Chapter 4

Results

During the study (July 4 to October 10, 1989), 653 mm of rain fell. This represented 56% of the total annual rainfall. The temperature was high and stable (Figure 2).

4.1 Plant growth

There was no significant effect of SSC on final shoot dry matter accumulation, although the dry matter in SSC was slightly lower at early stages and marginally higher at later stages than under CI (Figure 3). Generally, dry matter in SJ5 treatments was higher than that in NW1 but there was no interaction between variety and water or between starter nitrogen and water although NW1 showed more effects by SSC (Figure 4 and Appendix B, Table B-1-1 and B-1-2).

The profiles of dry matter accumulation in all treatments followed S-shape. The least squre polynomial regressed equations are well fitted as shown in Table 1.

4.2 Changes of plant nitrogen status

During early growth SSC decreased plant nitrogen concentrations, while starter nitrogen tended to increased it (Figure 5). A level of 3.3-3.4% N was detected in the SSC treatment without nitrogen fertilizer amendment compared with 3.7-3.8% N in CI 8 days after water was raised (Table 2).

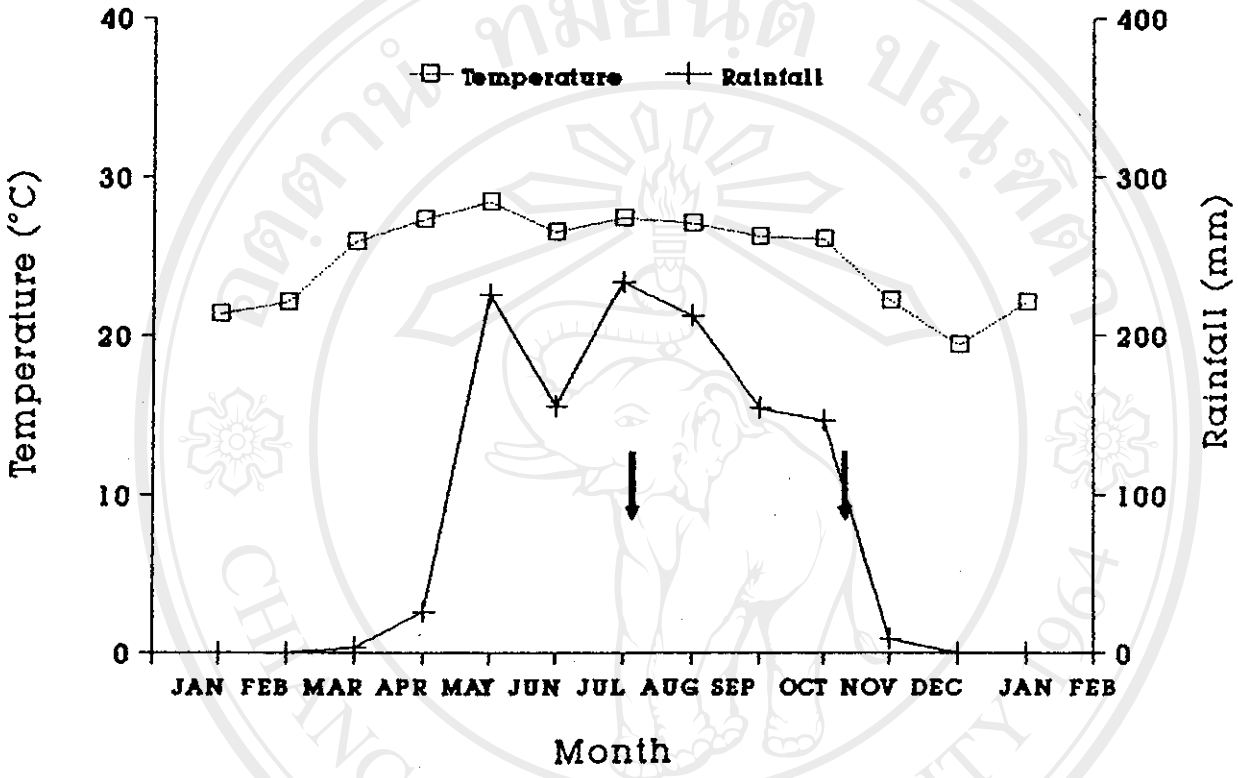

Figure 2. Monthly rainfall(mm) and mean temperature (°C) recorded in the experimental station of the Multiple Cropping Center in 1989. Arrows indicate the date of soybean sowing and harvesting.

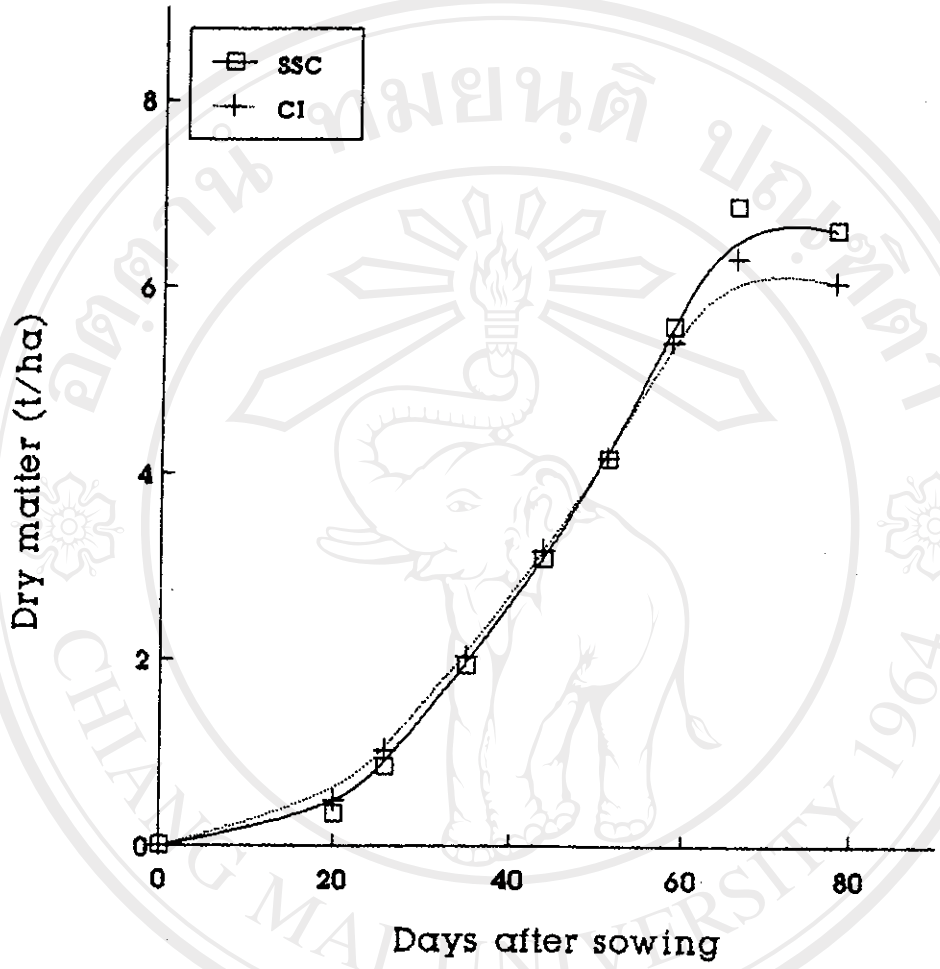

Figure 3. Effects of water regimes on the seasonal profile of shoot dry matter (t/ha) averaged over varieties and starter nitrogen treatments.

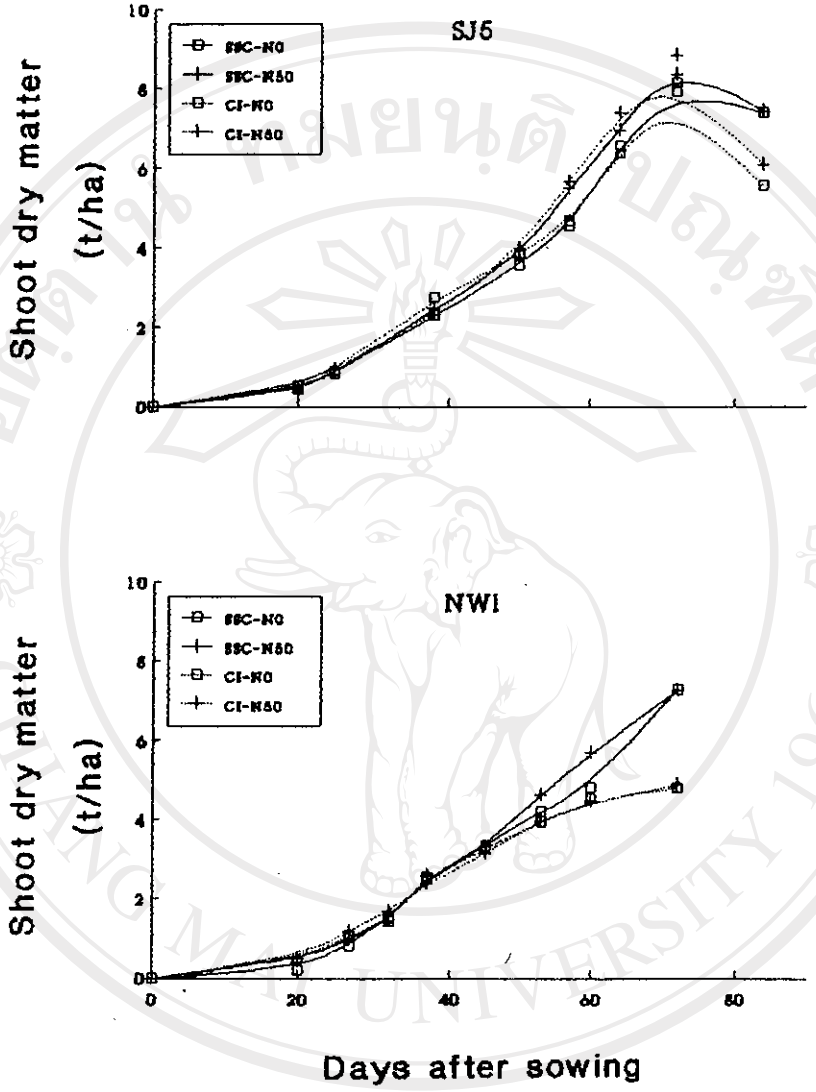

Figure 4. Effects of water regimes and starter nitrogen on the accumulation of dry matter (t/ha) by SJ5 and NW1.

Table 1 Least square polynomial regressions of total plant dry matter accumulation, Y (kg/ha) on days after sowing, X (days) for 8 treatments.

Treatment	Regression equation	R^2
SSC-SJ5-N0	$Y= 6.1180 - 3.7222X + 1.3424X^2 + 0.00389X^3$	0.99^{**}
SSC-SJ5-N50	$Y= - 52.169 - 6.5689X + 1.6455X^2 + 0.00239X^3$	1.00^{**}
CI-SJ5-N0	$Y= - 18.129 + 1.1170X + 1.6372X^2 - 0.0018BX^3$	0.99^{**}
CI-SJ5-N50	$Y= - 82.885 - 4.7497X + 1.9037X^2 - 0.00189X^3$	0.99^{**}
SSC-NW1-N0	$Y= - 72.003 - 24.210X + 2.7561X^2 - 0.01441X^3$	0.98^{**}
SSC-NW1-N50	$Y= 0.3652 - 50.692X + 4.0130X^2 - 0.02651X^3$	1.00^{**}
CI-NW1-N0	$Y= - 8.7135 - 53.259X + 4.6110X^2 - 0.04095X^3$	0.99^{**}
CI-NW1-N50	$Y= - 12.325 - 36.607X + 3.9376X^2 - 0.04552X^3$	1.00^{**}

** indicates statistically significant, $P<0.01$

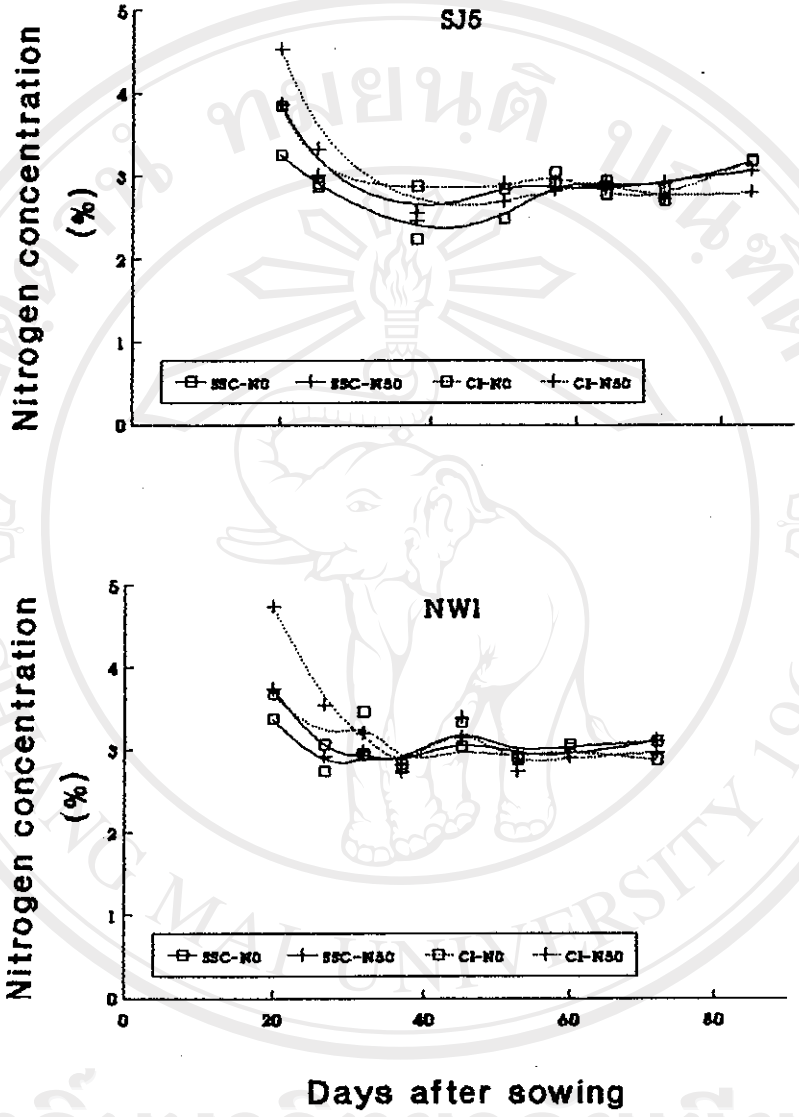

Figure 5. Effects of water regimes and starter nitrogen on shoot nitrogen concentration (%) by SJ5 and NW1.

Table 2 Effects of moisture and starter nitrogen on shoot nitrogen concentration (%) by SJ5 and NW1 at V4

Factors	SJ5		NW1	
	SSC	CI	SSC	CI
N0	3.26	3.84	3.38	3.68
N50	3.87	4.53	3.74	4.74

At V4 the application of 50 kg N/ha eliminated the SSC effect on plant nitrogen status. The nitrogen concentrations of the soybean shoot was increased in both SSC and CI treatments by 11-19% and 18-29%, respectively. However, these effects of fertilizer treatment on plant nitrogen disappeared 1-2 weeks later (Figure 5 and Appendix B, Table B-2-1 and B-2-2).

The difference in plant nitrogen status was reflected in the leaf color. Yellowing of leaves was observed in SSC 7 days after the treatment was imposed, and lasted for about 7 days, while with starter nitrogen, yellowing under SSC was less pronounced and was not as prolonged.

4.3 Plant total nitrogen

The seasonal profile of total shoot nitrogen content resembled that of shoot dry matter accumulation (Figure 6). At early stages, significant reductions of shoot nitrogen were observed under SSC. The lowest nitrogen accumulation at V4 and V6 occurred in the SSC treatment without starter nitrogen, and the highest in CI with the application fertilizer. No differences were detected after R1 (Figure 7 and Appendix B, Table B-3-1 and B-3-2). No interactions of variety and starter nitrogen with SSC were detected.

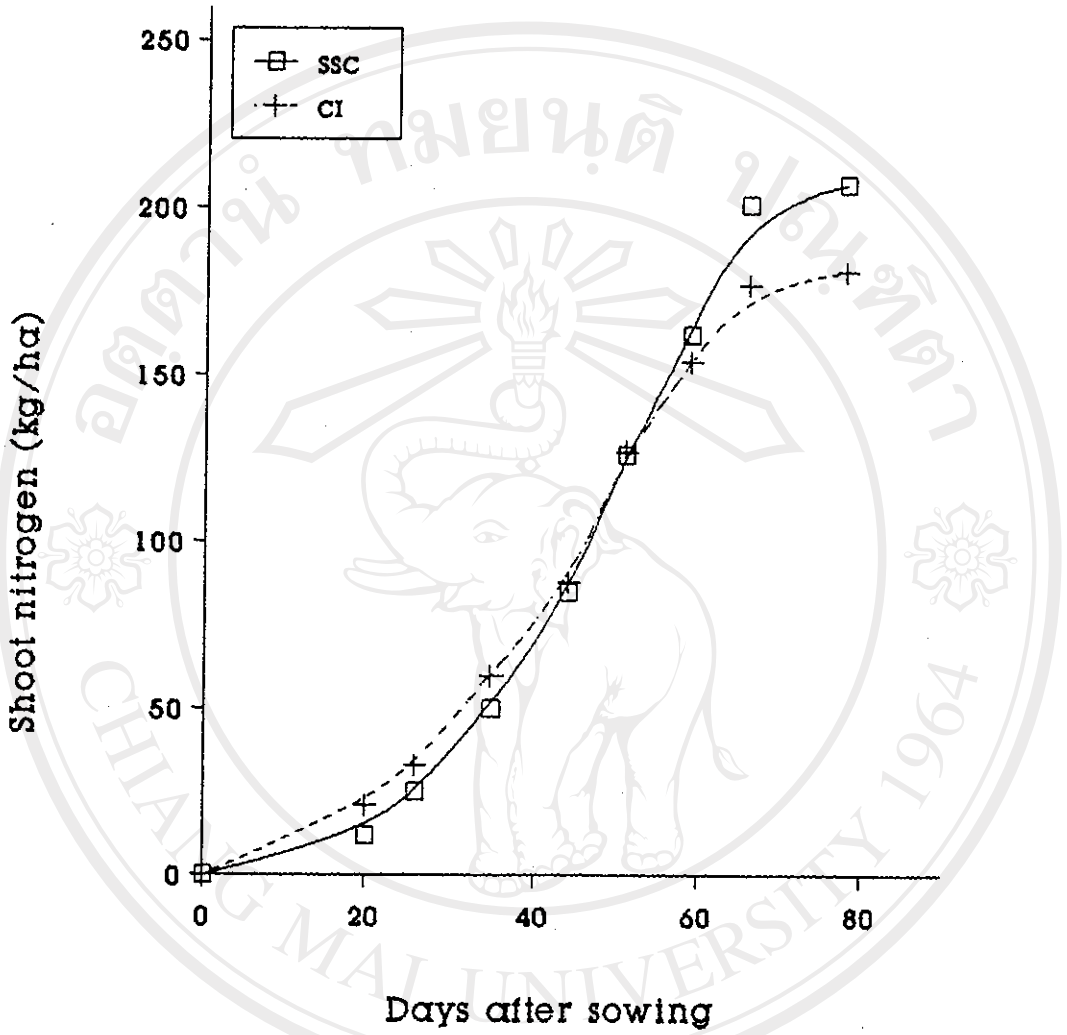

Figure 6. Effects of water regimes on the seasonal profile of total shoot nitrogen (kg/ha) averaged over varieties and starter nitrogen treatments.

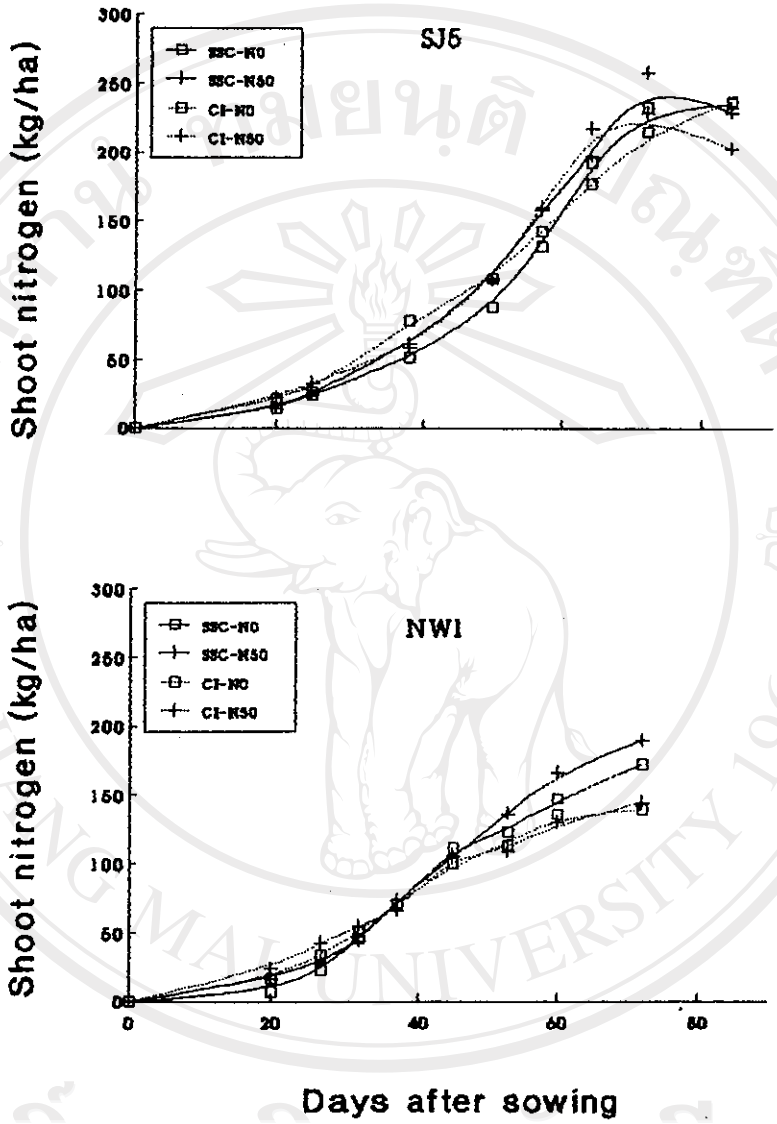

Figure 7. Effects of water regimes and starter nitrogen on shoot total nitrogen content (kg/ha) by SJ5 and NW1.

The rate of shoot nitrogen accretion reflected the status of plant development. As in the total nitrogen profile, the rate of nitrogen accumulation in SSC was less than that in CI during the first 8 days after water initiation, but was higher after the R1 stage when plant had acclimatized to the saturated soil conditions. Starter nitrogen only temporarily increased the rate of nitrogen accretion at early stages (Figure 8).

4.4 Root growth and nodule distribution

In this study, the soybean plant was found to adjust its rooting pattern to the high water table through a prolification of lateral root growth. After taproot development was stunted by flood water, the roots were laterally invading the saturated soil within two weeks of the imposition of water. Instead of exploring downward and outward as in the CI treatment, the lateral roots in SSC were concentrated horizontally above the water table. At flowering, abundant surface roots were observed in SSC. Although some roots were also found under the water table after flowering, the majority of roots were in a dense mat layer in the top 10 cm of soil.

The nodules also gathered in the top 10 cm soil layer in a limited zone of saturated soil immediately above the water table. Nodules on the taproot were also more concentrated in SSC in the upper root zone than that in CI. After flowering many nodules were even observed on the surface of the soil.

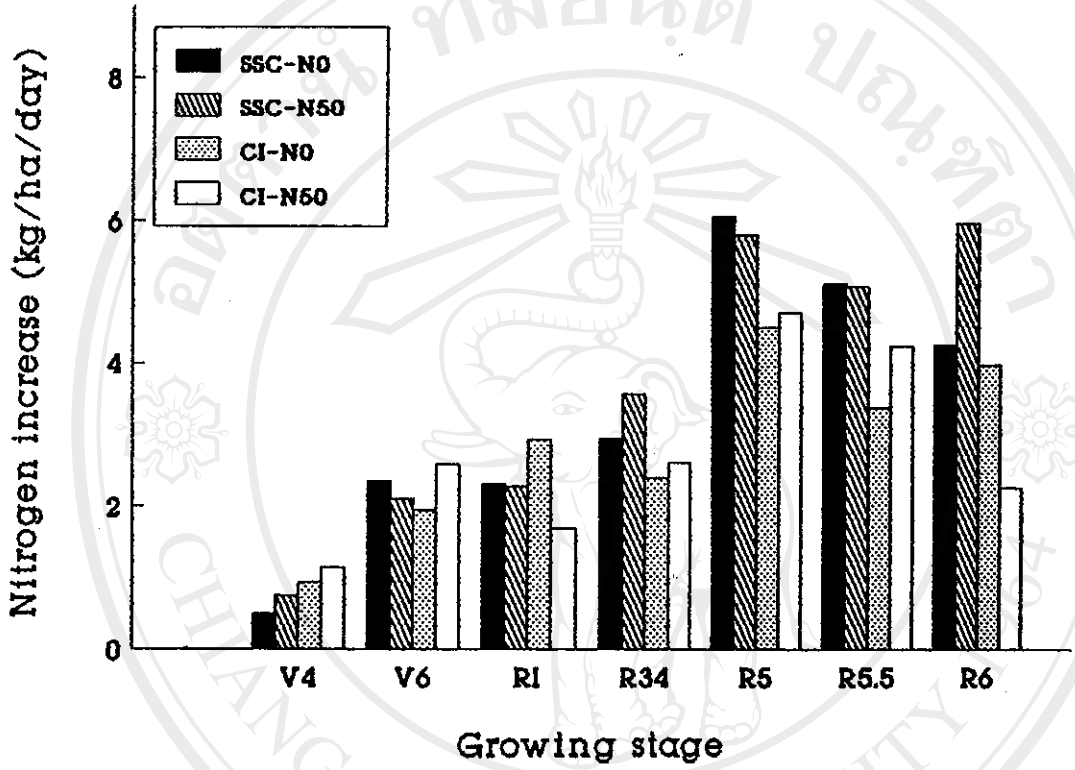

Figure 8. Effects of water regimes and starter nitrogen on the rate of shoot nitrogen accretion (kg/ha/day) averaged over varieties.

4.5 Nodulation

Low levels of nitrogen in the plant shoot was accompanied by a more prolific nodulation, while high plant nitrogen levels were related to poor nodule growth. The nodule dry weight of SJ5 at the V4 stage of growth in SSC was about 4 to 6 times greater than that in CI, and in NW1 it was 2 to 5 times higher than under CI (Table 3). Starter nitrogen treatments depressed nodulation. With 50 kg N/ha fertilizer, nodule dry weight in SSC was decreased by 14% in SJ5 and 34% in NW1. Nodule number of SJ5 under SSC was about 70% higher than that in CI and that of NW1 was 56% higher. The depression of nodule number by 50 kg N/ha was also significant at the early V4 stage (Table 3). The effects of SSC on nodule weight and number continued throughout the growing season (Figure 9a, 9b). The inhibitory effects of nitrogen fertilizer on the other hand disappeared with time (Figure 10 and Figure 11). For example, nodule dry weight per plant during seed-fill (R5) in SSC was 0.4-0.6 grams and that in CI was 0.2-0.3 grams. Nodule number also was higher (86 to 125 nodules per plant) in SSC, compared with CI (38 to 62 nodules per plant in Table 3). In contrat to this, the effects from starter nitrogen was no longer obvious throughout most of reproductive development (Appendix B, Talbe B-4-1 and B-4-2, Table B-5-1 and B-5-2).

Table 3 Effects of moisture and starter nitrogen on nodulation of SJ5 and NW1 soybean in vegetative growth and during bean filling

Water regime	Starter nitrogen	Early vegetative (V4)		Bean filling (R5)	
		SJ5	NW1	SJ5	NW1
		Nodule dry weight (g/plant)			
SSC	N0	0.0632	0.0723	0.4871	0.4243
	N50	0.0597	0.0567	0.5855	0.4034
CI	N0	0.0153	0.0320	0.2260	0.2301
	N50	0.0077	0.0123	0.2817	0.1666
		Nodule number (nodules/plant)			
SSC	N0	38	47	86	125
	N50	33	39	106	100
CI	N0	23	30	38	62
	N50	19	25	61	54

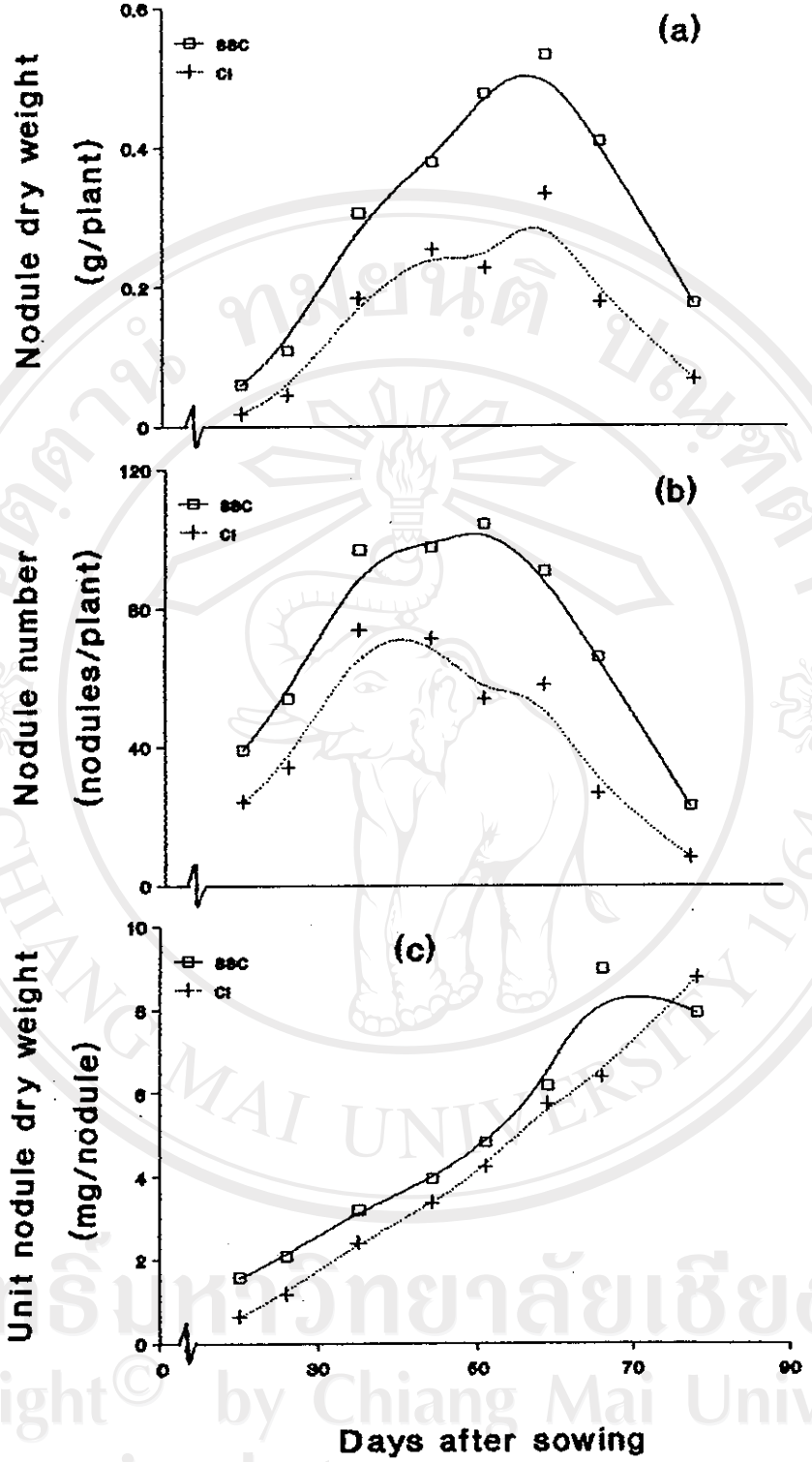

Figure 9. Effects of water regimes on nodule dry weight (a), number (b) and unit weight (c) averaged over starter nitrogen treatments and varieties.

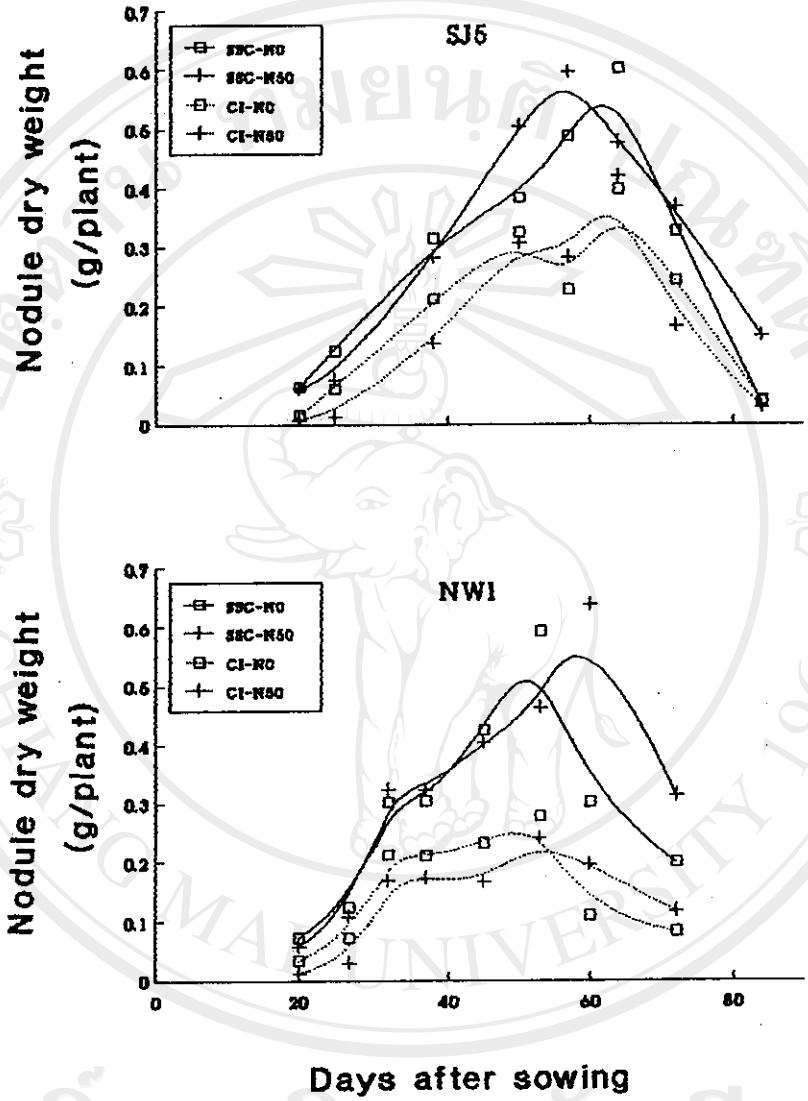

Figure 10. Effects of water regimes and starter nitrogen on nodule dry weight (g/plant) by SJ5 and NW1.

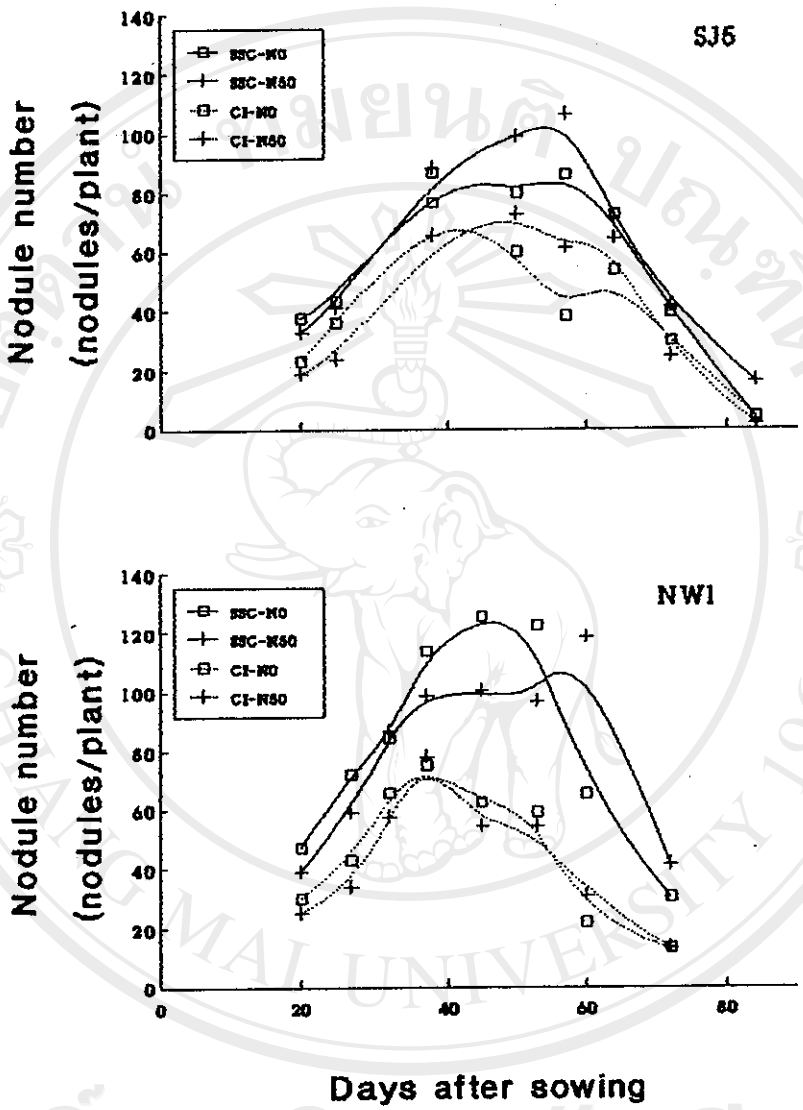

Figure 11. Effects of water regimes and starter nitrogen on nodule number (nodules/plant) by SJ5 and NW1.

SSC increased unit nodule weight throughout the growing season except R7 (Figure 9c). SJ5 had higher individual nodule weights than NW1, and starter nitrogen depressed unit nodule weight before flowering (Appendix B, Table B-6-1 and B-6-2).

4.6 Nitrogen fixation using the ureide method

In the study, the reliance of plant growth on nodule activity was determined by measuring the relative ureide contents of soybean xylem sap. Generally, the prolific nodulation resulted in high levels of relative ureide and in turn indicated high dependence on fixed nitrogen (Table 4). The coefficient of the simple correlation between nodule dry weight and the proportion of nitrogen fixed was as high as 0.89 ($P<0.01$).

4.6.1 Relative ureide

Results showed that xylem relative ureide in SSC was consistently and substantially higher than that in CI for both soybean varieties (Figure 12 and Appendix B, Table B-7-1 and B-7-2). In SJ5 soybean, for example, relative ureide at V6 in SSC without starter nitrogen was 46% compared with 30% in CI and that in NW1 was 39%, 50% higher than that in CI. The continuous increase of relative ureide under SSC over CI was further shown by averaging other two factors (Figure 13).

Table 4 Coefficient of determination (r^*) between trials based on grant means

	N-fixed	Shoot-DM	Shoot-NC	N-Pfixed	Total-N	Nodule-DW
N-fixed	1.00					
Shoot-DM	0.61	1.00				
Shoot-NC	-0.28	-0.50	1.00			
N-Pfixed	0.87	0.24	-0.31	1.00		
Total-N	0.71	0.90	-0.17	0.28	1.00	
Nodule-DW	0.94	0.64	-0.48	0.89	0.60	1.00

* $r_{0.01}$ = 0.87, $r_{0.05}$ = 0.75 (Gomez et al, 1984)

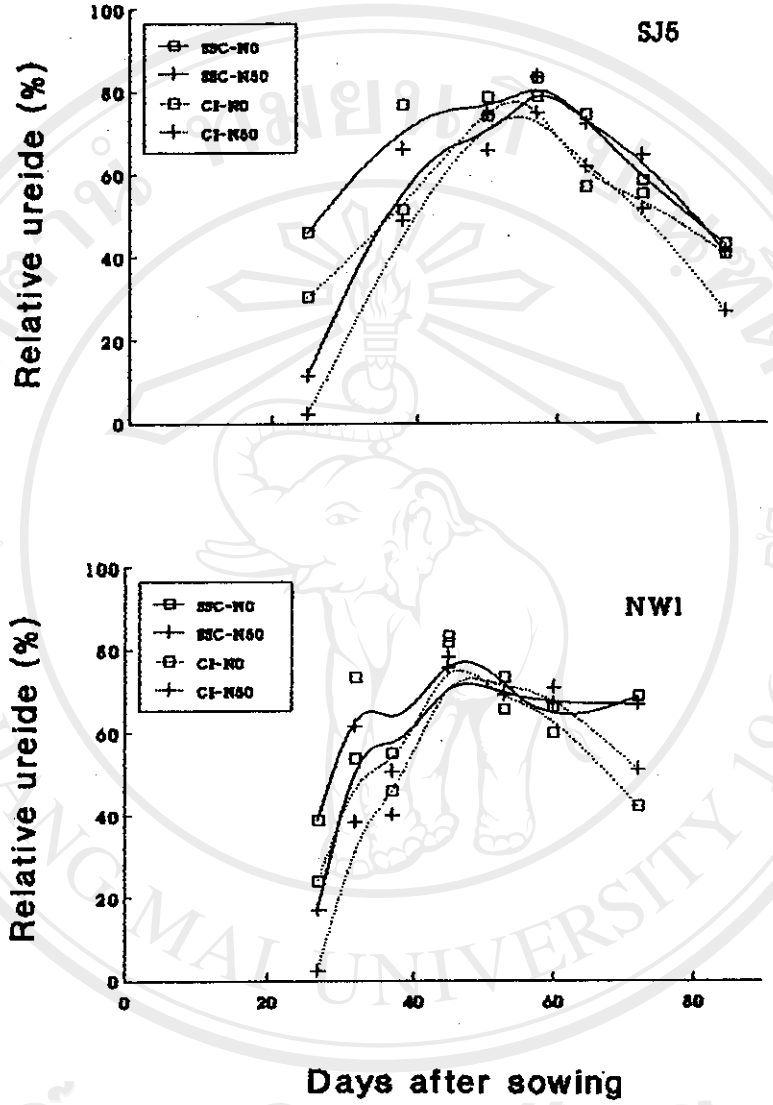

Figure 12. Effects of water regimes and starter nitrogen on relative ureide (%) by SJ5 and NW1.

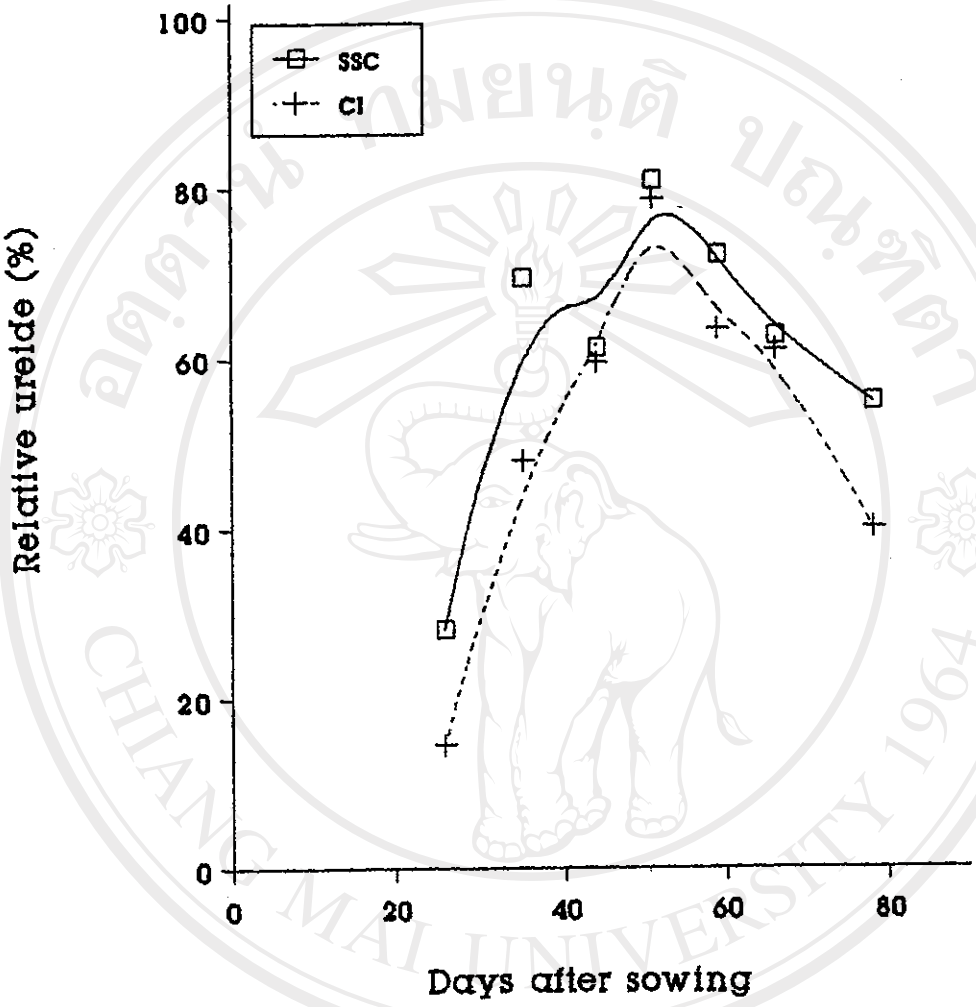

Figure 13. Effects of water regimes on relative ureide (%) averaged over starter nitrogen treatments and varieties.

An application of fertilizer nitrogen reduced plant relative ureide before pod setting but the effects were disappeared later. However, neither starter nitrogen or variety showed any effects on the response to SSC (Appendix B, Table B-7-1 and B-7-2).

4.6.2 Proportions of nitrogen fixation

Proportions of nitrogen fixed represent the estimates of the extent of plant nitrogen accumulated between harvests that is derived from symbiotic fixation. In this study, SSC caused an earlier onset and later decline in nitrogen fixation, and a maintenance of a higher level of symbiosis throughout the growing season for both soybean lines (Figure 14, 15). The seasonal pattern of symbiotic dependence indicated that the proportion of nitrogen fixed rapidly increased from V6 to R1, and was maintained at high levels (at about 70%) until the late seed-filling (R6, Figure 14). At all stages, reliance on nitrogen fixation was higher under SSC than in CI.

Applications of 50 kg N/ha greatly reduced soybean nitrogen fixation within 2 weeks of flooding. The proportion of nitrogen fixed then remained somewhat lower than in unamended plots until the beginning of bean setting. The SJ5 line tended to have a higher reliance on nitrogen fixation than NW1 before pod setting stage, but lower after that stage (Table 16). There was no significant interaction between variety and irrigation treatment (Figure 17 and Appendix B, Table B-8-1 and B-8-2).

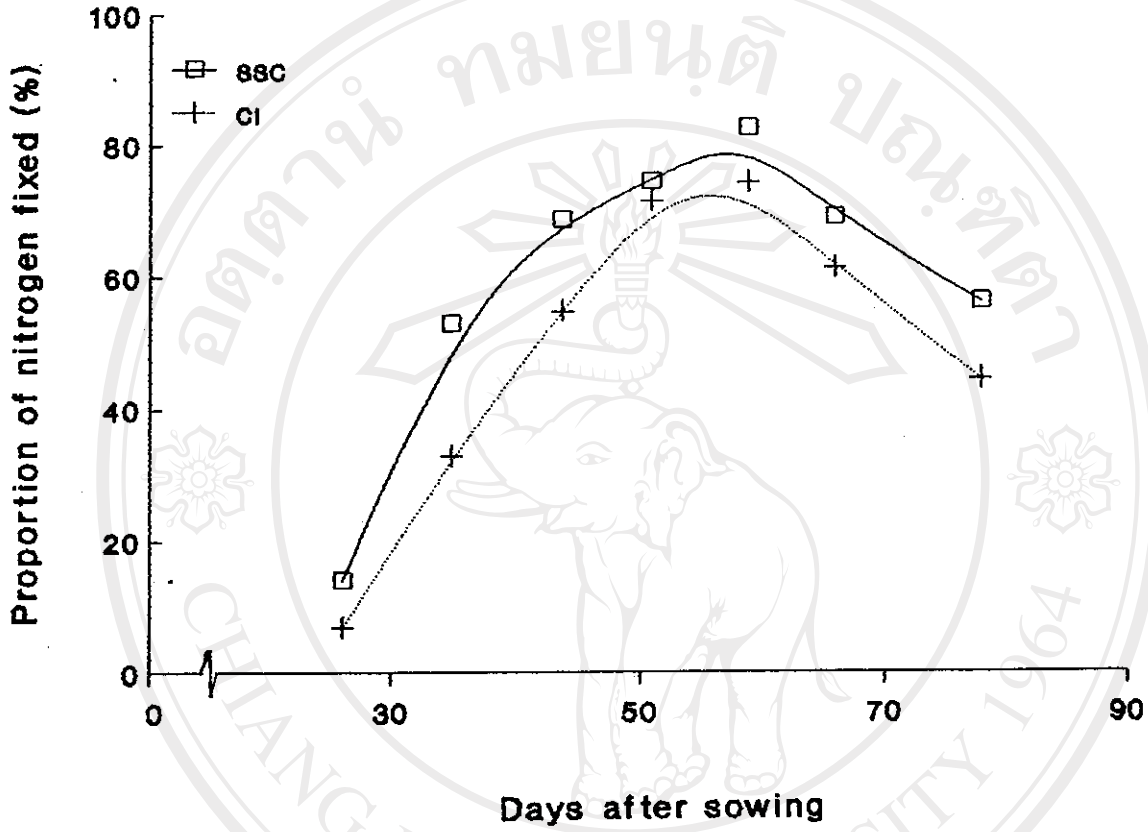

Figure 14. The changes of seasonal profile on the proportion of nitrogen fixed (%) affected by water regimes averaged over starter nitrogen treatments and varieties.

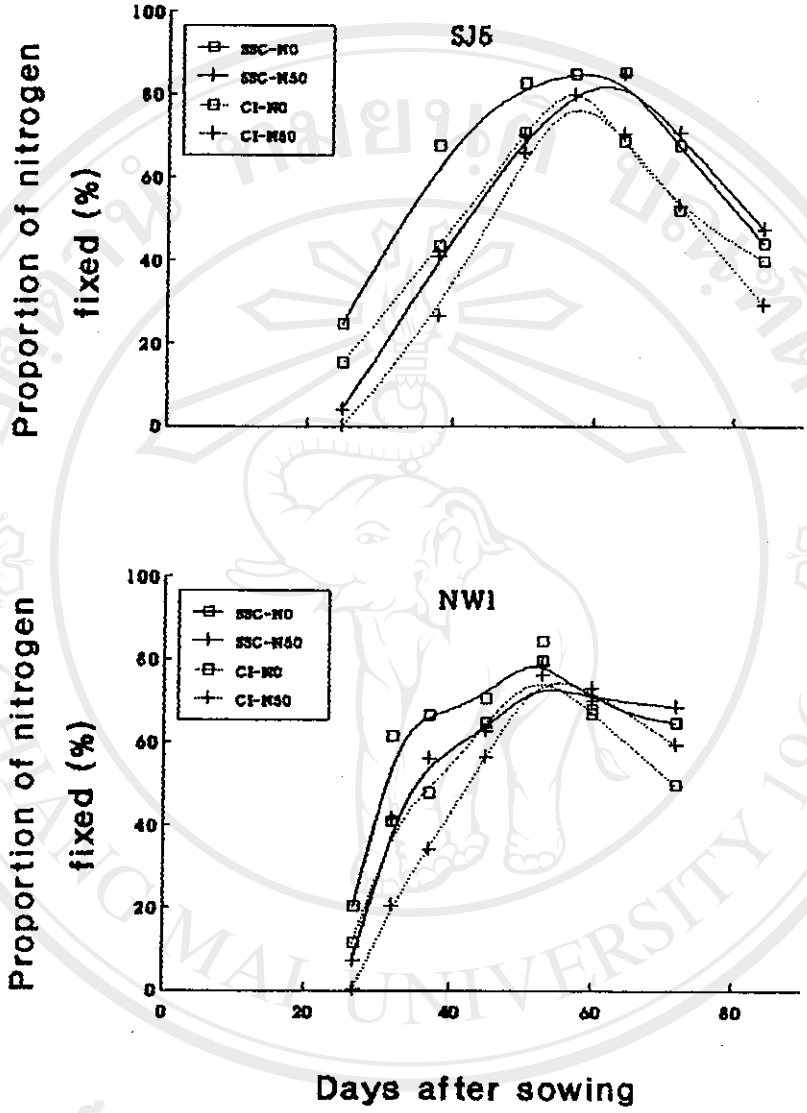

Figure 15. Effects of water regimes and starter nitrogen on the proportion of nitrogen fixed (%) by SJ5 and NW1

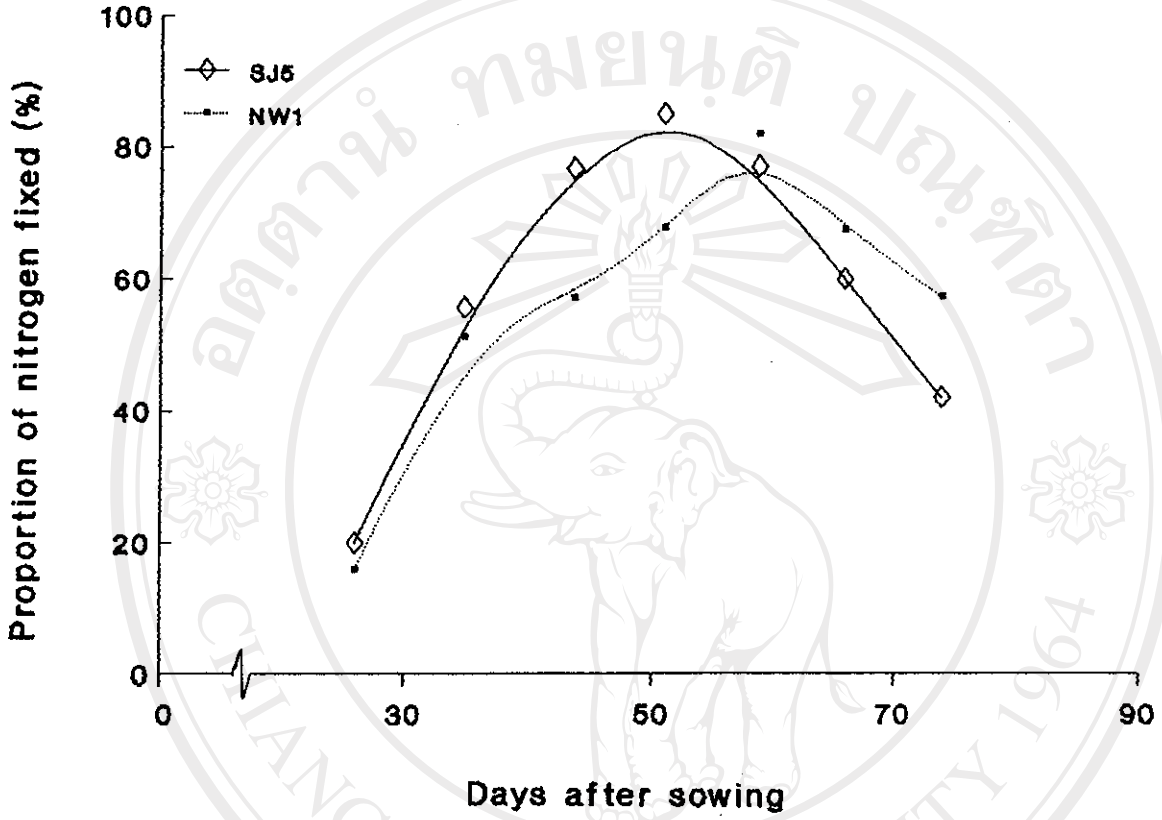

Figure 16. Effects of genotypes on the proportions of nitrogen fixed (%) averaged over water regimes and starter nitrogen treatments.

4.6.3 Amount of nitrogen fixed

Nitrogen fixation inputs were calculated by multiplying the amount of plant nitrogen accumulated between harvests with the proportion of nitrogen fixed. The profile of nitrogen fixation clearly showed the plant response to the SSC treatment (P=0.02) (Figure 17 and Appendix B, Table B-12). More nitrogen was fixed in SSC than under CI. At physiological maturity , SJ5 fixed 150-174 kg N/ha under SSC compared with 123-127 kg N/ha in CI. A similar response was detected for the NW1 cultivar (Figure 18).

4.7 Yield and yield components

There were no significant differences in final yield response between water regime treatments and starter nitrogen (Table 5). Neither did seed weight, seeds per pod, pods per node and nodes per plant, or plant height show any significant variation, even though the yield was slightly higher under SSC than in CI.

4.8 Nitrogen fixation and balance

At physiological maturity (R7) (Table 6), SSC had no effect on total shoot nitrogen (TN), seed yield or nitrogen removal (Nseed) for either soybean varieties, but the effect of SSC on nitrogen fixation was clearly apparent. For example, in absence of starter nitrogen, the SJ5 soybean grown under SSC derived a seasonal average of 74% of its nitrogen from the air, compared with 54% when irrigated conventionally (Table 6 and Appendix B,

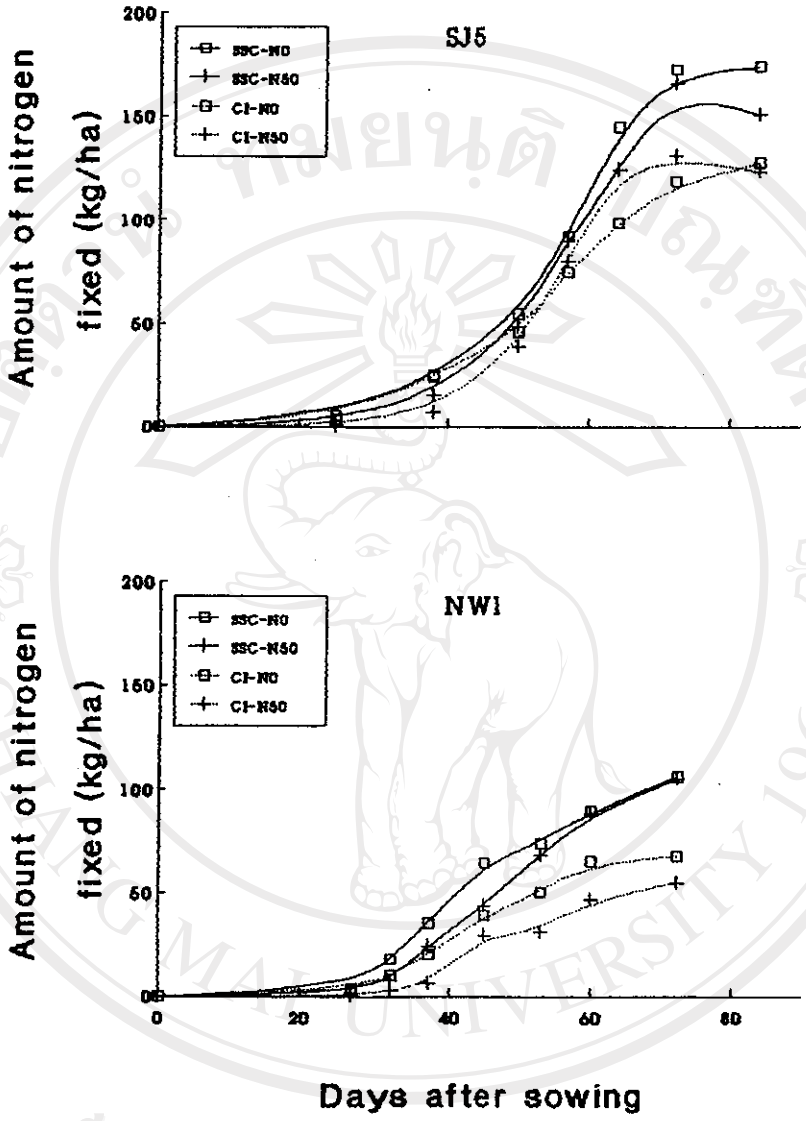

Figure 17. Effects of water regimes and fertilizer nitrogen on cumulative amounts of nitrogen fixed (kg/ha) by SJ5 and NW1.

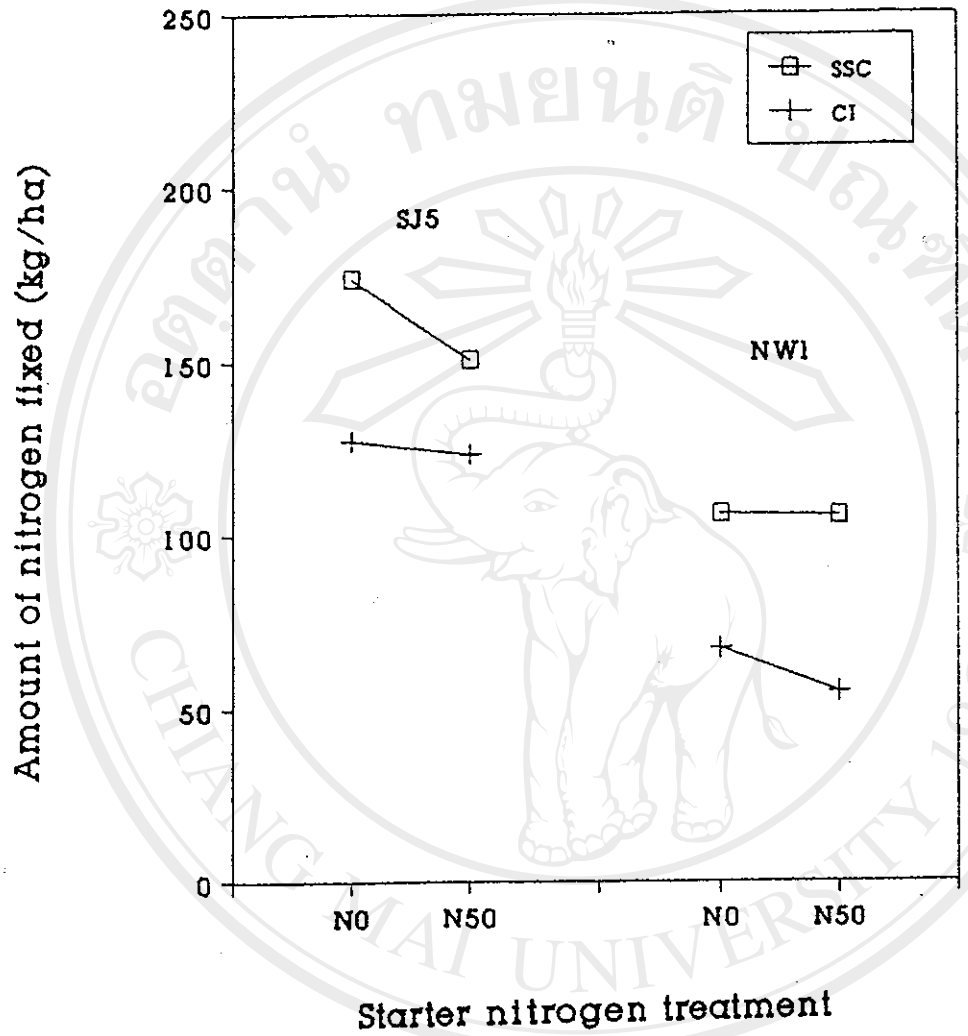

Figure 18. Effects of water regimes, varieties and starter nitrogen treatments on amount of nitrogen fixed (kg/ha) at physiological maturity stage (R7).

Table 5 Effects of water regimes on yield and components by SJ5 and NW1

Variety	Treatment	Yield components and yield					
		Height (cm)	Nodes/ plant	Pods/ nod	Seeds/ pod	g/100 seeds	Yield t/ha
SJ5	SSC-N0	95.60	9.63	3.67	1.80	11.05	2.04
	SSC-N50	94.57	9.40	3.89	1.83	11.52	2.17
	CI-N0	90.57	8.87	3.37	1.82	11.02	1.95
	CI-N50	92.67	9.80	3.66	1.86	11.87	2.13
NW1	SSC-N0	56.40	6.80	2.65	1.72	17.71	1.64
	SSC-N50	66.27	6.77	3.06	1.78	18.29	1.94
	CI-N0	61.27	6.50	2.75	1.75	17.68	1.58
	CI-N50	65.23	6.83	3.00	1.85	17.47	1.62

Table 6 Effects of water regimes, varieties and starter nitrogen on nitrogen balance at R7[a]

Trial	SJ5				NW1			
	N0		N50		N0		N50	
	SSC	CI	SSC	CI	SSC	CI	SSC	CI
Yield (t/ha)	2.0	2.0	2.2	2.1	1.6	1.6	1.9	1.6
TN (kg/ha)	235.6	237.4	229.5	203.3	172.1	139.1	189.5	144.3
N seed (%)	7.31	7.22	7.36	7.26	6.70	6.87	6.80	6.79
N seed (kg/ha)	148.7	140.9	158.9	155.0	109.7	109.0	131.9	110.2
N fixed (kg/ha)	174.0	127.4	150.7	123.4	106.1	67.6	105.4	55.0
N fixed % [b]	73.8	53.7	66.7	60.7	61.6	48.6	55.6	38.1
N balance (kg/ha)[c]	25.3	- 13.4	- 8.2	- 31.6	- 3.6	- 41.4	- 26.5	- 55.2

a. Data means for three replicates referred to Appendix B.

b. Calculated as N fixed % = (N fixed / TN) * 100.

c. Calculated as N balance = N fixed (kg/ha) - N seed (kg/ha).

Table B-11). As the result of this enhanced nitrogen fixation, a total of 174 kg N/ha was fixed in SSC, 47 kg N/ha more than that under CI. With removal of 2 t/ha of soybean seed yield from the field, there was a positive balance of 25 kg N/ha after the SSC treatment, compared with a depletion of -13.5 kg N/ha from soil after a CI crop. The NW1 line, responded in a similar way, but since it had a larger negative balance under CI (41 kg N/ha), and SSC only resulted in reducing the depletion of soil nitrogen to -4 kg N/ha.

The effect of SSC on nitrogen fixation was also clear when 50 kg/ha of fertilizer nitrogen was applied. The NW1 soybean grown under SSC with starter nitrogen, for example derived 56 % of its nitrogen from the air, compared with 38% in CI. This results in NW1 plants fixing 105 kg N/ha from atmospheric nitrogen, almost doubled that achieved in CI. A similar response was found for the SJ5 variety.