9 to 48.9 (Figure 19). In SW 41, at sowing date 1, grains per ear were markedly lower ($P<0.05$) in B0 plants (30.9) than that in B1, B2 and B3 plants (ranged 45.6 - 50.5). At sowing date 2, there was a trend for the higher plant B supply to have the higher grains per ear. There was a significant interaction ($P<0.05$) between plant B treatment and genotype.

A considerable interaction ($P<0.01$) between plant B treatment and sowing date was detected only in B0 plants for SW 41. The grains per ear were much lower at sowing date 1 (30.9) than that at sowing date 2 (42.6).

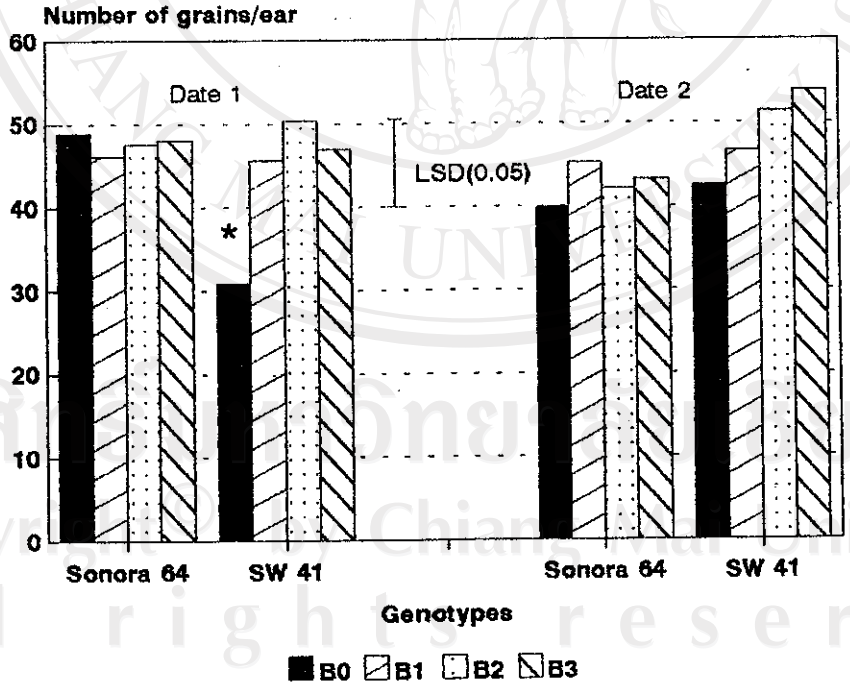


Figure 19. Effects of plant B treatments on grains per ear for two genotypes at both sowing dates.

4.2.6.3 1000 grain weight

Effects (P<0.01) of plant B treatments on 1000 grain weight were evident (Figure 20). For Sonora 64, at sowing date 1, the lowest weight of 1000 grains was recorded in B3 plants; at sowing date 2, the 1000 grain weight varied little among various B supply plants. For SW 41, at both sowing dates, the 1000 grain weight was obviously higher in B0 and B1 plants than that in B2 and B3 plants.

The 1000 grain weight was higher (P<0.01) at sowing date 1 than that at sowing date 2 in all B supply plants of both genotypes.

4.2.6.4 Ears per pot

With failure of tillers to set grain, the plants were found to produce next generation of tillers (late ear), however, these also became sterile.

Total ears (mature and late ears) per pot show in Figure 21. Mature ears (set grains) differed little among plant B treatments either at sowing date 1 or at sowing date 2.

However, effects of plant B treatments on late ears were significant. At sowing date 1, large effects were found only in SW 41 (P<0.05). Late ears drastically depressed as plant B supply increased. At sowing date 2, for Sonora 64, late ears were markedly higher (P<0.01) in B0 and B1 plants than that in B2 and B3 plants; in SW 41, the highest (P<0.01) late ears were in B0 plants.

At sowing date 1, plants consistently produced more mature ears per pot as well as more late ears than that at sowing date 2 (P<0.05) (One Way ANOVA).

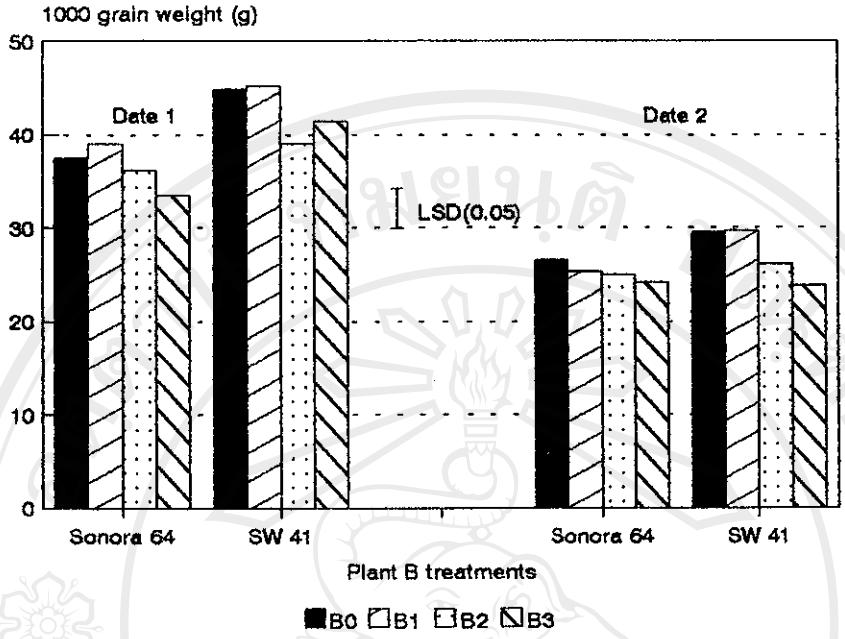


Figure 20. Effects of plant B treatments on 1000 grain weight for two genotypes at both sowing dates.

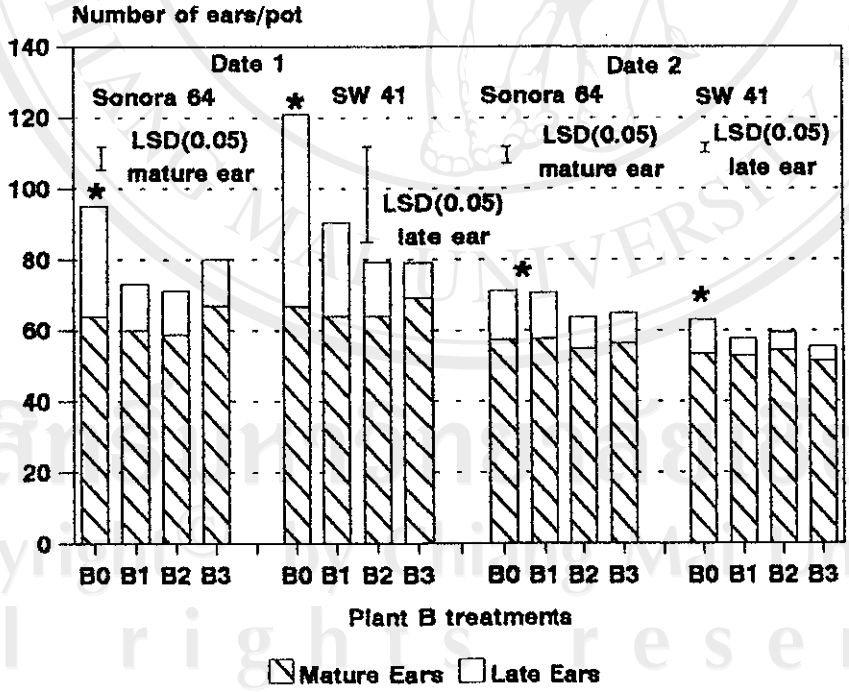


Figure 21. Effects of plant B treatments on ears per pot for two genotypes at both sowing dates

4.2.7 Boron concentration ([B]) in tissue

4.2.7.1 Whole tops at tillering stage (Zadoks 2.0)

There was a significant interaction ($P<0.05$) among plant B treatment, genotype and sowing date. In SW 41, there was a strong trend that [B] in whole tops at tillering stage responded to plant B supply at both sowing dates (Figure 22). For Sonora 64, at sowing date 1, [B] was markedly lower in B0 and B1 plants than that in B2 and B3 plants; at sowing date 2, a slight trend was observed for the higher plant B supply to have the higher [B] in whole tops, although [B] was lower in B2 plants than that in B1 plants.

[B] in whole tops at tillering stage varied little between two sowing dates for both genotypes.

4.2.7.2 Whole tops at double ridge stage (Zadoks 3.0)

Effects of plant B treatments on [B] in whole tops were apparent ($P<0.01$) at double ridge stage. At sowing date 1, for Sonora 64, [B] was evidently lower in B0 and B1 plants than that in B2 and B3 plants; in SW 41, the highest value of [B] was recorded in B3 plants (8.57 mg Bkg^{-1} dry wt) (Figure 23). At sowing date 2, the largest effects were only for SW 41; [B] in whole tops was relatively higher in B3 plants than that in B0, B1 and B2 plants.

In SW 41, [B] in whole tops was evidently higher ($P<0.05$) at sowing date 1 than that at sowing date 2 for all B supply plants. For Sonora 64, the largest effects were only for B3 plants; [B] was much higher at sowing date 1 than that at sowing date 2.

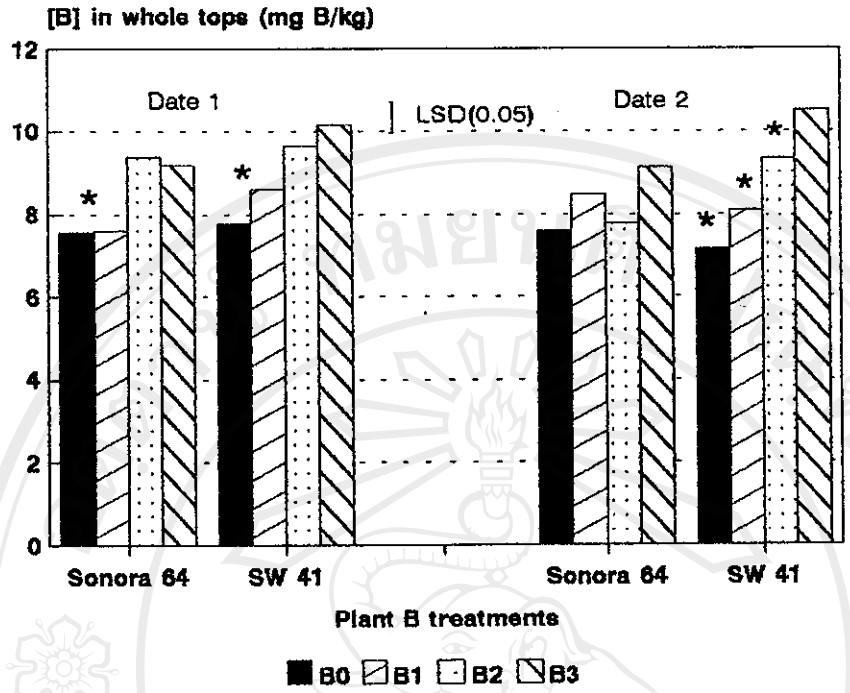


Figure 22. Effects of plant B treatments on [B] in whole tops at tillering for two genotypes at both sowing dates.

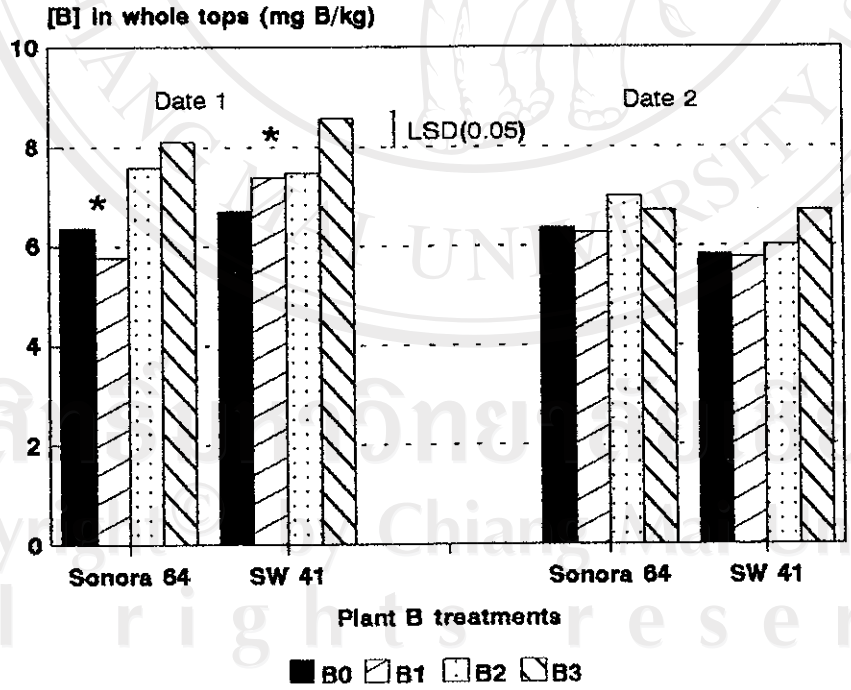


Figure 23. Effects of plant B treatments on [B] in whole tops at double ridge for two genotypes at both sowing dates.

4.2.7.3 Flag leaf at booting stage (Zadoks 4.5)

Effects of plant B treatments on [B] in flag leaf at booting stage ($P<0.01$) were the same for both genotypes, but they varied with sowing dates (Figure 24). At sowing date 1, [B] in flag leaf was relatively lower in B0 and B1 plants than that in B2 and B3 plants. At sowing date 2, there was a strong trend that [B] in flag leaf responded to plant B treatments.

In general, [B] in flag leaf was significantly higher ($P<0.01$) at sowing date 1 than that at sowing date 2. The effects of sowing dates were detected in all B supply plants of Sonora 64. For SW 41, the effects were found only in B1, B2 and B3 plants.

4.2.7.4 Flag leaf at booting stage (Zadoks 4.5)

Effects of plant B treatments on [B] in developing ear at booting stage were evident ($P<0.01$) (Figure 25). At sowing date 1, the largest effects were for SW 41; [B] in developing ear was significantly higher in B3 plants (5.60 mg Bkg^{-1} dry wt) than that in B0, B1 and B2 plants. At sowing date 2, [B] of both genotypes responded to plant B treatments. The highest [B] in developing ear at booting stage was recorded in B3 plants for both genotypes, which was 6.57 mg Bkg^{-1} dry wt for Sonora 64 and 6.41 mg Bkg^{-1} dry wt for SW 41.

[B] in developing ear at booting stage was higher ($P<0.05$) at sowing date 2 than that at sowing date 1 only in B3 plants for Sonora 64 and in B2 plants for SW 41. It did not differ in B0 and B1 plants between both sowing dates for both genotypes.

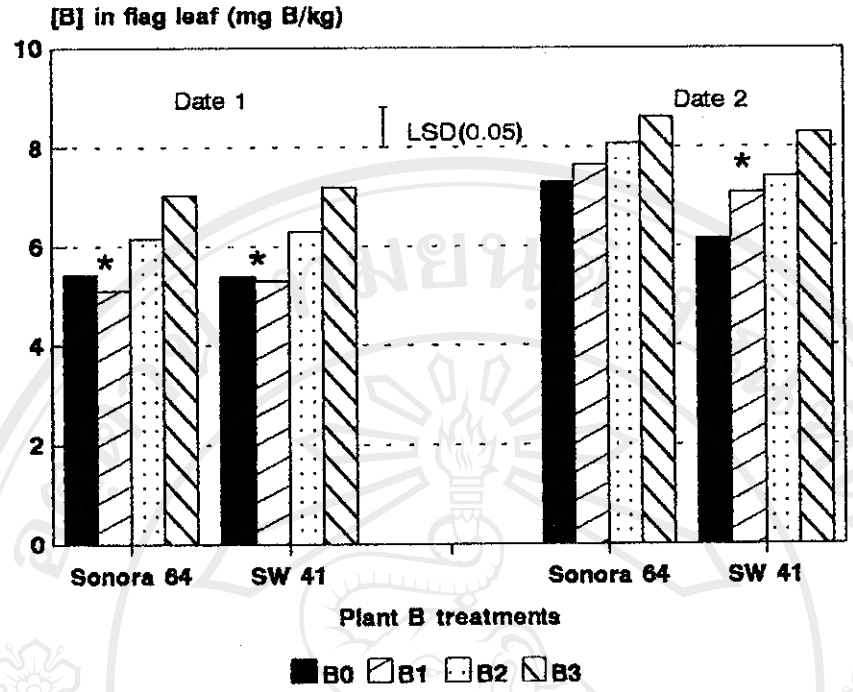


Figure 24. Effects of plant B treatments on [B] in flag leaf at booting stage for two genotypes at both sowing dates.

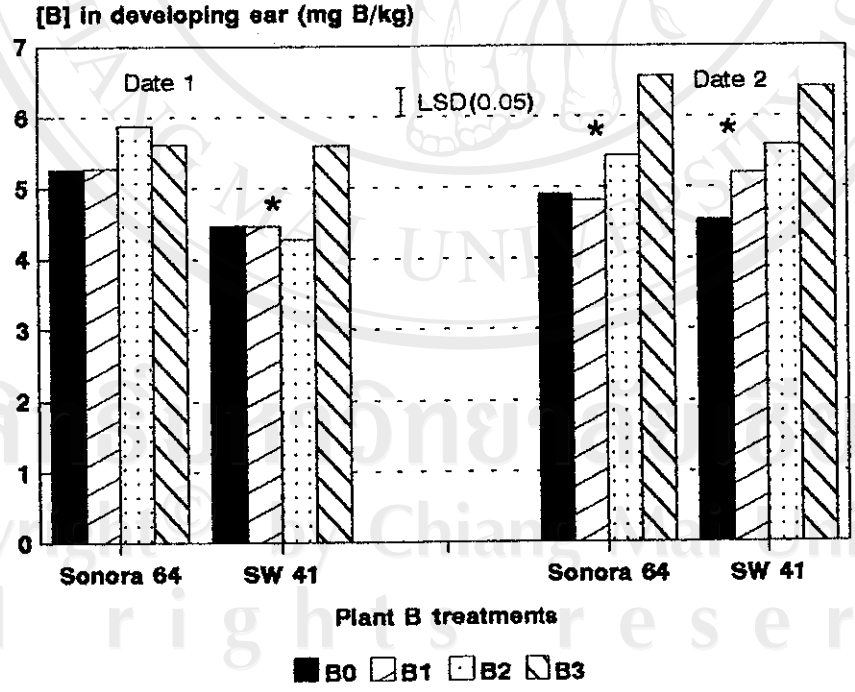


Figure 25. Effects of plant B treatments on [B] in developing ear at booting for two genotypes at both sowing dates.