days to anthesis from days to physiological maturity.

3.3.6 Yield and Yield Components

At maturity, 10 plants were sampled randomly from each plot to determine number of spikelets/spike and grains/spike. Spike number and grain yield were determined on 2.0 m^2 area from the central portion of each plot. The 1,000-grain weight was determined after dried at 65 ^{0}C for 48 hours.

4. RESULTS

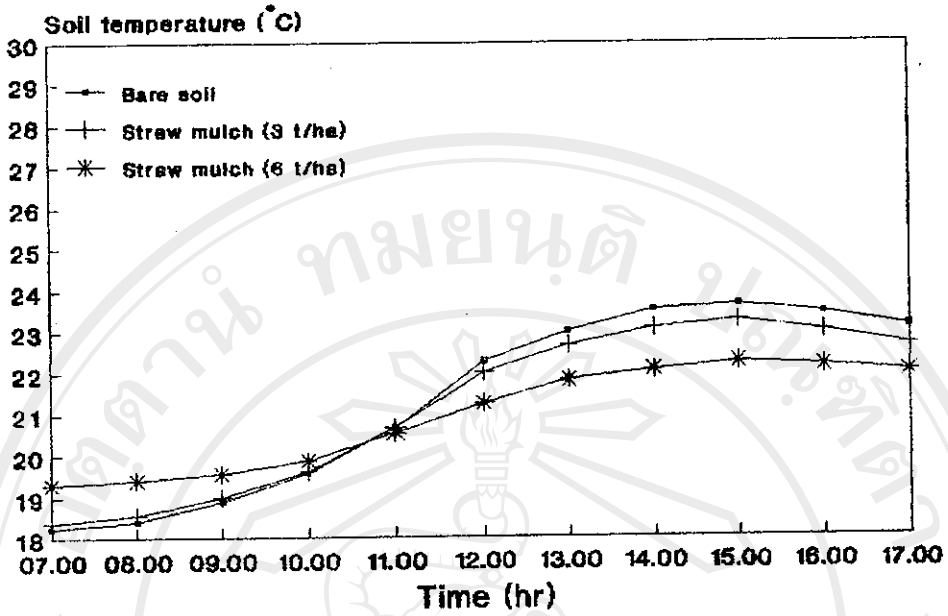
4.1 Soil Temperature

4.1.1 Daytime Changes

The changes of daytime soil temperature from 07:00 am. to 05:00 pm. during the booting stage of wheat are presented in Figures 1a, 1b and Appendix Table 11. It was observed that soil temperature in all treatments increased substantially from 07:00 am., reached the maximum at about 03:00 pm. and started to decline thereafter. Under non-irrigated condition, soil temperature in bare soil treatment increased drastically and reached the maximum at about 30^{0}C . In contrast, soil temperature in straw mulched treatment increased gradually and reached the maximum at about 25^{0}C. Under full irrigated condition, soil temperatures were very consistent among bare soil and straw mulched treatments. However, 03:00 pm. soil temperature in straw mulched treatments were relatively lower than that in bare soil treatment. On

the contrary, soil temperature at 07:00 am. in straw mulched treatment was relatively higher than that in bare soil treatment. During this period, average air temperature at 07:00 am. and 03:00 pm. were 13 and 31^{0}C respectively.

(b) Early irrigation



(a) Late irrigation

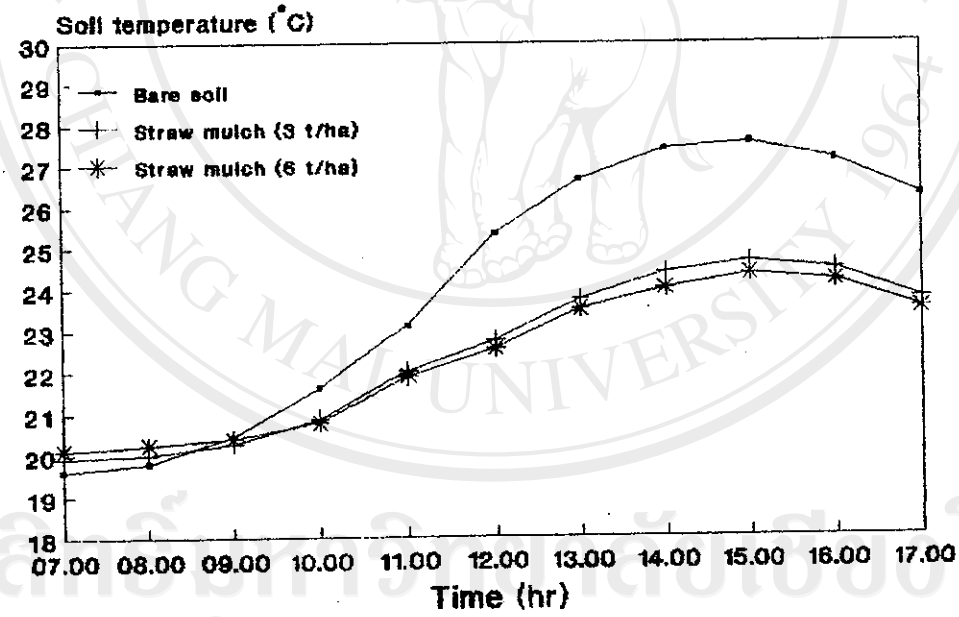
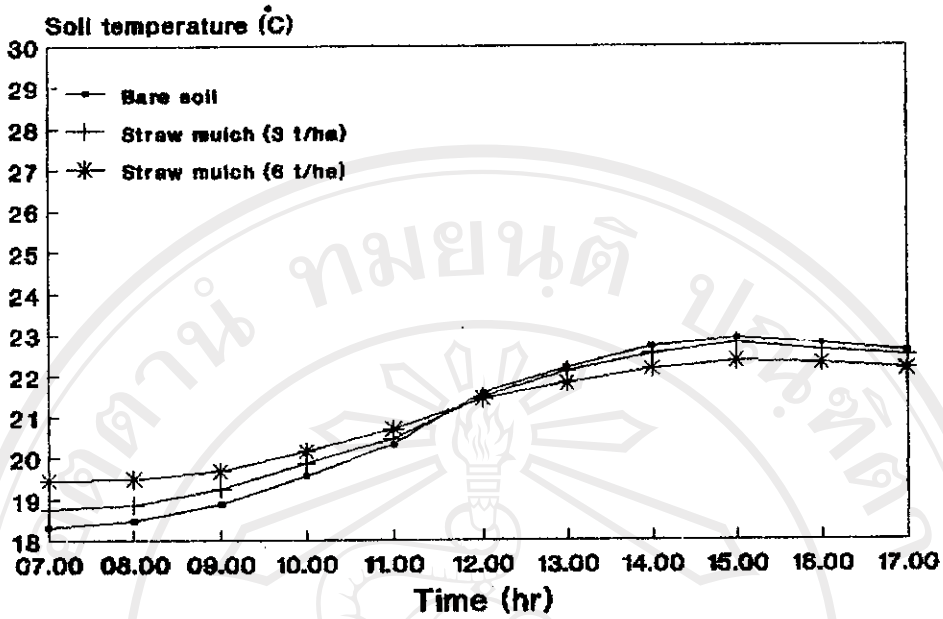


Figure 1a. Daytime changes of soil temperature during the booting stage in different mulching treatments under early irrigated (a) and late irrigated conditions (b)

(a) Full irrigation



(b) No irrigation

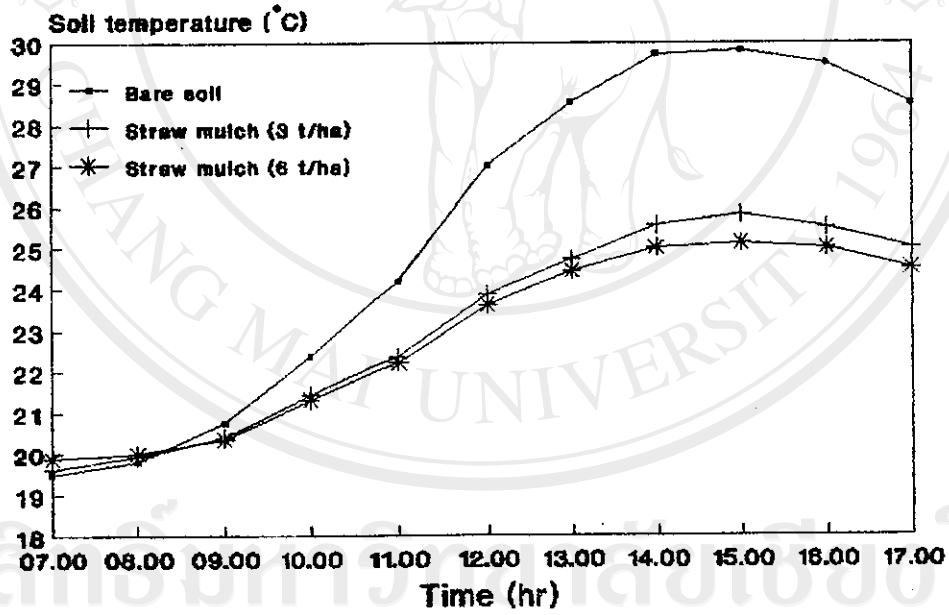


Figure 1b. Daytime changes of soil temperature during the booting stage in different mulching treatments under full irrigated (a) and non-irrigated conditions (b)

4.1.2 Seasonal Changes

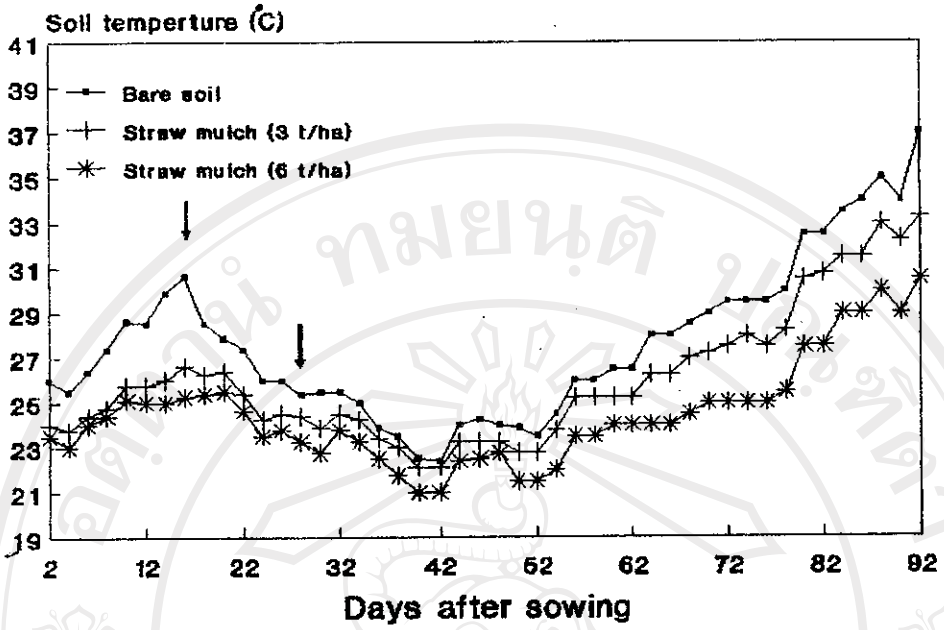
(a) At 03:00 pm.

The seasonal changes of 03:00 pm. soil temperature under different irrigation and mulching treatments are presented in Figures 2a and 2b. It was observed that 03:00 pm. soil temperature tended to increase with advance in crop growth, particularly under non-irrigated condition. Mulching with rice straw caused a marked reduction in 03:00 pm. soil temperature as compared to bare soil. Among different rates of mulching, higher rate of straw (6 t/ha) resulted to a relatively lower 03:00 pm. soil temperature as compared to that under lower rate of straw (3 t/ha). Apart from mulching, frequent irrigations also caused a reduction in 03:00 soil temperature particularly under full irrigated condition.

(b) At 07:00 am.

In contrast to 03:00 pm. soil temperature, soil temperatures at 07:00 am. were not greatly difference among bare soil and straw mulched treatments. However, rice straw mulching caused a relatively higher soil temperature at 07:00 am. throughout the crop growth period as compared to bare soil (Figures 2c and 2d). Similarly, frequent irrigations also caused a reduction in 07:00 am. soil temperature in all treatments.

(a) Early irrigation



(b) Late irrigation

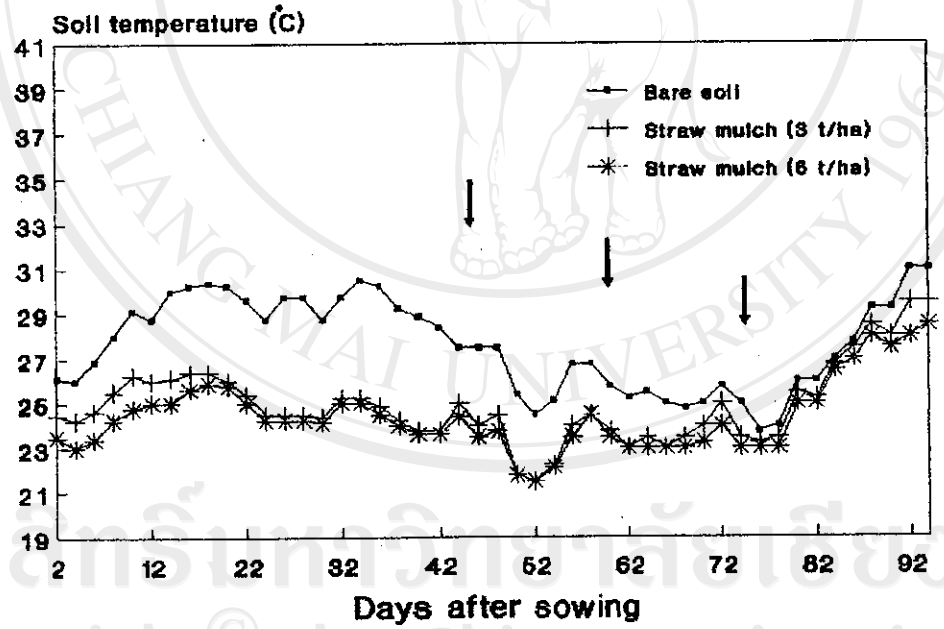
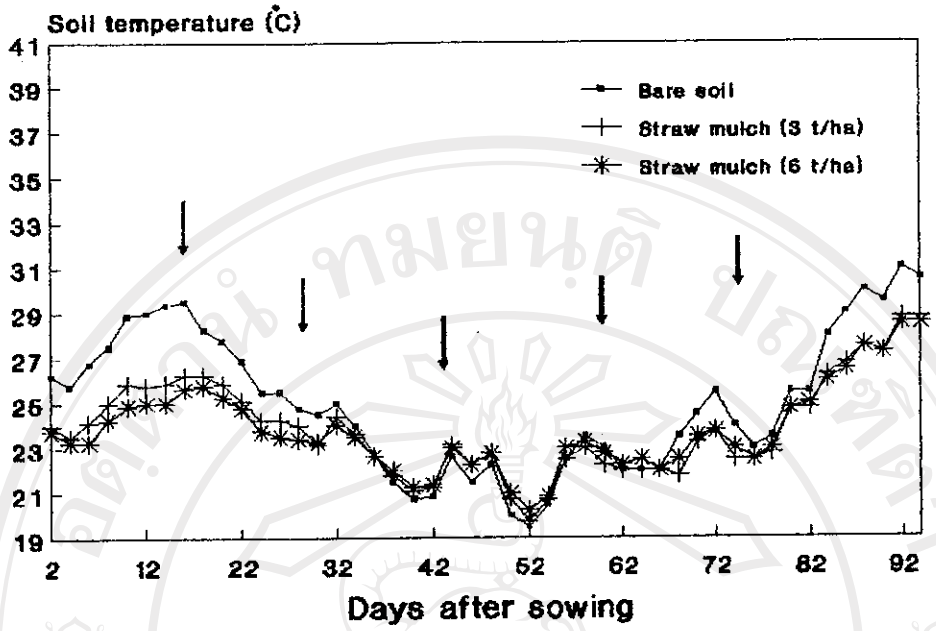


Figure 2a. Seasonal changes of 03:00 pm. soil temperature in different mulching treatments under early irrigated (a) and late irrigated conditions (b) [arrows indicate irrigations]

(a) Full irrigation



(b) No irrigation

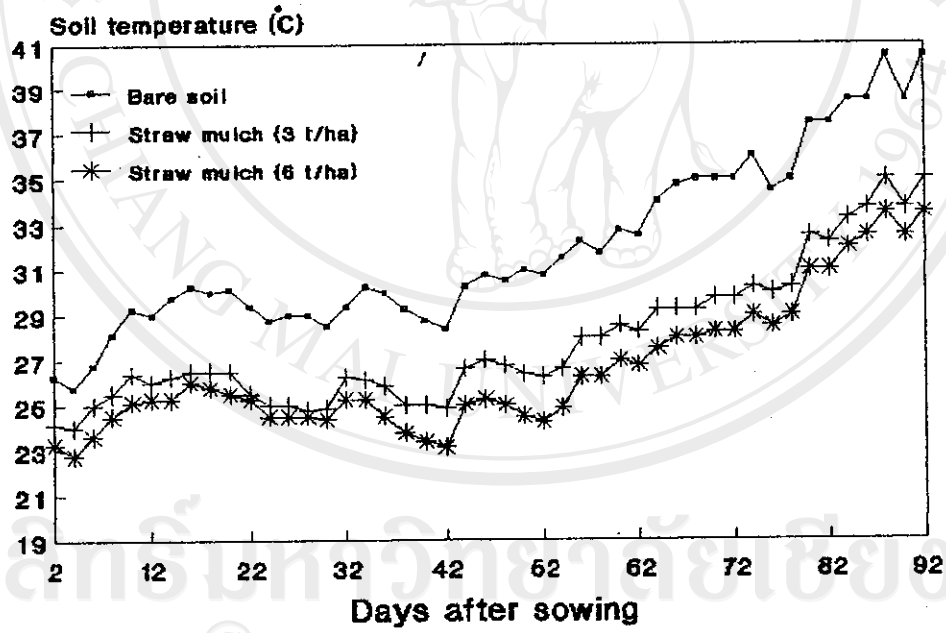
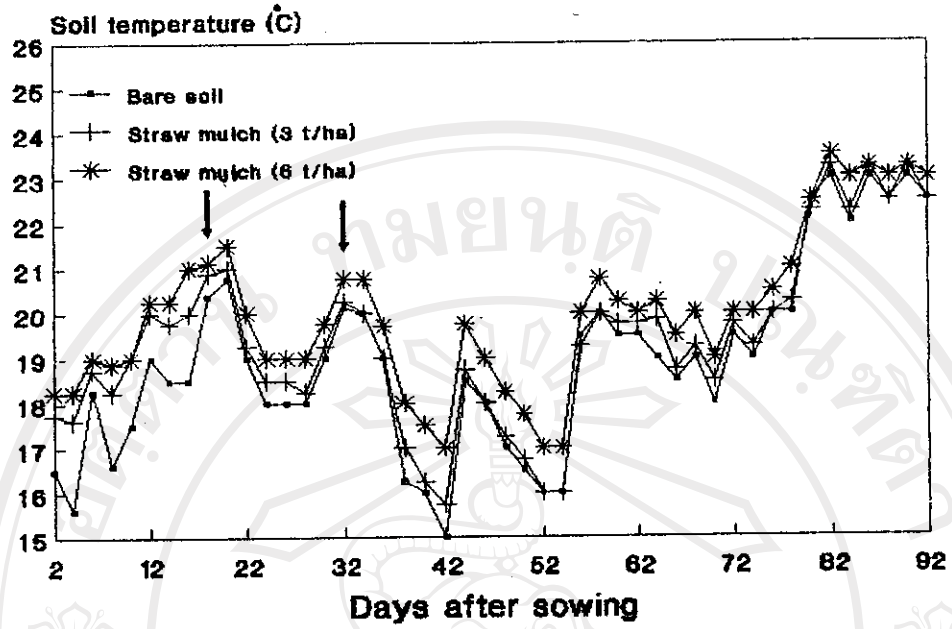


Figure 2b. Seasonal changes of 03:00 pm. soil temperature in different mulching treatments under full irrigated (a) and non-irrigated conditions (b) [arrows indicate irrigations]

(a) Early irrigation



(b) Late irrigation

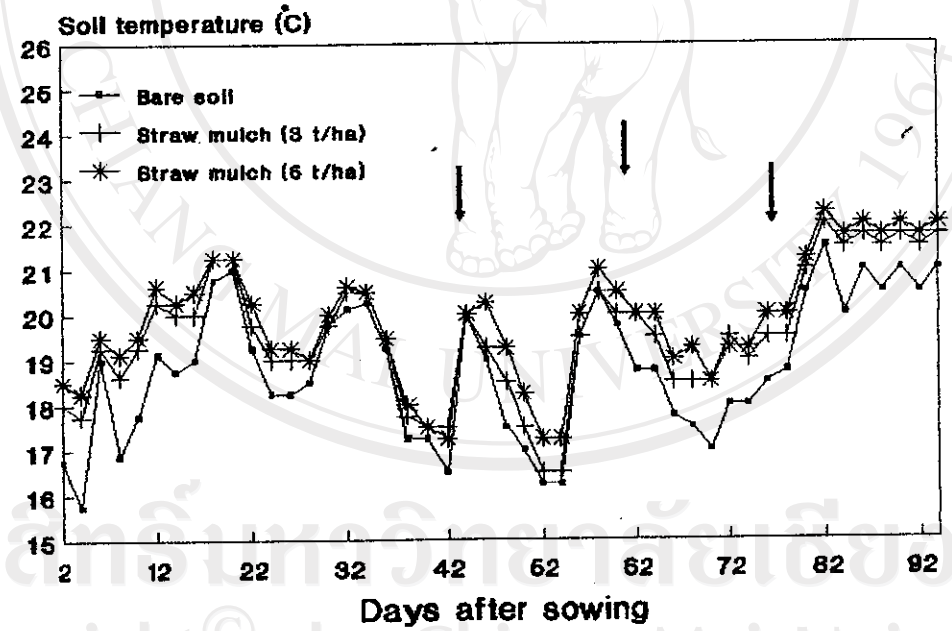
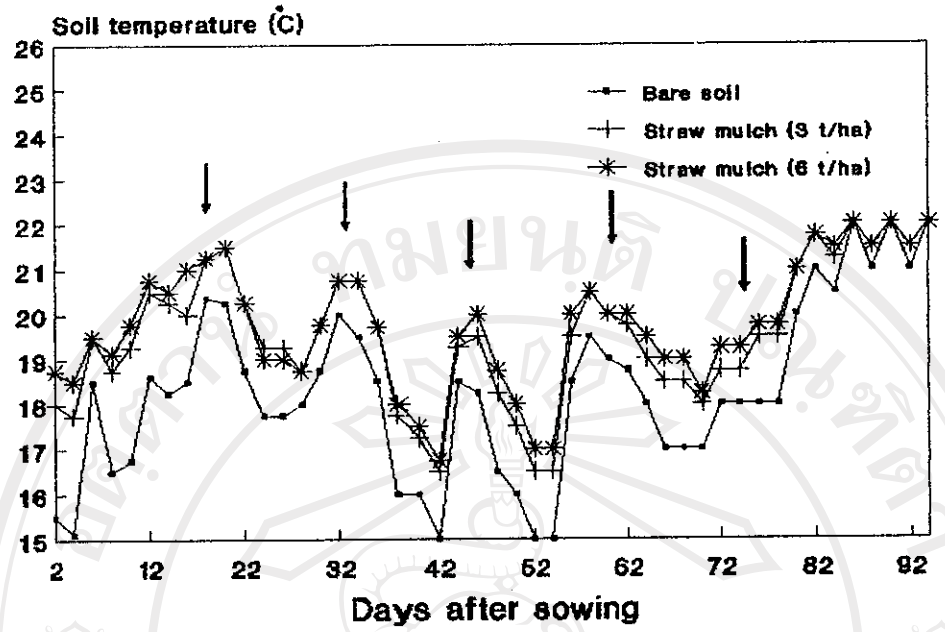


Figure 2c. Seasonal changes of 07:00 am. soil temperature in different mulching treatments under early irrigated (a) and late irrigated conditions (b) [arrows indicate irrigations]

(a) Full irrigation



(b) No irrigation

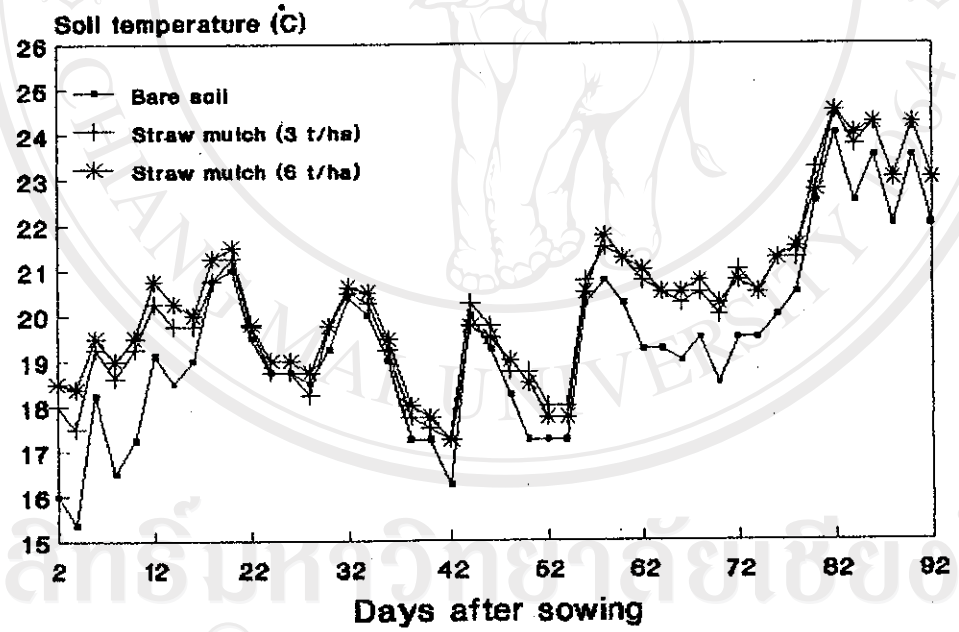


Figure 2d. Seasonal changes of 07:00 am. soil temperature in different mulching treatments under full irrigated (a) and non-irrigated conditions (b) [arrows indicate irrigations]

4.1.3 Average Soil Temperature

(a) At 03:00 pm.

Average soil temperature at 03:00 pm. throughout the crop growth period are presented in Table 2. Rice straw mulching caused a marked reduction in 03:00 pm. soil temperatures in early irrigated (1.2-2.6^{0}C), late irrigated (2.6-2.9^{0}C) and non-irrigated conditions (3.7-4.8^{0}C). In contrast, the reduction of 03:00 pm. soil temperature by rice straw mulching was relatively less (1^{0}C) in full irrigated condition. However, average 03:00 pm. soil temperature in all treatments were markedly lower than average air temperature during the same period (31.9^{0}C).

(b) At 07:00 am.

In contrast to soil temperature at 03:00 pm., soil temperature at 07:00 am. was slightly increased by straw mulching as compared to bare soil (0.5-1.2^{0}C in early irrigated, 0.9-1.3^{0}C in late irrigated, 1.3-1.6^{0}C in full irrigated and 1.0-1.5^{0}C in non-irrigated conditions). However, average soil temperature at 07:00 am. in all treatments were markedly higher than average air temperature during the same period (14.8^{0}C).

Table 2. Average soil temperature at 5 cm. depth during the wheat growth period

(a) At 03:00 pm.

Irrigation	Straw Mulch (t/ha)			Mean
	0	3	6	
Early Irrigation	26.9	25.7	24.3	25.6
Late Irrigation	27.4	24.8	24.5	25.6
Full Irrigation	24.8	23.8	23.8	24.1
No Irrigation	30.9	27.2	26.1	28.1
Mean	27.5	25.4	24.7	25.9

Average air temperature at 03:00 pm. during the same period was 31.9^{0}C

(b) At 07:00 am.

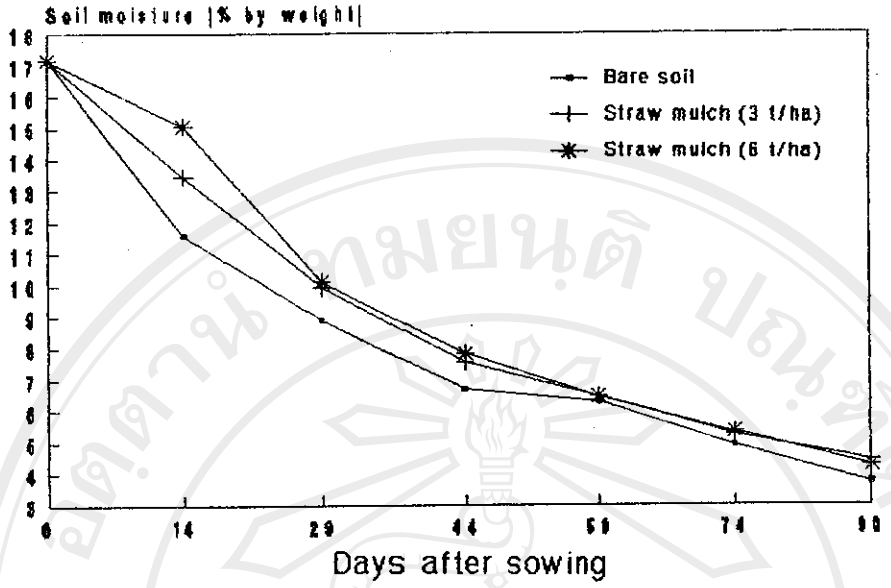
Irrigation	Straw Mulch (t/ha)			Mean
	0	3	6	
Early Irrigation	18.7	19.2	19.9	19.3
Late Irrigation	18.6	19.5	19.9	19.3
Full Irrigation	18.2	19.5	19.8	19.2
No Irrigation	18.9	19.9	20.4	19.7
Mean	18.6	19.5	20.0	19.4

Average air temperature at 07:00 am. during the same period was 14.8^{0}C

4.2 Soil Moisture

It was observed that soil moisture content before irrigation changes mostly in the top 25 cm. layer, particularly under non-irrigated treatment (Figures 3a, 3b, 3c and 3d). This is probably due to the higher root density of wheat in this layer as reported previously by Jongdee and Limpiti (1987). Though the changes pattern of soil moisture content were comparable among bare soil and straw mulched treatments, mulching with rice straw resulted in relatively higher soil moisture content as compared to bare soil.

(a) 0-25 cm. depth



(b) 25-50 cm. depth

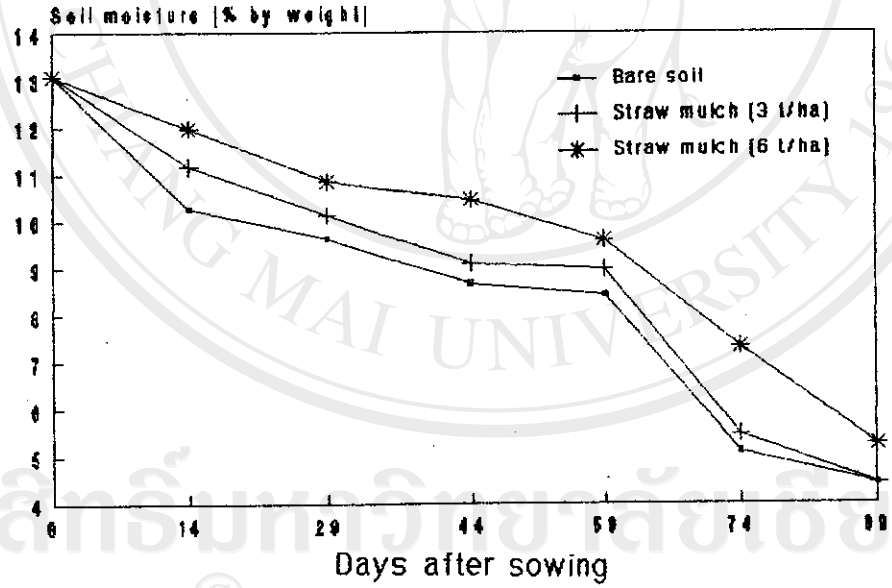
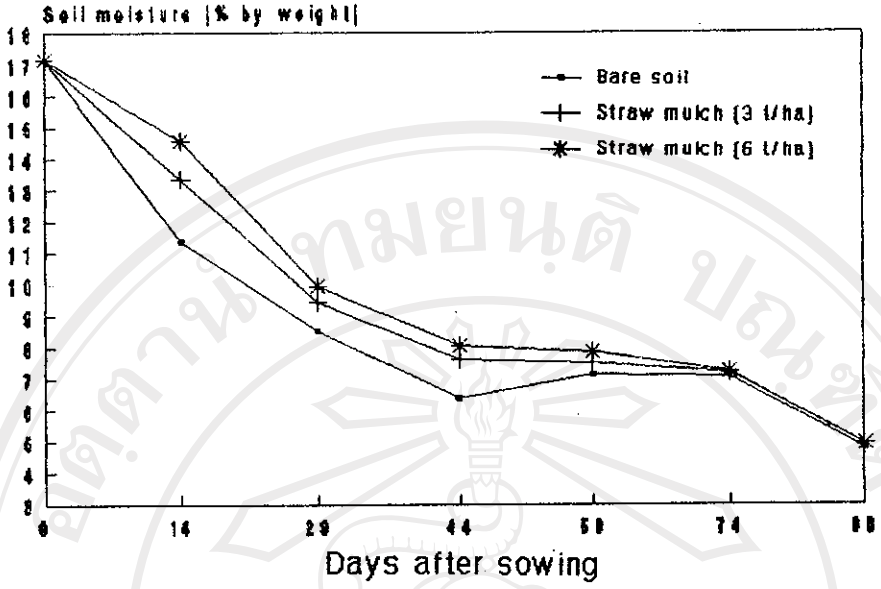


Figure 3a. Changes of soil moisture content at 0-25 cm.depth (a) and 25-50 cm.depth (b) in different mulching treatments under early irrigated condition

(a) 0-25 cm. depth



(b) 25-50 cm. depth

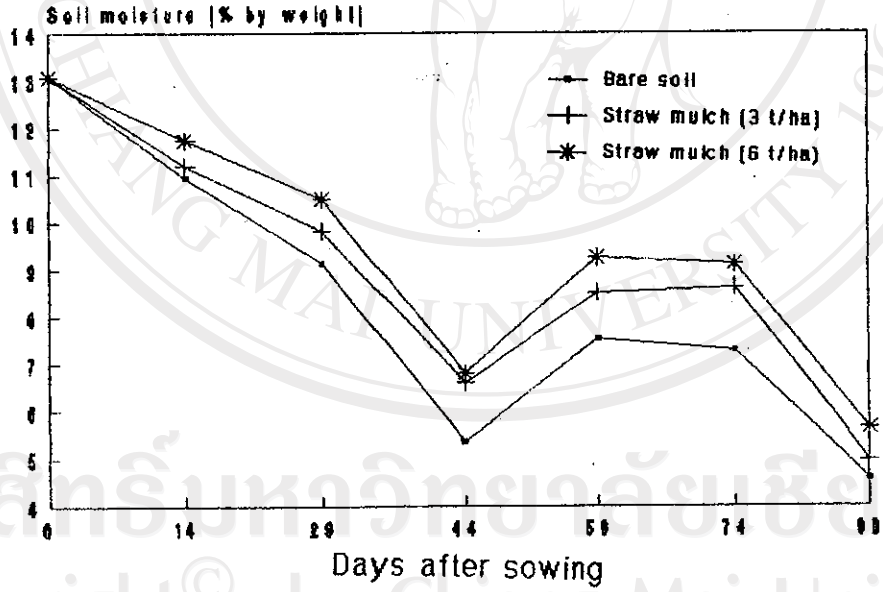
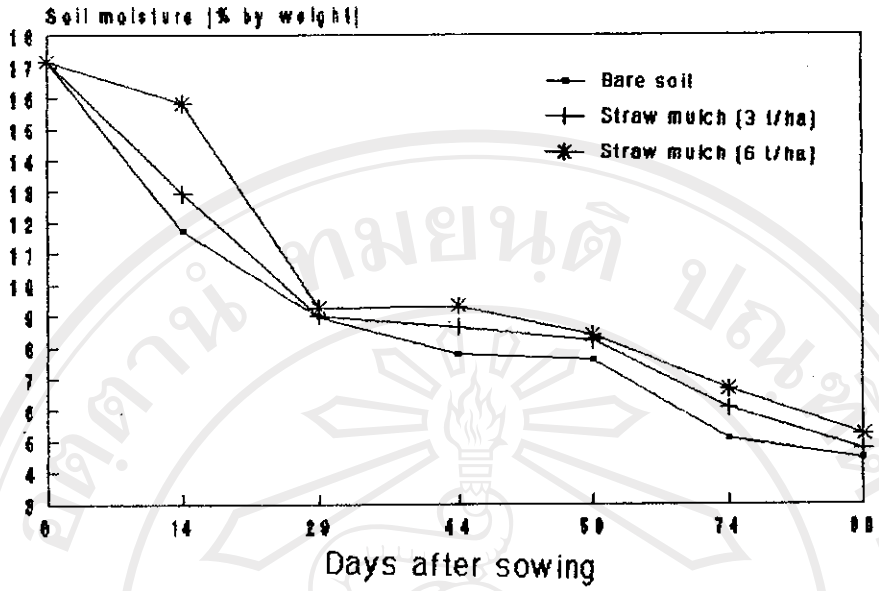


Figure 3b. Changes of soil moisture content at 0-25 cm.depth (a) and 25-50 cm.depth (b) in different mulching treatments under late irrigated condition

(a) 0-25 cm. depth



(b) 25-50 cm. depth

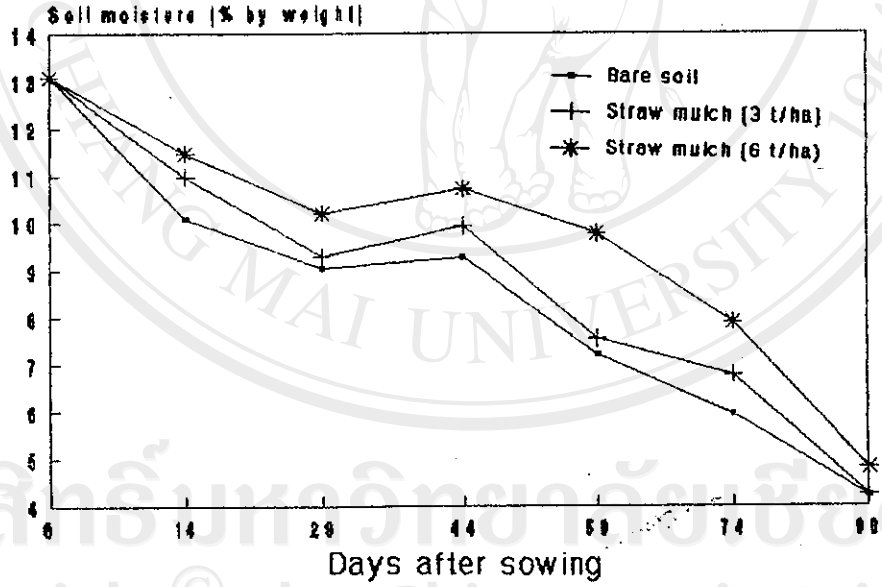
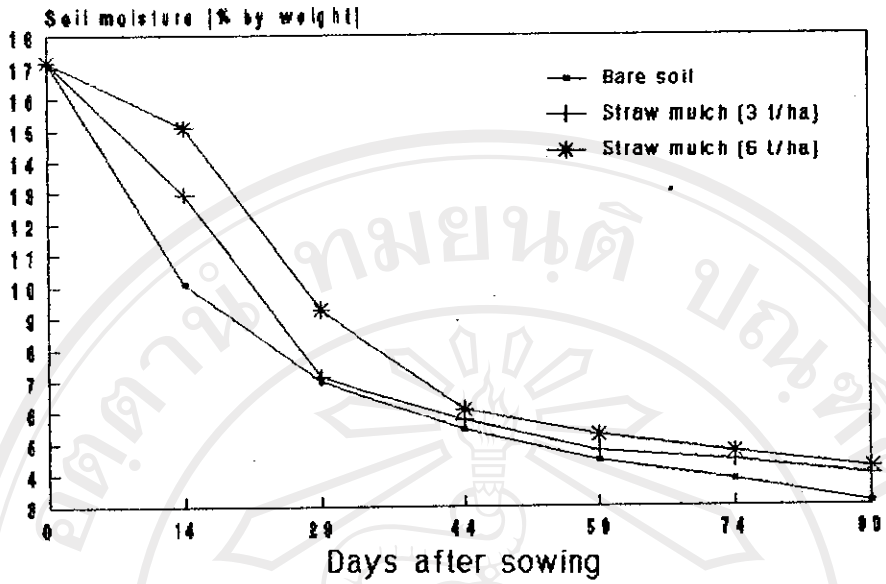


Figure 3c. Changes of soil moisture content at 0-25 cm.depth (a) and 25-50 cm.depth (b) in different mulching treatments under full irrigated condition

(a) 0-25 cm. depth



(b) 25-50 cm. depth

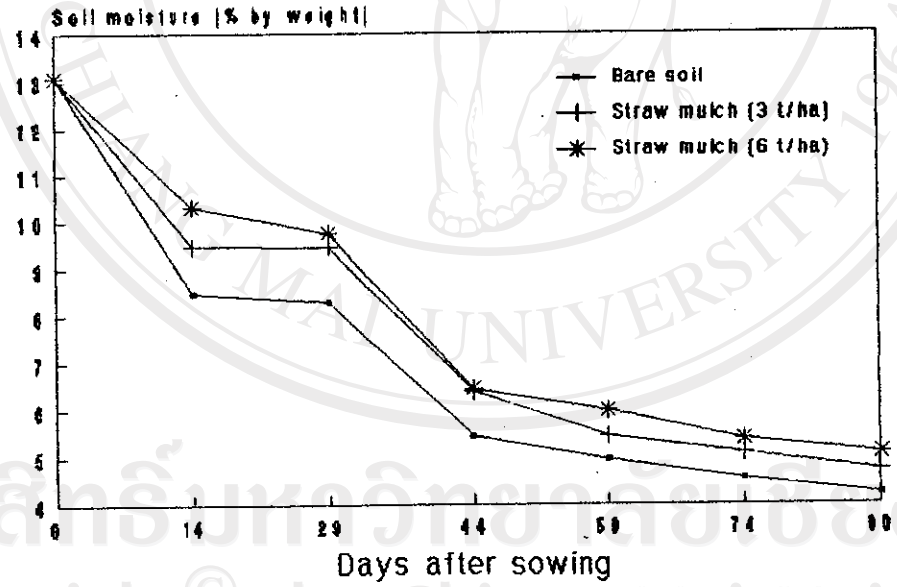


Figure 3d. Changes of soil moisture content at 0-25 cm.depth (a) and 25-50 cm.depth (b) in different mulching treatments under non-irrigated condition

4.3 Seedling Emergence, Tiller Number and Plant Height

Wheat emergence began at 4 days and was completed 7 days after sowing in all treatments. No significant differences were detected on wheat seedling number, giving an overall density of 273 plants/m^2 (Appendix Table 15). The optimum density in this environment was between 300-700 plants/m^2 (Jongkaewwattana and Rerkasem, 1982).

In case of tiller number, there were significant interactions between irrigation and mulching treatments. Mulching with rice straw increased tiller number of wheat by about 44-52% in late irrigated and about 54-97% in non-irrigated treatments (Table 3). No significant differences were found in early irrigated and full irrigated treatments.

For wheat plant height, the significant interactions between irrigation and mulching treatments were also detected. Mulching with rice straw increased plant height of wheat by about 15-17 cm. in late irrigated and about 11-12 cm.in non-irrigated treatments (Table 4). On the average, rice straw mulch increased wheat plant height by about 9 cm. over bare soil. No significant differences were found in early irrigated and full irrigated treatments.

Table 3. Effects of irrigation and mulching on tiller number of wheat (tillers/m^2) at 35 days after sowing

Mulching	Irrigation				Mean
	Early	Late	Full	None	
Bare soil	563	374	536	287	440
Straw (3 t/ha)	592	569	634	443	560
Straw (6 t/ha)	553	537	655	566	578
Mean	569	493	608	432	526

$LSD_{0.01}$ for irrigation (I) = 129.39 tillers/m^2
$LSD_{0.01}$ for mulching (M) = 88.19 tillers/m^2
$LSD_{0.05}$ for I x M = 130.16 tillers/m^2

Table 4. Effects of irrigation and mulching on plant height of wheat (cm.)

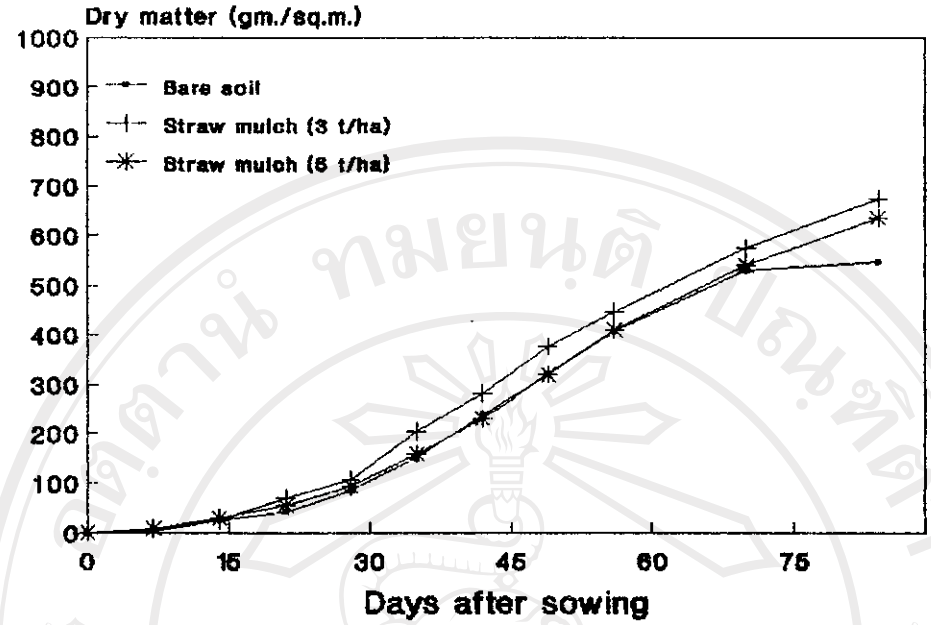
Mulching	Irrigation				Mean
	Early	Late	Full	None	
Bare soil	83.00	69.00	90.75	58.75	75.37
Straw (3 t/ha)	87.50	86.25	93.75	70.00	84.37
Straw (6 t/ha)	85.75	84.25	94.75	71.00	83.94
Mean	85.42	79.83	93.08	66.58	81.23

$LSD_{0.01}$ for irrigation (I) = 7.35 cm.
$LSD_{0.01}$ for mulching (M) = 3.74 cm.
$LSD_{0.01}$ for I x M = 7.49 cm.

4.4 Shoot Dry Matter

Shoot dry matter of wheat was significantly affected by mulching treatment throughout the crop growth period. Rice straw mulch increased shoot dry matter of wheat significantly as compared to bare soil (Figure 4a, 4b and Appendix Table 3,4). No significant effects of irrigation treatments were found during the period before booting (42 days after sowing). However, the significant effects were found from booting stage until maturity.

(a) Early irrigation



(b) Late irrigation

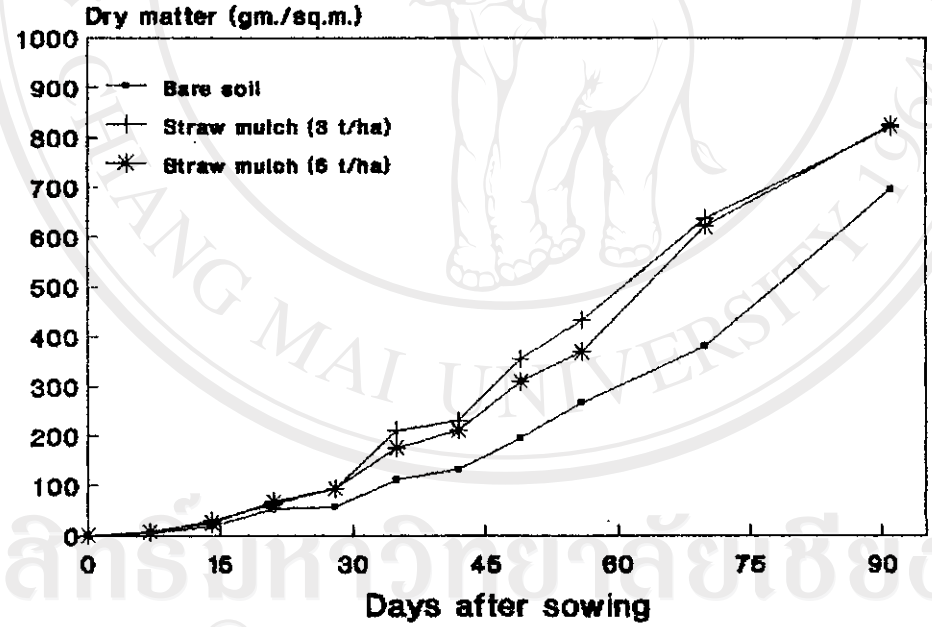
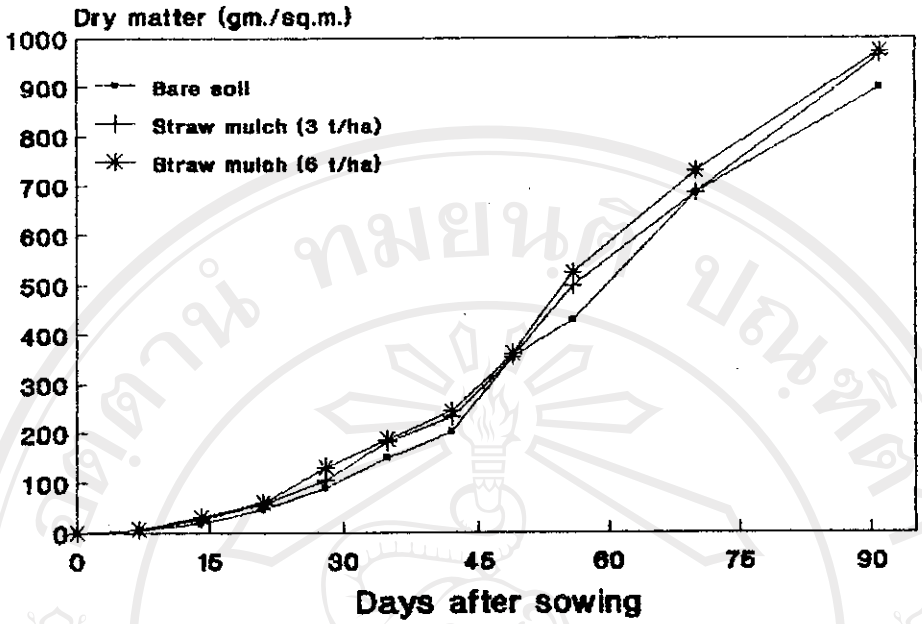


Figure 4a. Changes in total shoot dry matter of wheat at successive harvests in different mulching treatments under early irrigated (a) and late irrigated conditions (b)

(a) Full irrigation



(b) No irrigation

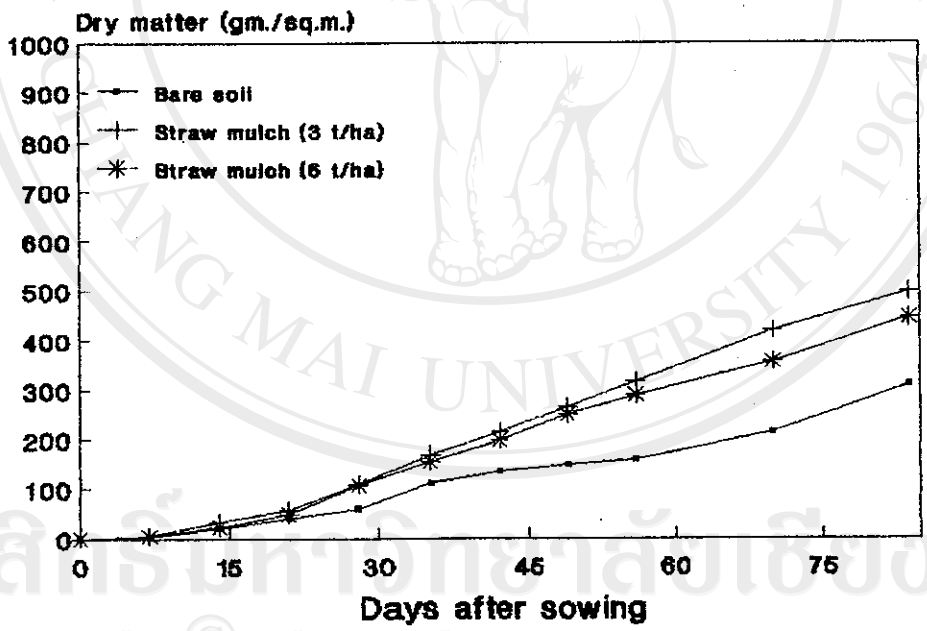


Figure 4b. Changes in total shoot dry matter of wheat at successive harvests in different mulching treatments under full irrigated (a) and non-irrigated conditions (b)

4.5 Nutrient Uptake

4.5.1 Nitrogen Uptake

Nitrogen uptake by wheat at 35 and 56 days after sowing were significantly increased by rice straw mulching (47-59% and 28-32% respectively) (Table 5, 6 and Appendix Table 5, 6, 7). No significant effects of irrigation treatments were found at 35 days after sowing. However, the significant effects were found at 56 days after sowing.

4.5.2 Phosphorus Uptake

Phosphorus uptake at 35 days and 56 days after sowing were also significantly increased by rice straw mulching (23-31% and 24-26% respectively) (Table 7, 8 and Appendix Table 5, 6, 7). No significant effects of irrigation treatments were found at 35 days after sowing but the significant effects were found at 56 days after sowing.

4.5.3 Potassium Uptake

Similar to nitrogen and phosphorus uptake, potassium uptake at 35 days and 56 days after sowing were significantly increased by straw mulching (57-66% and 42-53% respectively) (Table 9, 10 and Appendix Table 5, 6, 7). No significant effects of irrigation treatments were found at 35 days after sowing but the significant effects were found at 56 days after sowing.

Table 5. Effects of irrigation and mulching on nitrogen uptake (kg./ha) by wheat at 35 days after sowing

Mulching	Irrigation				Mean
	Early	Late	Full	None	
Bare soil	44.58	32.79	48.38	28.13	38.47
Straw (3 t/ha)	60.96	74.91	54.05	54.92	61.21
Straw (6 t/ha)	53.27	63.63	56.77	51.87	56.39
Mean	52.94	57.11	53.07	44.97	52.02

$LSD_{0.05}$ for irrigation (I) = NS
$LSD_{0.01}$ for mulching (M) = 9.42 kg./ha
$LSD_{0.05}$ for I x M = 9.16 kg./ha

Table 6. Effects of irrigation and mulching on nitrogen uptake (kg./ha) by wheat at 56 days after sowing

Mulching	Irrigation				Mean
	Early	Late	Full	None	
Bare soil	75.44	58.97	74.99	21.34	57.69
Straw (3 t/ha)	70.62	85.03	90.40	49.68	73.93
Straw (6 t/ha)	79.18	79.85	87.85	57.99	76.22
Mean	75.08	74.62	84.42	43.00	69.28

$LSD_{0.01}$ for irrigation (I) = 20.73 kg./ha
$LSD_{0.01}$ for mulching (M) = 16.69 kg./ha
$LSD_{0.05}$ for I x M = NS

Table 7. Effects of irrigation and mulching on phosphorus uptake (kg./ha) by wheat at 35 days after sowing

Mulching	Irrigation				Mean
	Early	Late	Full	None	
Bare soil	5.457	3.697	5.582	4.170	4.727
Straw (3 t/ha)	7.267	6.380	6.415	4.690	6.189
Straw (6 t/ha)	5.495	5.652	6.842	5.300	5.822
Mean	6.073	5.243	6.280	4.721	5.579

$LSD_{0.05}$ for irrigation (I) = NS
$LSD_{0.05}$ for mulching (M) = 1.26 kg./ha
$LSD_{0.05}$ for I x M = NS

Table 8. Effects of irrigation and mulching on phosphorus uptake (kg./ha) by wheat at 56 days after sowing

Mulching	Irrigation				Mean
	Early	Late	Full	None	
Bare soil	8.327	6.557	9.245	4.770	7.224
Straw (3 t/ha)	9.632	9.045	12.50	4.777	8.988
Straw (6 t/ha)	8.220	8.297	13.12	6.592	9.057
Mean	8.742	7.967	11.62	4.771	8.423

$LSD_{0.01}$ for irrigation (I) = 2.72 kg./ha
$LSD_{0.01}$ for mulching (M) = 1.73 kg./ha
$LSD_{0.05}$ for I x M = NS

Table 9. Effects of irrigation and mulching on potassium uptake (kg./ha) by wheat at 35 days after sowing

Mulching	Irrigation				Mean
	Early	Late	Full	None	
Bare soil	66.44	45.93	70.83	42.93	56.53
Straw (3 t/ha)	106.80	77.49	97.10	75.05	94.12
Straw (6 t/ha)	88.55	82.38	109.80	75.15	88.97
Mean	87.27	75.27	92.57	64.38	79.87

$LSD_{0.05}$ for irrigation (I) = NS
$LSD_{0.01}$ for mulching (M) = 19.37 kg./ha
$LSD_{0.05}$ for I x M = NS

Table 10. Effects of irrigation and mulching on potassium uptake (kg./ha) by wheat at 56 days after sowing

Mulching	Irrigation				Mean
	Early	Late	Full	None	
Bare soil	112.2	64.00	114.2	32.76	80.77
Straw (3 t/ha)	153.6	125.70	157.9	57.63	123.71
Straw (6 t/ha)	135.3	97.59	163.2	63.11	114.80
Mean	133.7	95.75	145.1	51.17	106.42

$LSD_{0.01}$ for irrigation (I) = 89.04 kg./ha
$LSD_{0.01}$ for mulching (M) = 27.89 kg./ha
$LSD_{0.05}$ for I x M = NS

4.6 Anthesis, Maturity and Grain Filling Period

Regardless of irrigation treatments, mulching with rice straw tended to prolong days to anthesis (by 2-3 days), days to maturity (by 2-9 days) as well as grain filling period (by 1-6 days) in wheat as compared to bare soil (Appendix Table 8). Among irrigation treatments, no irrigation hastened maturity (by 8-10 days) and shortened grain filling period (by 5-7 days) as compared to full irrigation.

4.7 Yield and Yield Components

4.7.1 Grain Yield

Analysis of variance of wheat grain yields indicated a significant interactions between irrigation and mulching treatments. Rice straw mulching increased wheat grain yield by about 42-56% in late irrigated and about 75-76% in non-irrigated treatments (Table 11). On the average, rice straw mulch increased wheat grain yield by about 21-28%. No significant differences were found in early irrigated and full irrigated treatments.

4.7.2 Spike Number/m^2

Spike number/m^2 was significantly effected by irrigation and mulching treatments. No significant interactions between irrigation and mulching were detected. Mulching the soil with rice straw resulted in 319-338 spikes/m^2 as compared to 266 spikes/m^2 from bare soil (Table 12).

Table 11. Effects of irrigation and mulching on grain yields (kg/ha) of wheat

Mulching	Irrigation				Mean
	Early	Late	Full	None	
Bare soil	2086	2511	3579	809	2246
Straw (3 t/ha)	2427	3905	3784	1415	2883
Straw (6 t/ha)	1978	3571	3865	1420	2708
Mean	2163	3329	3743	1215	2612

$LSD_{0.01}$ for irrigation (I) = 733.15 kg/ha
$LSD_{0.01}$ for mulching (M) = 342.11 kg/ha
$LSD_{0.01}$ for I x M = 684.24 kg/ha

Table 12. Effects of irrigation and mulching on spike number/m^2 in wheat

Mulching	Irrigation				Mean
	Early	Late	Full	None	
Bare soil	321.5	225.9	334.7	183.5	266.4
Straw (3 t/ha)	342.0	375.2	367.4	265.2	337.5
Straw (6 t/ha)	320.0	338.2	369.5	248.7	319.1
Mean	327.8	313.1	357.2	232.5	307.7

$LSD_{0.01}$ for irrigation (I) = 77.38 spikes/m^2
$LSD_{0.05}$ for mulching (M) = 27.46 spikes/m^2
$LSD_{0.05}$ for I x M = NS

4.7.3 Grain Number/Spike

Irrigation and mulching significantly influenced grain number/spike in wheat. It was also found that there were significant interactions between irrigation and mulching treatments. Rice straw mulching increased grain number/spike in wheat by about 12-14 grains in late irrigated and about 3-6 grains in non-irrigated treatments (Table 13). No significant differences were found in early irrigated and full irrigated treatments.

Table 13. Effects of irrigation and mulching on grain number/spike in wheat

Mulching	Irrigation				Mean
	Early	Late	Full	None	
Bare soil	23.75	23.75	35.00	18.25	25.19
Straw (3 t/ha)	28.25	37.25	33.25	21.25	30.00
Straw (6 t/ha)	24.00	35.75	36.25	23.75	29.94
Mean	25.33	32.25	34.83	21.08	28.38

$LSD_{0.01}$ for irrigation (I) = 8.74 grains/spike
$LSD_{0.01}$ for mulching (M) = 2.27 grains/spike
$LSD_{0.01}$ for I x M = 4.53 grains/spike

4.7.4 Thousand Grain Weight

Thousand grain weight was significantly difference among mulching treatments. In contrast to other yield components, 1,000-grain weight was significantly decreased by straw mulching as compared to bare soil (Appendix Table 16).