Responses of Specific Leaf Weight, Biomass and Seed Yield of Soybean to Nitrogen Starter Rate and Plant Density

Myint Myint Maw[1, 2], Sutkhet Nakasathien[2]* and Ed Sarobol[2]

ABSTRACT

The combined effects of fertilizer and plant population density (PPD) on specific leaf weight (SLW), plant biomass, grain yield and quality of soybean (*Glycine max* (L.) Merrill) and relationships between these traits are of considerable interest. The purpose of this study was to investigate the response of SLW, biomass distribution in plant parts and seed yield of soybean to nitrogen (N) application and PPD levels. Field experiments were established during the wet season (June to October) and the dry season (November to March) in 2008-2009, using a split-plot design with three replications. The SJ5 cultivar was planted at the National Corn and Sorghum Research Center, Nakhon Ratchasima, Thailand. Four levels of PPD (20, 30, 40, 60 plants m^{-2}) were used as main plots and four rates of N fertilizer (0, 25, 50, 75 kg ha^{-1}) were applied as sub-plots. There were no interactions between PPD levels and N rates in all observations. In both seasons, the greatest SLW was measured at the highest N level (N_{75}) and the lowest value was detected at the highest PPD (60 plants m^{-2}). The SLW at V5 was positively correlated with dry weight (DW) at V5 (r = 0.593*) in the wet season, and with DW at V5 (r = 0.727**) and DW at R5 (r = 0.695**) in the dry season. Accordingly, the highest biomass yield with N_{75} might be related with SLW at V5. Compared to the control, N_{75} increased the whole plant biomass at R5 by 14 and 53% in the wet and dry seasons, respectively. The greatest seed yield in both seasons was observed at N_{75}. Pods $plant^{-1}$ and seed size were the main yield components responsible for a higher seed yield of N_{75}. Significant differences in seed yield among PPD levels were not observed, indicating that a plant density of 20 plant m^{-2} with N_{75} would be appropriate for soybean cv. SJ5 sown at the National Corn and Sorghum Research Center in both the wet and dry seasons.
Keywords: *Glycine max* (L.) Merrill, nitrogen fertilizer, plant population, biomass, seed yields

INTRODUCTION

High SLW, the dry mass of tissue per unit leaf area, was associated with increasing leaf photosynthesis (Dornhoff and Shibles, 1970). A strong correlation (r = 0.76**) between SLW and apparent photosynthesis (AP) which may improve seed yield in soybean (Thompson *et al*., 1995) during flowering was observed by Buttery *et al.* (1981). Kokubun *et al*. (1988) found that the correlations between AP and SLW were not consistent at the pod formation or seed development stage. At the vegetative growth stage, there was a consistent tendency of AP to be correlated with SLW. The stages of development and physiological factors had significant

[1] Department of Agricultural Planning, Ministry of Agriculture and Irrigation, Myanmar.
[2] Department of Agronomy, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand.
* Corresponding author, e-mail: agrskn@ku.ac.th

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influences on SLW and the photosynthetic rate (Lugg and Sinclair, 1980).

Determining the minimum population required to reach an optimum leaf area index (LAI) and maximized yield for a specific environment is economically important (Boquest, 1990), because plant density has a strong effect on leaf area, light interception (LI) and canopy photosynthesis in soybean (Singer, 2001). Herbert and Litchfield (1984) concluded that narrow rows (25 cm) with higher densities (80 seeds m^{-2}) produced both higher LAI and more dry matter than did narrow rows with lower densities (25 seeds m^{-2}). The high population level ensured early canopy coverage and maximized light interception, greater crop growth rate and crop biomass, resulting in increased seed numbers and yield potential (Ball *et al*., 2000).

Although soybeans can obtain N through symbiotic fixation, application of N as a starter can increase vegetative growth and grain yield in numerous studies. Starling *et al*. (1998) determined that broadcast N (50 kg ha^{-1}) applied at the planting time increased R1 (Fehr and Caviness, 1977) dry matter accumulation of determinate (AU 86-23970D) and indeterminate (AU 86-23971I) by 25% but had no effect on determinate (Cook). However, seed yield of all three genotypes was increased by N application. Research conducted in China showed that applying N in a top dressing of urea (50 kgN ha^{-1}) at either V2 or R1 stage significantly increased N accumulation, yield and total amount of N_2 fixed (Gan *et al*., 2003). Soybeans require a large amount of N to support the synthesis of seed storage protein. Wesley *et al*. (1999) found that the application of N at the beginning of the pod growth stage increased yield at four irrigated sites in Kansas, but had no effect on grain protein or oil concentration. Nakasathien *et al*. (2000) used supra-optimal N to regulate seed protein concentration (SPC) in soybean genotypes with different SPCs : normal, intermediate and high lines. The results showed that supra-optimal N supplied from V5 and R5 to maturity increased the SPC of normal (NC 107) and intermediate (N 87-984-16) lines by an average of 28%, and of the high line (NC 111) by 15%.

Little information can be obtained from the literature concerning combinations of factors, such as fertilizer regime, row width and plant population level for obtaining maximum soybean yield and protein concentration. Normally, yields of soybean are increased as the row width is reduced and, in general, the optimum seeding rate ha^{-1} increases, but some factors can limit the potential yield advantage of these two combination effects. From the existing data, it is difficult to determine what factors limit soybean yield. Among the limiting factors, N stress can effectively prevent the yield response of soybean to a narrow row system (Cooper and Jeffers, 1984). The objectives of this study were (i) to observe the response of SLW and biomass distribution in the plant parts and seed yield to N application and plant density, (ii) to evaluate the relationships among variables related to vegetative and reproductive growth (V5 and R5 stages), seed yield and quality at maturity and (iii) to determine the appropriate combination of N application rate and plant density for maximizing the seed yield in soybean.

MATERIALS AND MATHODS

Experimental design

Field experiments were conducted at the National Corn and Sorghum Research Center, Nakhon Ratchasima, Thailand (Latitude: 14° 38′ N, Longitude: 101° 19′ E, Altitude: 387.92 m). Soil samples from the experimental site were analyzed at the Soil Science Department, Faculty of Agriculture, Kasetsart University, Thailand. The soil was composed of sand (19%), silt (12%), clay (69%, texture C) and a medium amount of organic matter with pH 6.8. The previous crop on the experimental site was corn.

For each experiment, a split-plot design with three replications was developed. Four arrangements of plant population density (PPD): 50 × 20 cm × 2 plants per hill (20 plant m^{2}), 50 × 20 cm × 3 plants per hill (30 plant m^{-2}), 50 × 10 cm × 2 plants per hill (40 plant m^{-2}), 50 × 10 cm × 3 plants per hill (60 plant m^{-2}); were assigned as the main plots. Subplots comprised four rates of N starter: 0 (N_0, control); 25 (N_{25}); 50 (N_{50}); and 75 (N_{75}) kg ha^{-1}, respectively. Each individual plot size was 4 m wide and 5 m long. Each sub-plot was composed of eight rows of soybean (cv. SJ5) planted during the wet season (June to October) and the dry season (November to March) in 2008-2009.

Cultural practices

Just prior to the start of the experiment, soil samples from the experimental site were collected for determination of the nutrient contents. The experimental plot was prepared for seeding and sown using six seeds per hill. Two weeks after sowing, thinning was done to get the final populations to 200,000 (20 plant m^{-2}), 300,000 (30 plant m^{-2}), 400,000 (40 plant m^{-2}) and 600,000 (60 plant m^{-2}) plant ha^{-1}. For the basal fertilizer application, 56.25 kg ha^{-1} P_2O_5 as triple super phosphate (45% P_2O_5) and 37.5 kg ha^{-1} K_2O (60% K_2O) were applied in all sub-plots (Chainuvati *et al*., 1994). Four rates of N were applied in the form of urea (46% N) as starter doses. Irrigation practices were done according to farm regulation. Pest and disease controls were done as necessary. Data on seed yield were determined from the middle two rows of each plot (4 m length). After harvesting, the residual nutrient levels in soil samples from the experimental plots were analyzed and compared.

Data collection

Whole plants were sampled three times during the growing season; starting at the vegetative stage V5, at the beginning seed stage R5, and at maturity stage R8 (Fehr and Caviness, 1977). At V5 and R5 stages, ten plants were randomly sampled from each treatment. The samples were partitioned into leaves, stems, roots at V5, and pods were separated into seeds and pod walls at R5. Fresh weight (FW) of every plant part was recorded immediately after harvesting and then oven-dried at 65°C for 72 h. Dry weight (DW) of plant parts was measured. The SLW was also sampled at the V5 and R5 growth stages. The ten youngest fully expanded leaflets (YFEL) were collected from five plants in each plot. Leaf samples were kept in plastic bags and placed on ice immediately until the FW was measured. Two leaf discs, 10 mm in diameter, were taken from each sampled leaflet with a leaf punch. Care was taken to avoid major veins, leaf margins, and any damaged sections. The punched samples were stored in paper envelopes, oven-dried at 65°C for 48 h and weighed on an electronic balance. At maturity stage (R8), yield components, (number of branches per plant, number of pods per plant, number of seeds per pod and 100-seed weight), were collected on a randomly selected subsample of 10 plants. Total seed yield was determined from a harvested area of 4 m^2 and was adjusted to 130 g kg^{-1} moisture. For measurement of protein and oil concentration in the seed, seeds were pulverized into a powder that provided maximum homogeneity and minimum sampling variation. Homogenates were determined in whole grain samples by a near infrared spectroscopy method. The calibration process was described by Rippke *et al*. (1996) and was subsequently based on a standard method of the American Association of Central Chemistry (1999).

Statistical analysis

All data were subjected to analysis of variance (ANOVA) appropriate for a randomized complete block (RCB) split-plot design. Separated analysis of variance was performed for each measurement. Mean separations were considered significant using a least significant difference (LSD) test at the 5% level. Correlations among parameters were analyzed using the SPSS computer software, version 16.0.

RESULTS AND DISCUSSION

Responses of SLW to N starter rate and plant density

In the wet season, SLW was gradually increased with increasing PPD from 20 to 40 plant m^{-2} at the V5 stage and from 20 to 30 plant m^{-2} at the R5 stage, respectively (Figure 1A). The lowest SLW values at both growth stages were found at the maximum PPD (60 plant m^{-2}). The response of soybean to no N application (N_0) showed the lowest SLW values at both stages (Figure 1B). There was a steady increase in SLW at R5, but there was no linear progress at V5. SLW at V5 increased rapidly when the supply of N fertilizer was increased from N_0 (control) to N_{25}. No further increase in SLW was observed when the N fertilizer rate was increased from N_{25} to N_{50} and thereafter the SLW increased when N application was increased from 50 to 75 kg ha^{-1}. The highest N rate (N_{75}) attained the largest SLW at both the V5 and R5 stages. The N_{75} application increased SLW by 43.8 and 17.4% at V5 and R5, respectively, compared with the control.

In the dry season, PPD and N fertilization showed a significant effect on SLW at V5, but not at R5. At V5, SLW reduced with increasing PPD but increased with increasing N rates (Figures 2A and 2B). In both seasons, the N application rate of 75 kg ha^{-1} produced the highest SLW value. These results were interpreted to support the conclusion that the highest level of N fertilizer (N_{75}) gave the greatest seed yield, because SLW and AP have been positively correlated with chlorophyll concentration (Buttery and Buzzell, 1977; Buttery *et al.*, 1981) and AP may improve seed yield in soybean (Thompson *et al.*, 1995). By comparison, the SLW value in the dry season was greater at the R5 stage, but lower at the V5 stage than for soybean grown in the wet season (Figures 1B and 2B). These results indicated that the effects of PPD and N starter application on soybean SLW are heavily dependent on the development stages and the growing season.

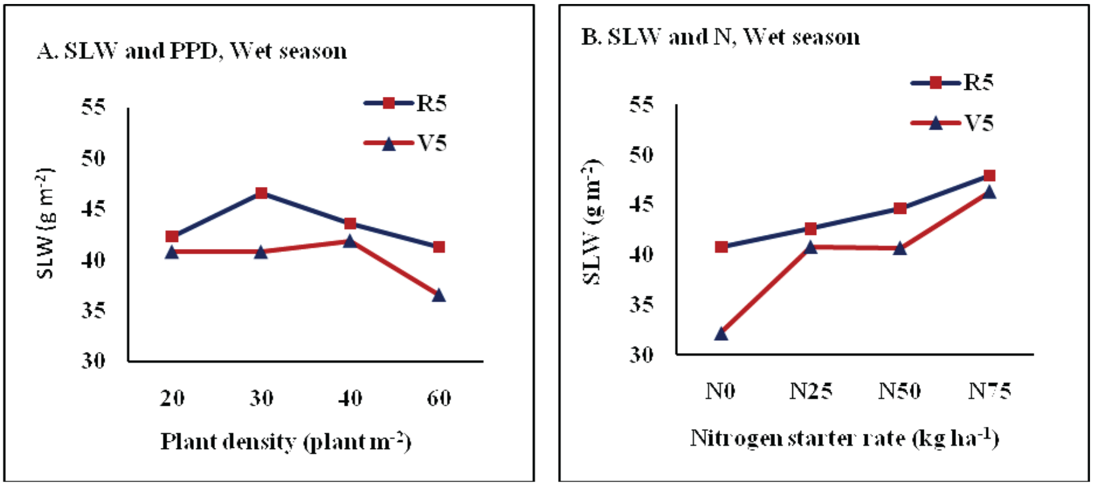

Figure 1 Effects of N starter rate and plant population on specific leaf dry weight of soybean SJ5 cultivar at V5 and R5 stages sown at National Corn and Sorghum Research Center in the wet season of 2008.

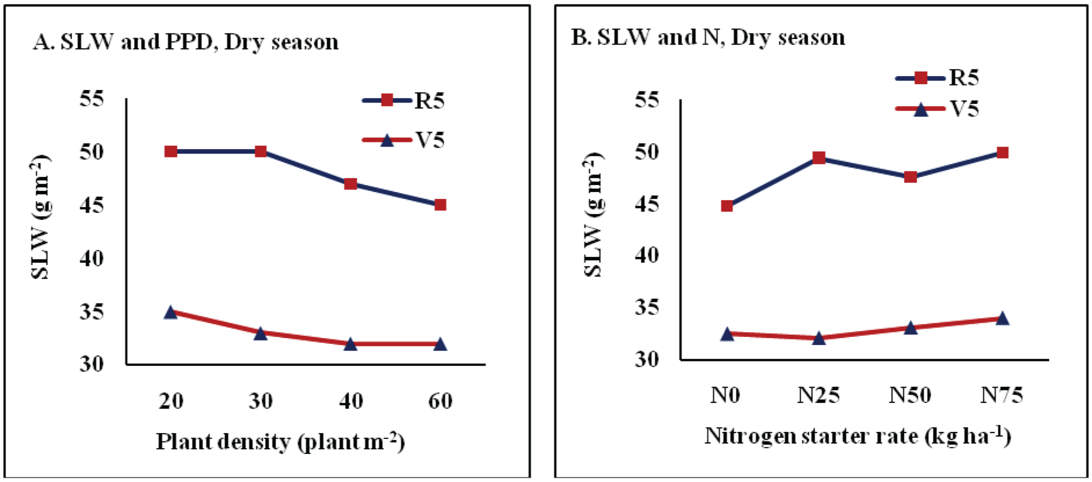

Figure 2 Effects of N starter rate and plant population on specific leaf dry weight of soybean SJ5 cultivar at V5 and R5 stages sown at National Corn and Sorghum Research Center in the dry season of 2008-2009.

Biomass partition at V5 and R5

There were no interactions between PPD and N rates, and dry matter of each plant part and of the whole plant at the vegetative and reproductive stages (Table 1).

In the wet season, whole plant dry matter increased by an average of 17% at V5 when PPD changed from 20 to 30 plant m^{-2}, and no increase in plant biomass yield was detected using greater PPD values. At R5, dry matter accumulation in the whole plant was reduced at an increasing rate when PPD increased to 40 and 60 plant m^{-2}, possibly due to intra-row plant competition. Therefore, the greatest plant biomass was obtained from lower PPD values (20 and 30 plant m^{-2}). The DW of reproductive parts (pod wall and seed) was statistically different among PPD levels. Nitrogen application had a positive impact on the DW of all plant parts at V5. Whole plant biomass increased by an average of 23% when the application rate of N was increased from 0 to 75 kg ha^{-1}. On average, 62% of total biomass was in leaves and petioles. At R5, there were significant differences in the DW of the leaf and the pod wall, but there was no difference in the DW of the stem, root and seed among N rates. In addition, increasing the rate of N fertilizer from N_0 to N_{75} resulted in a higher accumulation of pod wall dry matter by an average of 86%. Application of N fertilizer at the highest rate (N_{75}) also increased whole plant biomass by 14%. On average, leaves and petioles accounted for 57% of the total biomass.

In the dry season, PPD had a negative effect on the DW of the leaf and stem at V5. The lowest PPD (20 plant m^{-2}) produced the largest whole plant DW. At R5, vegetative biomass (leaf, stem and root) was influenced significantly by PPD. The greatest vegetative biomass was obtained from the lowest PPD. This led to the highest whole plant biomass of the treatment because of the substantial amount of vegetative parts. Application of N starter fertilizer made no significant impact on the DW of any plant part at V5. In contrast, every plant part biomass at R5 was impacted significantly by N treatments. The largest significant gain in whole plant biomass resulted from the application of the maximum amount of N (N_{75}). The application of N at the rate of 75 kg ha^{-1} (N_{75}) increased average biomass

Table 1 Effects of nitrogen starter rate and plant population density on dry matter distribution in soybean SJ5 cultivar at V5 and R5 stages sown at National Corn and Sorghum Research Center in 2008 and 2009.

Treatment	V5 Stage			Whole	R5 Stage					Whole
	Leaf (g)	Stem (g)	Root (g)	plant (g)	Leaf (g)	Stem (g)	Root (g)	Pod Wall(g)	Seed (g)	plant (g)
				Wet season, 2008						
Plant density										
20 plant m^{-2}	14.26 b	4.57	4.34 bc	23.27 b	178.75 a	92.42 a	31.33 a	10.48	1.24	314.22 a
30 plant m^{-2}	16.95 a	5.25	5.11 a	27.31 a	167.42 a	85.58 a	29.17a	8.40	1.42	291.99 a
40 plant m^{-2}	14.64 b	4.84	4.05 c	23.53 b	137.25 b	70.58 b	24.00 b	7.25	0.91	239.99 b
60 plant m^{-2}	15.06 b	5.14	4.51 b	24.71 b	119.58 c	63.50 b	20.25 c	7.03	0.87	211.23 c
N rate										
N_0	13.43 c	4.62 b	4.03 b	22.08 c	138.00 b	75.25	26.17	5.25 b	0.95	245.62 b
N_{25}	15.30 b	4.83 b	4.57 a	24.07 b	159.00 a	82.67	26.92	9.12 a	1.21	278.92 a
N_{50}	15.40 b	4.88 b	4.57 a	24.85 b	145.42 ab	73.42	24.67	9.02 a	0.93	253.46 ab
N_{75}	16.79 a	5.46 a	4.84 a	27.09 a	160.58 a	80.75	27.00	9.78 a	1.36	279.47 a
				Dry season, 2008-2009						
Plant density										
20 plant m^{-2}	11.42 a	3.16 a	2.41 a	16.99 a	41.20 a	40.95 a	15.04 a	5.92	0.38 b	103.49 a
30 plant m^{-2}	9.42 b	2.88 ab	1.94 b	14.24 b	31.70 b	24.71 b	10.90 b	5.56	0.33 b	73.20 b
40 plant m^{-2}	9.16 c	2.86 ab	2.13 a	14.15 b	29.68 b	26.14 b	10.87 b	6.10	0.52 a	73.31 b
60 plant m^{-2}	8.01 d	2.57 b	1.88 b	12.46 c	21.78 c	26.40 b	10.37 b	6.08	0.33 b	64.96 c
N rate										
N_0	9.08	2.76	2.07	13.91	25.17 b	22.88 c	10.45 c	3.86 c	0.29 b	62.65 c
N_{25}	9.16	2.76	2.00	13.92	27.34 b	28.35 b	11.98 b	6.03 b	0.49 a	74.19 b
N_{50}	9.74	2.95	2.12	14.81	32.78 a	31.27 b	11.65 b	6.29 ab	0.34 b	82.33 b
N_{75}	10.03	2.99	2.18	15.20	39.07 a	35.70 a	13.10 a	7.46 a	0.43 b	95.76 a

Note:Means within columns followed by the same lower case letter are not significantly different at the 0.05 probability level based on the LSD procedure.

N_0, N_{25}, N_{50} and N_{75} indicate N application rates of 0, 25, 50 and 75 kg ha^{-1}, respectively.

yield by 53% more than no N application (N_0). Of total plant biomass, 14% was in the leaves and petiole.

Yield components, seed yield, protein and oil content in the seed

There were no interactions between yield and yield components among PPD and N rates in both seasons (Table 2).

In the wet season, PPD levels had a significant effect on the number of branches and pods per plant. The number of pods per plant decreased with increasing PPD with an average of about 41% when the PPD increased from 20 to 40 to 60 plant m^{-2}. This was similar to results reported by Liu *et al*. (2010), who found that the pod number per plant reduced with increasing density for all soybean cultivars grown in 2007. Increasing PPD levels had no significant effect on 100-seed weight and seed yield per unit area. It is notable that although the maximum seed yield (2,656.75 kg ha^{-1}) was observed at 40 plant m^{-2}, there were no statistical differences in seed yield per unit area among PPD levels. Starter N fertilizer application had no effect on the number of branches per plant and pods per plant, but had a significant effect on 100-seed weight and seed yield per unit area. Compared with the control (N_0), the highest N rate (N_{75}) increased 100-seed weight and seed yield by 10 and 31%, respectively. In addition, seed yield increased with increased rates of N. The results also agreed with Osborne and Riedell (2006) who reported that the grain yield of soybean increased with the application of starter N in two out of three years.

In the dry season, the number of branches per plant and pods per plant decreased significantly with increasing PPD levels. The maximum number of branches per plant and pods per plant was obtained from the lowest PPD (20 plant m^{-2}). Seed yield per unit area was not significantly different between populations. The present study illustrated that there was no effect on economic yield due to increasing PPD. The level of 20 plant m^{-2} would be suitable for soybean (cv. SJ5) at the National Corn and Sorghum Research Center. Application of starter N had a positive impact on the number of pods per plant and 100-seed weight. The number of branches per plant was not significantly different from the control (N_0), hence the greatest seed yield (1,602.52 kg ha^{-1}) was associated mainly with the higher number of pods per plant and 100-seed weight under the application of the highest N rate of N application (N_{75}). The number of pods per plant, 100-seed weight and seed yield obtained from the N_{75} treatment were 40, 8 and 57%, respectively, and were superior to the results from no application of N. This increase in seed yield in both seasons could have been due to an increase in whole plant biomass.

Soybean seed protein and oil contents were measured as an estimate of soybean seed composition. In both seasons, seed protein concentration (SPC) was not affected statistically by PPD, but was influenced significantly by the application of N. The highest N rate (N_{75}) showed significantly higher SPC by an average of 4% in the wet season, whereas no significant difference was measured in the dry season in the study. The oil content in the mature seed was not affected significantly in either season by either the PPD level or N fertilizer application. This result was consistent with work by Ham *et al*. (1975), whose study in Minnesota observed that preplant broadcast N application increased soybean yield, weight per seed and seed protein, but had no effect on seed oil concentration. Osborne and Riedell (2006) also reported that N treatment effects on soybean seed N and oil concentrations were inconsistent among the different growing seasons. In the present study, there were no treatment interactions for all observations in both growing seasons.

Table 2 Effects of nitrogen starter rate and plant population density on yield components, seed yield and quality of soybean SJ5 cultivar at National Corn and Sorghum Research Center in 2008 and 2009.

Treatment	Yield components			Seed yield	Protein	Oil
	Branch/Plant	Pods/Plant	100-Seed Wt.(g)	(kg/ha)	(%)	(%)
			Wet season, 2008			
Plant density						
20 plant m^{-2}	4.14 a	73.70 a	16.64	2339.02	37.96	19.82
30 plant m^{-2}	3.98 a	68.88 a	16.80	2479.26	38.03	19.80
40 plant m^{-2}	2.33 b	43.45 b	16.75	2656.57	37.31	19.82
60 plant m^{-2}	2.26 b	43.75 b	17.08	2585.18	37.56	19.59
N rate						
N_0	3.05	56.31	15.80 b	2174.28 c	37.08 b	19.68
N_{25}	3.43	56.63	16.59 ab	2483.94 b	37.15 b	20.00
N_{50}	3.13	59.98	17.44 a	2558.75 b	38.19 a	19.86
N_{75}	3.10	56.86	17.43 a	2843.06 a	38.44 a	19.48
			Dry season, 2008-2009			
Plant density						
20 plant m^{-2}	2.63 a	31.09 a	16.08	1176.72	36.36	15.31
30 plant m^{-2}	1.83 b	27.04 b	15.17	1310.30	35.85	15.41
40 plant m^{-2}	1.12 c	20.64 c	15.50	1358.90	36.46	14.48
60 plant m^{-2}	0.81 c	17.72 c	14.92	1294.18	35.54	15.79
N rate						
N_0	1.71 a	20.72 b	15.17 b	1017.43 c	36.52 a	14.47
N_{25}	1.23 b	20.20 b	15.00 b	1134.01 c	35.22 b	15.74
N_{50}	1.61 ab	26.50 a	15.08 b	1386.14 b	35.68 ab	15.76
N_{75}	1.84 a	29.08 a	16.42 a	1602.52 a	36.79 a	15.02

Note:Means within columns followed by the same lower case letter are not significantly different at the 0.05 probability level based on the LSD procedure.

N_0, N_{25}, N_{50} and N_{75} indicate N rates of 0, 25, 50 and 75 kg ha^{-1}, respectively.

Correlations between seed yield and some characters

Based on correlation analysis (Table 3), seed yield was correlated positively with SLW at both growth stages and with biomass at the V5 stage in the wet season, but was not correlated with any other agronomic characters in the dry season. SPC was correlated strongly with SLW at the R5 stage in the wet season and was correlated negatively with oil content in the dry season. In the wet season, SLW at the R5 stage seemed to be an important factor that had a relationship with seed yield and SPC in soybean. A positive relationship between SLW and biomass at V5 was consistent in both seasons. In addition, SLW at V5 was correlated highly with biomass at R5 in the dry season. Thompson *et al*. (1995) reported that the R5 growth stage possessed the greatest range in SLW, which was similar to earlier reports (Lugg and Sinclair, 1980; Buttery *et al*., 1981).

CONCLUSION

Statistically significant differences in seed yields among plant densities were not observed in both seasons. The highest level of N fertilizer (N_{75}) gave the greatest seed yield in both experiments. This increase in seed yield response was due primarily to the N_{75} treatment having the highest number of pods per plant and the highest 100-seed weight. In all experiments, the highest rate of N application also induced plants to the highest SLW and whole plant biomass. Leaves and petioles were responsible for the highest amount of whole plant biomass. The growing season affected the correlation between seed yield and SLW. The amounts of seed yield and biomass were greater in the wet season than those in the dry season when N was applied at the highest rate. N fertilizer application had a significant impact on SPC. A plant density of 20 plant m^{-2} would be

Table 3 Correlation coefficients for specific leaf weight, dry matter, seed yield, protein and oil content in the seed of soybean SJ5 cultivar.

Variables	V5-SLW	R5-SLW	V5-DW	R5-DW	Seed yield	Seed protein	Seed oil
Wet season, 2008							
V5-SLW	1						
R5-SLW	0.50	1					
V5-DW	0.59*	0.84**	1				
R5-DW	0.27	0.11	0.15	1			
Seed-Yield	0.66**	0.51*	0.58*	-0.15	1		
Seed-Protein	0.44	0.62**	0.47	0.23	0.24	1	
Seed-Oil	-0.15	-0.07	-0.07	0.08	-0.15	0.13	1
Dry season, 2008-2009							
V5-SLW	1						
R5-SLW	0.41	1					
V5-DW	0.73**	0.46	1				
R5-DW	0.70**	0.59*	0.87**	1			
Seed-Yield	0.33	0.20	0.28	0.46	1		
Seed-Protein	0.13	0.07	0.47	0.39	0.25	1	
Seed-Oil	0.20	0.16	-0.14	0.02	-0.02	-0.73**	1

Note:*, ** = significantly different at the 0.05 and 0.01 probability levels, respectively.

appropriate, due to no significant differences in seed yield being observed among PPD levels. Based on the result of the present study, it can be suggested that using a PPD level of 20 plant m^{-2} combined with N application at 75 kg ha^{-1} would be suitable for growing soybean.

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